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Article

Sustainable Urban Transport in the Developing World: Beyond Megacities

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Abstract: Megacities have frequently received a disproportionate amount of attention over other sizes of cities in recent discourse on urban sustainability. In this article, the authors argue that a focus on smaller and medium-sized cities is crucial to achieving substantial progress towards more sustainable urban development, not only because they are home to at least a quarter of the world's population but because they also offer great potential for sustainable transformations. In principle, their size allows for flexibility in terms of urban expansion, adoption of "green" travel modes, and environmental protection. At the same time, smaller and medium-sized cities often have fewer resources to implement new transport measures and can be more vulnerable to fluctuations in the world economy. This article critically reviews the potential role and impact of nine commonly considered options for sustainable urban transport in cities in developing countries: (1) road infrastructure; (2) rail-based public transport; (3) road-based public transport; (4) support for non-motorized travel modes; (5) technological solutions; (6) awareness-raising campaigns; (7) pricing mechanisms; (8) vehicle access restrictions; and (9) control of land-uses. Drawing on international research and examples of policies to reduce the environmental impacts of transport in urban areas, this article identifies some key lessons for sustainable urban transport in smaller and medium-sized cities in developing countries. These lessons are certainly not always identical to those for megacities in the global south.

Keywords: urban transport; sustainable transport; developing cities; medium-sized cities

1. Introduction

In the space of just a few decades, urban areas across the world, in both developed and developing countries, have become increasingly automobile-dominated and less sustainable. In developing countries in particular, cities have experienced a rapid growth in transport-related challenges, including pollution, congestion, accidents, public transport decline, environmental degradation, climate change, energy depletion, visual intrusion, and lack of accessibility for the urban poor. In more developed countries, particularly in Northern Europe, some cities have witnessed a trend of reclaiming urban space from the automobile and prohibiting cars from major parts of downtown areas and/or confining them in other ways. Today, these places are often considered as leading examples of sustainable urban development, as cities across the world strive to meet urban sustainability standards by improving public transport, encouraging non-motorized modes, creating pedestrian zones, limiting the use of private cars, and otherwise trying to undo the transformation of cities caused by automobile dominance. Concepts of automobile restraint that were unthinkable just a few decades ago are now being considered or even adopted in many urban areas around the globe, both north and south, with the encouragement and support of major international organizations (see [1–5]).

This article critically reviews the potential role and impact of nine commonly considered options for sustainable urban transport in medium-sized cities located in developing countries: (1) road infrastructure; (2) rail-based public transport; (3) road-based public transport; (4) support for non-motorized travel modes; (5) technological solutions; (6) awareness-raising campaigns; (7) pricing mechanisms; (8) vehicle access restrictions; and (9) control of land uses. These options for action are overlapping and interconnected. They cover both the demand and the supply side of urban transport with a focus on the latter. The article is organized around "interventions" rather than according to geographic regions, implementation stages, or types of impact.

A focus on smaller developing cities (*i.e.*, with fewer than one million inhabitants) is important in current urban sustainability discourses since nearly half of the world's 3.9 billion urban dwellers reside in relatively urban settlements with fewer than 500,000 inhabitants, while only around one in eight live in the 28 megacities of 10 million inhabitants or more [6]. Overall, the urban population in developing countries is set to double from 2010 to 2050 while remaining stable in developed countries [7]. At the moment, cities with less than 100,000 inhabitants represent a third of world's urban population, a figure which is predicted to grow to 40% in 2050. The fastest-growing urban agglomerations are medium-sized cities with less than 1 million inhabitants, located in Asia and Africa [7,8]. The term "developing cities" used in this article refers to the cities of all countries included in the World Bank's 2015 list of developing countries [8]. It should be noted that, since this categorization of countries is based on average Gross National Income (GNI) statistics, the wealth of different cities within the same country (and its distribution across society) can vary substantially.

Emerging megacities have received a disproportionate amount of attention, while smaller developing cities are extensively underserved with respect to basic services and lack the necessary institutional capacity to be able to manage their rapidly growing populations [9]. The authors argue that medium-sized cities in the developing world can offer greater potential for more sustainable transformations than megacities. They generally have a smaller ecological footprint, and in principle, their size allows for flexibility in terms of urban expansion, adoption of "green" travel modes, and environmental protection. At the same time, smaller developing cities might have fewer resources to implement necessary transport measures and might be more vulnerable to fluctuations in the world economy and climate. Also, due to their size and density, they are often characterized by less efficient public transport systems, lower modal shares of public transport, and higher transport-related energy consumption per capita than larger developing cities [2].

This article draws on examples of international experience with policies to reduce car use in urban areas. The examples are indicative given the complicated and complex nature of urban transport issues; the authors do not attempt to quantify a particular mix of policies (see, for example, [10]). While most examples are from developing countries, a few come from developed contexts when examples from developing countries are less available. This article targets two main audiences: (a) urban transport sustainability researchers, who are seeking a review of academic literature and state-of-the-art practice; and (b) policy-makers (and politicians) in developing countries, seeking an overview of practice that can be used to inform the development of new urban transport strategies.

The authors strike a cautionary note about the potential for international policy transfer in the urban transport arena. Contrary to a common belief amongst some development agencies that policy solutions already exist and simply need to be implemented more widely, the search, analysis, and uptake of urban transport policy ideas, concepts, or instruments from elsewhere are subject to a range of different influences, including political, professional, institutional, economic, and social. Research to date indicates that there is little evidence or prospect of "copying" of one policy from one area to another, certainly outside national boundaries. The potential for replication of "best practices" is questionable. City size is certainly not the only variable that determines the transferability of policy options.

Cultural penchants and historic trajectories of transport demand and supply (implying path dependence) prevent cities (including smaller ones) from applying the same solutions to apparently similar problems. For example, the public transport trip share is 19% in Latin American cities compared to 5% in African cities; the average non-motorized trip distance is 1.0 km in Latin American cities and 2.1 km in Southeast Asian cities [11]. Where contexts are quite dissimilar (e.g., north to south), caution is suggested both in terms of the appropriateness and effectiveness of standard policy solutions being exported from one place to another [12–14]. Developing cities are advised to consider examples of transport solutions from both developing and developed contexts and to keep in mind that not all innovation originates from the global north. After all, some of the most efficient and cost-effective public transport systems have been developed in Latin America.

2. Nine Options for Promoting Sustainable Urban Transport in Medium-Sized Developing Cities

2.1. Road Infrastructure

In the immediate post-WWII decades, increasing the size and number of roads (including flyovers and tunnels) was a commonly-used approach for addressing congestion and other urban travel issues. In more recent years an understanding has emerged that increasing capacity can lead to greater demand as a result of "induced travel" (also referred to as "latent demand" or "generated traffic"). Induced travel is due to diversion of travel from: (1) other lower volume hours of the day to more peak hour use of improved facilities; (2) parallel commuting routes; and (3) public transportation. The consequence is that congestion levels are soon restored to almost pre-expansion levels and little travel time savings are realized. Road investments also have adverse long-term effects on traffic congestion. They spawn new trips due to the land-use development (and possibly sprawl), which improved car access induces. Moreover, road construction itself is disruptive for densely-built urban areas. In many cases, the demolition of buildings and/or open space is necessary [15].

While induced demand claims have elicited strong reactions and polarized political factions, academic studies have confirmed the induced travel demand theory (see [16–18]). While the degree (*i.e.*, the travel demand elasticity) and the circumstances (a single road facility or a metropolitan area) in which induced travel occurs remain a matter of debate, there is no question that road improvements prompt traffic increases and provide little congestion relief. Since this is the case in developed cities with saturated or nearly saturated car ownership markets, it follows that the findings would certainly apply to developing cities, in which incomes and car ownership are still growing. However, there have been no academic studies testing the induced travel demand in these settings.

The prospect of induced travel lends credence to a transportation policy based on alternative modes. Policy makers in Europe have been sensitive to claims of induced demand and have taken steps to jettison the traditional "predict and provide" policy of trying to accommodate traffic growth (see for example [16,19]). In North America, funding incentives and political inertia have made major change difficult [19]. In developing countries, where new road construction is often seen as a yardstick of modernization, governments have often allocated public expenditures in favor of new road construction at the expense of other urban transport investments and the maintenance of existing infrastructure. In terms of road investment, evidence to date suggests that developing cities need to focus their resources on existing road maintenance rather than new road construction.

Estimates suggest that $45 billion worth of road infrastructure (urban, interurban, and rural) was lost in 85 developing countries in Asia, Africa, and Latin America between 1970 and 1990 due to inadequate maintenance. This loss could have been averted with preventive maintenance costing less than $12 billion [20]. There are multiple reasons why the problem is widespread. They include economic adversity and mistaken investment choices (*i.e.*, policymakers cut maintenance if donors raise funding for new construction) as well as institutional failures (*i.e.*, separation of responsibility and control between the providers and users of roads). Without corrective action, poor roads–as well as inadequate road-based (public and private) transport–can become an insurmountable obstacle to the economic recovery and growth of developing cities. Current evidence suggests that, in developing cities, maintenance expenditures have a positive effect on economic output whereas the construction of new highly-visible road infrastructure is less beneficial for economic development [21,22].

2.2. Rail-Based Public Transport

Increased investments in all types of public transport promise to help boost the urban economy of developing countries. The case of Japan is illustrative in this respect. In the post-WWII period, the

Japanese government played a key role in urban transport by adopting public policies that discouraged automobile use and channeled investment into public transport. This urban transportation system contributed to rapid economic growth by minimizing aggregate transportation costs, constraining the consumption of private automobiles, and encouraging savings, albeit with a decided lack of attention to passenger comfort [23].

It is debatable whether rail-based or road-based public transport should be emphasized in medium-sized developing cities. Mobility patterns are influenced by both population size and population density, especially the latter. Urban sprawl has a significant effect on travel distances and hinders public transport supply. In urban areas with a small but dispersed population, the provision of either rail- or road-based public transport might not be economically viable [24]. In particular, rail should have a definite advantage over road-based systems to justify implementation in smaller and/or dispersed cities, since new rail systems are very expensive to construct and operate. A full cost-benefit analysis of both options should guide decision-making. A brief overview of the two main rail-based urban transport systems, Light Rail Transit (LRT), and metro (suburban or heavy rail), is provided below.

LRT ranges from the historical tramways, trolleys, and streetcars of Eastern Europe, which run along other traffic in urban streets, to the sophisticated elevated and completely segregated systems of Singapore. LRT vehicles can be developed on urban streets and run alongside urban traffic because they are fed electricity from overhead wires. This is an advantage over metro systems, which require fully segregated rights-of-way because they have an electrified third rail that increases speeds but is fatal on contact. LRT is expanding rapidly in developed cities with low corridor volumes, sometimes feeding heavy rail systems. In developing countries, LRTs exist only in larger cities such as Tunis, Alexandria, Manila, Buenos Aires, and São Paulo. The cost of building and operating LRT varies widely but it is considerably higher than the cost of alternative public transport forms, such as busways (see below) [25,26]. If LRT operates at grade without priority or protection from obstruction by other traffic, it has little or no performance (speed) advantage over busways [27].

In the past, LRT advantages over busways were the lower local air pollution impact and possibly smother rides for urban travelers. Older LRT vehicles generally had higher carrying capacity than most buses [27]. Evolving technologies (e.g., electric buses, see later) have minimized the differences between bus and rail in terms emissions, capacity, and comfort. However, LRT is generally more appealing to middle class passengers, and investment in this mode is seen as a signal of a more permanent commitment to public transport on a government's part [26]. Surprisingly, a few quantitative analyses employing data from the U.S.-a country in which aversion to bus transport is perhaps the strongest-have shown that riders' preferences for rail travel over bus is null when service characteristics such as travel time and cost are equal. A preference only arises when one mode offers a higher quality service (*i.e.*, fewer transfers and higher frequency) [28].

In view of the evidence, investments in new LRT systems in medium-sized developing cities may have limited economic and practical value. Due their high costs, developing cities often can only construct such systems over a few kilometers in a few limited corridors, which do not meet the broader transport needs of the population. Nevertheless, the public sector may end up with a long-term debt that can affect investment in more pressing policy areas [26]. A secondary argument is that, in many developing cities, power shortages are common which means that a public transport system which relies on grid electricity may not always be a feasible or desirable option. At the same time, full reliance on fossil fuels for public transport is also controversial, especially in countries which lack oil resources.

Metro systems are usually the most expensive form of public transport in terms of construction and operation, but, as fully segregated systems, have the best performance. Since most metros are designed for capacities around 30,000 to 40,000 passengers per hour in the peak direction, usually, only cities with a population of 2–3 million have at least one corridor, which requires this type of facility [29]. In the developing world, only some of the larger cities, such as Beijing, Mexico City, Bombay, and Cairo have metro or suburban rail systems.

As with LRT, the capital costs of building metro systems can vary substantially between cities, between metro systems, and between metro lines within the same city and system. However, they are taxing even for developed nations: $50–$150 million per kilometer, with cost over-runs being the rule rather than the exception [30]. The reasons for high cost variations include differences between projects in terms of the ratio of underground to above-ground construction, ground conditions, station spacing, type of rolling stock, environmental and safety constraints, and labor costs. Underground metro systems cannot be easily integrated into existing urban physical structures, without disrupting building foundations and utility lines [30]. In addition to high capital costs, metro systems have high operating costs and usually require operating subsidies; otherwise the price of the tickets would be prohibitive even in developed cities. While in principle public transport operations do not need to be profitable, given the valuable service that they provide to society, the high capital and operation cost of metros makes them less economically viable in medium-sized developing cities than in megacities.

Ropeways or air gondolas are a special case of rail transport. With capacities comparable to small or medium-sized tramways on rail tracks and with moderate costs, ropeways have evolved to become a reasonable and attractive proposition for mainstream urban public transport in a number of medium-sized developing cities, including Algiers and Oran (Algeria), Medellin (Colombia), and Caracas (Venezuela). They can provide suitable urban transport in hilly terrains, and over rivers, harbors, motorways, as well as over dense housing and historic buildings, and can complement other public transport options [31]. Due to the limited amount of literature available on this mode, policy options in this area are not reviewed in detail here.

2.3. Road-Based Public Transport

Effective road-based public transport is central to economic growth of developing cities. For the majority of residents, road-based public transport (bus and paratransit) is the only means to access employment, education, and public services. In medium and large developing cities, such destinations are beyond viable walking and cycling distances while vast numbers of individuals have limited access to automobiles. Unfortunately, the current state of road-based public transport services in many developing cities does not serve the mobility needs of the population adequately. Formal bus services are often unreliable, inconvenient, uncomfortable, or even dangerous. Informal paratransit services, while providing benefits including on-demand mobility for the transit-dependent, jobs for low-skilled workers, and service coverage in areas devoid of formal transit supply, carry major costs, such as increased traffic congestion, air and noise pollution, traffic accidents, and even violence among route cartels [32]. In addition to regulating paratransit systems through measures in between the extremes of acceptance and outright prohibition, several options are available to medium-size developing cities that wish to improve the quality of formal bus services.

In recent decades, the creation of bus lanes on existing roads (painting of a lane in a different color from the rest of the asphalt) has been a common low-cost strategy for improving the quality of bus systems throughout the world. In some cases, they are shared with high-occupancy vehicles, taxis, and/or non-motorized vehicles, and even with vehicles near turning points. New technologies allow vehicles in bus lanes to gain priority at intersections, with lights automatically turning red for cars and green for buses whenever the later approach shared intersections. Despite their advantages, in developing cities, unsegregated bus lanes alone, particularly those situated in the curb lane, do little to enhance the effectiveness of public transport. Temporary parking by taxis and delivery vehicles, low levels of respect for traffic rules, the unavoidable conflicts with turning vehicles, and limitations in narrow street configurations degrade the usefulness of bus lanes in these contexts. Here, a more effective intervention in favor of public transport is the construction of busways that are physically segregated from other traffic by means of barriers, cones, or other well defined physical features. Located on the curb or in the median of a roadway, they are permanently and exclusively for the use of public transport vehicles-although emergency vehicles are often allowed to use the lane [26].

Bus Rapid Transit (BRT) is a recently developed bus-based mass transit which emulates the performance and amenities of rail transit. "Full BRT" (Box 1) is often more appropriate for large cities as it can transport up to 45,000 passengers per hour per direction, surpassing the capacity of many rail systems. To date, full BRT has been developed only in a few large cities (including Bogotá, Curitiba, and Guangzhou) with very high levels of political commitment and charismatic political leadership in support of quality public transport [26,33]. More standard forms of BRT include segregated busways over the majority of the length of the system's trunk/city center corridors and at least two of the full BRT characteristics. These serve up to around 13,000 passengers per hour per direction, and may be more suitable for medium-sized cities [26].

Box 1. Characteristics of a "full BRT system" (based on [26]).

- metro-quality services
- location of busways in the median of the roadway rather than the curb
- integrated network of routes and fares
- closed high-quality stations that provide level access between the platform and vehicle floor
- pre-board fare payment/verification
- system management through a centralized computerized control center
- clear route maps, signage, and/or real time displays that are visibly placed within the stations/vehicles
- frequent and rapid service
- modern, clean vehicles
- special physical provisions to ease access for the physically disabled
- marketing identity
- clean vehicle technology
- superior images and customer service (*i.e.*, clean buses and uniformed staff)
- entry to system restricted to prescribed operators and a restricted number of vehicles ("closed system")

Prior experience indicates that the best BRT results are achieved when private sector competition is combined with strong public sector oversight [26]. This type of business plan is generally desirable for public transport in developing cities, even those without BRT systems, because in these contexts both fully regulated sectors and completely deregulated sectors have failed [34]. Mainline services can be complemented by existing conventional bus and paratransit systems, which can provide feeder connections and serve remote areas [32]. To avoid overreliance on fossil fuels, BRT vehicles can run on natural gas, electricity, or biofuels (see below). Once a developing city has secured the right of way for a BRT system, it can later upgrade to light rail should funding become available.

To date more than 150 cities worldwide (at least 70 in Asia, Africa, and Latin America) have implemented BRT systems. Comparative assessments of BRTs throughout the world have found that most systems have greatly improved their local travel conditions and the quality and performance of public transport, especially in travel time savings and enhanced reliability. BRT systems have also reduced energy consumption and emissions. They have generally been well-received by the users leading to massive bus ridership increases. Urban enhancements are also evident [26,33,35,36].

BRT can be developed at substantially lower costs than rail transit. BRT systems typically cost between $1 m and $8 m per kilometer depending on the complexity and size of the project (the need for overpasses or underpasses and the need for property acquisition). Even in developed cities with higher labor costs, BRT costs less than $10 m per kilometer. If property designed, BRT can operate at affordable fares ($1/ride) without subsidies. Rapid implementation times (1–5 years) and flexibility to adapt to spatially-constrained historical centers and business districts with narrow roadway segments are other attractive features [26].

Despite the advantages, BRT systems in various developing countries suffer from a range of problems. These include rushed implementation (e.g., several components incomplete at the time of commissioning); very tight financial planning as systems usually do not receive operational subsidies; excessive occupancy levels; early deterioration of infrastructure; fare collection systems requiring very tight supervision; and insufficient user education for initial implementation and system changes. While many of these problems are associated with financial restrictions and institutional constraints, they are not intrinsic BRT issues. Nevertheless, these difficulties affect public perception which means that BRT is often regarded as a “second-best” mode compared to rail, and that politicians frequently offer rail alternatives as part of their electoral proposals [37].

2.4. Support for Non-Motorized Modes

Non-motorized transport—walking and cycling, but also pedicabs and other human-operated vehicles—is the dominant transport mode in many developing cities, especially in Asia and Africa. The smaller the city size, the higher the percentage of non-motorized transport use. Generally, bicycles are used more extensively in developing cities than in developed cities. The urban poor, who cannot afford motorized transport, most often walk or cycle to reach work, school, and other services. Pedicabs and other non-motorized taxi services provide employment for young and poor urban men. While non-motorized trips may last longer than vehicular trips, for many developing city residents a higher time cost is preferable to a higher financial cost for transport [38]. Moreover, increases in non-motorized transport improve traffic safety in cities. Research (employing data from developed cities) has shown that the likelihood of collision between a pedestrian or cyclist and a motor vehicle is inversely related to the amount of foot or bicycle traffic [39]. Therefore, in medium-size developing cities, investment and support for walking and cycling are paramount [38].

Despite its importance, non-motorized transport policy (Box 2) and its related infrastructure are often neglected in policy-making in developing cities. On one hand, the political climate is not favorable to soft modes. Politicians consider walking and cycling as a sign of backwardness and not commensurate with their goals and aspirations. Urban elites distort transport planning in favor of motorized modes, which they are more likely to use themselves. Major international lenders often invest minuscule amounts in non-motorized improvements. The groups which most heavily rely on non-motorized transport are poorly organized and unable to articulate their needs. On the other hand, urban street use in developing cities often has a conflicting nature, with a complex pattern of coexistence between pedestrians, vehicles, vendors, and even animals, which also makes interventions more difficult [38,40].

Box 2. Examples of non-motorized transport policies mainly from Northern European cities (based on [41,42]).

- auto-free zones in city centers
- sidewalks on both sides of the street
- pedestrian refuge islands for crossing wide streets
- zebra crosswalks, often raised and with special lighting for visibility
- pedestrian-activated crossing signals, both at intersections and at midblock crosswalks
- extensive networks of bike paths and lanes
- "bicycle streets" where cars are permitted but cyclists have strict right-of-way
- special bike turn lanes leading directly to intersections
- separate bike traffic signals with advance green lights for cyclists
- bike parking (ranging from secured boxes to simple racks)
- integration of bicycles with public transport (*i.e.*, allowing bicycles on public transport vehicles, at least outside peak hours)
- bike-activated traffic signals at key intersections
- modifications of street networks to create deliberate dead ends and slow, circuitous routing for cars but direct, fast routing for bikes
- traffic calming of residential neighborhoods through speed limits and physical barriers such as raised intersections and crosswalks, traffic circles, road narrowing, zigzag or chicane routes, curves, speed humps, and artificial dead ends created by midblock street closures
- lower speed limits for motor vehicles in cities (e.g., 50 km per hour)
- prohibitions of truck traffic and through traffic of any kind in residential neighborhoods
- driver training focused on avoiding collisions with pedestrians and cyclists
- traffic education of children
- traffic regulations that favor pedestrians and bicyclists, placing the burden of proof on drivers in case of collisions
- strict ticketing and high penalties for motorists, pedestrians, and cyclists who violate traffic regulations

Various recent examples of improvements and innovation in non-motorized transport policy in developing countries can be identified. For example, Chinese cities have rapidly transitioned from human-powered bicycles and gasoline-powered scooters to electric bicycles. Improvements in e-bike technology, growing incomes, and falling e-bike prices, as well as government policies including e-bike national standards and safety regulation, local sale restrictions for gasoline scooters, and banning of gasoline vehicles from city centers, have encouraged this modal shift [43]. The Chinese government has also mandated the reconversion of motorcycle lanes into bicycle lanes [38]. Cycle networks have been developed in several Latin American cities, including Bogotá, Colombia, and Sao Paolo, Brazil. As with buses, physically segregated bicycle paths are more effective than bicycle lanes. Bogotá's Ciclovia-Recreovia and Cicloruta programs are community-wide programs that promote the use of bicycle paths. In Chile, the Vida-Chile is a national program that uses a variety of strategies to promote physical activity [44]. Bicycle-sharing schemes have been introduced in a growing number of developing cities, including Rio de Janeiro (Brazil), Daejon (Korea), and Hangzhou (China). Evidence to date suggests that bicycle-sharing has led to growing bike use but no reductions in car use. The growth of this mode has been concentrated in medium- to small-sized towns with systems of 50 bicycles [45].

2.5. Technological Solutions

The main urban transport-related technological solutions that cities worldwide are currently pursuing (with North American and West European cities leading the way) include alternative-fuel vehicles and intelligent transportation systems (ITS). New technologies may help to tackle certain transport-related problems, such as air and noise pollution, oil dependency, traffic congestion, and accidents [46,47]. Their applicability in developing cities is considered below. The sustainability of these types of technological solutions is subject to three caveats. First, transport technology improvements cannot help tackle reduced physical activity due to car dependence. Second, in most developing countries, where car ownership is growing, the benefits of technological advances will often be offset by the rapid increase in the amount of car travel. Third, many new technologies are outside the financial reach of many residents of developing cities. Consequently, the pursuit of technology-based measures alone is not cost-effective in these contexts [48]. Nonetheless, technological optimism prevails in both developed and developing countries, which may be seen as an expression of people's reluctance to more fundamental changes in lifestyle [49].

A wide range of vehicles–passenger cars, heavy-duty trucks, garbage trucks, three-wheelers (primarily in Asian countries), and buses–can run on alternative fuels including natural gas, electricity, and biofuels. These fuels, which can be produced from any primary energy source, including biomass, wind and solar energy, nuclear energy and decarbonized fossil fuels, constitute a cleaner alternative to diesel and gasoline. Biodiesel can be used in any diesel engine without modification while ethanol, gas, hydrogen, and electricity can be used only in specially-produced or modified cars [50].

In some countries, especially in South America, the availability of natural gas resources and existing pipeline and delivery infrastructure are incentives to encourage natural gas use for transport (compressed natural gas and liquefied petroleum gas). Brazil and Argentina combined have more than half of the world's total natural gas vehicles, but several Asian countries, notably India, China, and Pakistan, have also had significant natural gas vehicle growth beginning in the late 1990s. In other countries, the adoption of natural gas for urban transport requires the co-existence of fuel supply, refueling stations, and appropriate vehicles–a classic "chicken and egg" dilemma [51].

Some governments in developing countries specifically mandate the use of natural gas for transport in highly polluted areas (e.g., for taxis in Buenos Aires, and more recently for buses in Beijing and all pre-1990 taxis in New Delhi). Other developing country governments offer financial incentives to consumers of natural gas fuels and vehicles and to equipment suppliers of alternative fuel vehicles. A pump price of at least 40%–60% below the gasoline price–attributed to government incentives such as favorable taxation, tax breaks for natural gas, or higher taxes on gasoline and/or diesel fuel–is common in most countries that have had successful natural gas vehicle penetration. Experiences in Argentina, Brazil, China, India, and Pakistan indicate that marketing and subsidy programs must be sustained for long periods before diffusion crosses the tipping point. This is due to the long life of a vehicle fleet and social and economic penetration barriers [51].

Electric cars (fuel-cell, battery, or plug-in) have a low range (e.g., 100 km on a full charge in city traffic conditions), and are therefore attractive for use in small and medium-sized urban areas. However, their widespread adoption in developing countries faces a range of barriers. The capital costs of electric vehicles are significantly higher than the costs of conventional cars. In order to amortize the acquisition costs through energy savings, an electric car has to be used to travel significant distances, typically more than 20,000 km a year [52]. While some estimates indicate that in a few decades capital costs could drop significantly, conventional cars will remain cheaper. In terms of fuel costs, accurate predictions are not possible. Another significant challenge is the bulkiness and cost of batteries or hydrogen tanks. In the recent past, recharging battery-powered vehicles was very time-consuming but fast-charging stations are now becoming available. While electric vehicles are non-polluting at the point of use, their overall environmental impact depends on the way in which electricity is generated, stored, and distributed and the problems associated with recycling expired batteries. The availability of lithium in the case of batteries and the availability of platinum in the case of fuel cells constitute barriers as well [50]. Overall, the market penetration of electric vehicles in developing cities is far from favorable, at least in the short term. For example, modelling estimates for Colombia predict that, even by 2050, electricity will not have surpassed gasoline in the Colombian passenger car fleet [53]. India aims to have 100,000 electric vehicles on the roads by 2020-a small share considering its population size-while China's modest target is for the annual sales of "new energy" vehicles (electric, hybrid, *etc.*) to reach 5% in the short term [52].

Biofuels (mainly ethanol, biodiesel, and blends) could provide a significant reduction in urban greenhouse-gas emissions, particulate matter, and volatile organic chemicals. They are attractive to many developing countries where surplus land (e.g., marginal land) can be used for biofuel production [54]. Brazil, China, and India are world leaders in ethanol production, surpassed only by the US [55]. Warm-climate countries such as Argentina, Colombia, Indonesia, India, Malaysia, Thailand, and the Philippines which produce large amounts of palm, coconut, soybean, and jatropha oil show promise for the adoption of biodiesel [56]. However, biofuels present various challenges depending on the type of feedstock. For corn-based biofuel, in particular, life-cycle assessment studies have highlighted a low or negative net contribution to emission reductions [57] Biofuels, especially biodiesel, generate up to 70% higher NO_X emissions depending on feedstock. Moreover, the greenhouse-gas savings potential may disappear once the full impacts of fuel production are taken into account (*i.e.*, the release of carbon stored in forests or grasslands during land conversion to crop production; the frequent burning of cleared vegetation for biofuel production; and the fugitive emission of methane from palm-oil production). Another key concern is the close link between biofuels and food consumption. A switch to second-generation biofuels (manufactured from non-food feedstock) might alleviate these concerns. However, second-generation biofuels still compete with food supply through land-use and are currently constrained by many technical and economic barriers [54].

In addition to alternative fuels, intelligent transportation systems (ITS) have the potential to address urban transport problems in a variety of applications (Box 3). In the industrialized world, ITS have only been adopted at a moderate pace and, in developing countries, adoption has been even slower. In East Asia, Eastern Europe, and Latin America, the most common forms of ITS that have been introduced to date include traffic signal systems, traffic surveillance systems using CCTV, commercial vehicle (e.g., taxi) tracking systems using GPS, electronic ticketing services, electronic toll collection and fare payment systems, bus management systems, and traveler information systems. Further ITS deployment is needed in these settings to improve road safety conditions and mitigate traffic congestion, especially in large, polluted, and congested cities and in harsh climates with hazardous driving scenarios [58].

Box 3. Potential applications of intelligent transportation systems (ITS) (based on [59]).

- advanced traffic management systems, which predict traffic congestion and provide alternative routing instructions to vehicles in real time to improve the efficiency of the road network and maintain priorities for high-occupancy and transit vehicles
- advanced traveler information systems, which provide data to travelers in their vehicles, homes, or workplaces about the location of incidents, weather problems, road conditions, parking availability, and optimal routings, to help them decide what route and mode they should use
- advanced vehicle control systems, which enhance driver's control of the vehicle to make travel both safer and more efficient, and range from collision warning systems to self-driving cars
- automated vehicles, including private cars and automated taxis with fares similar to public transport
- automated road systems, which rely on infrastructure information and control to automatically control the movements of high-occupancy or transit vehicles in special lanes
- on-demand transport and parking (aided by cell phone technology)

Although developing cities are often at a disadvantage in applying ITS relative to developed cities, they also have some advantages. For example, some developing cities can install electronic infrastructure at the same time that physical infrastructure is being constructed, which is far less expensive than retrofitting existing physical infrastructure. Developing cities are also not generally burdened with outdated IT infrastructure that has to be updated. They can take advantage of ITS products and applications, which have already been tested and deployed in developed cities and which are now mature and stable. In theory, they can then leapfrog to an ITS-enabled transportation infrastructure far more rapidly and far less expensively than developed countries [58]. Nevertheless, the viability of ITS in developing countries remains contentious due to a lack of financial resources, basic infrastructure, and institutional capacity. Substantial funding is required in order to implement high-level ITS at a large scale. The indifferent attitude of many local professionals and a lack of user trust in new technologies have also undermined wide-scale ITS acceptance [58,60]. Another concern is that the adoption of "hi-tech" transport solutions in developing cities might eliminate low-skilled jobs, which are desperately needed by the population. In view of these experiences and concerns, ITS needs to be introduced cautiously in smaller developing cities.

2.6. Awareness-Raising Campaigns

Developed and developing countries have used information, education, persuasion, and awareness-raising campaigns in favor of sustainable urban transport with various, but generally limited, degrees of success. Typically, the more effective a measure is, the more resistance it evokes [61]. Social mechanisms and processes, such as status seeking (*i.e.*, the automobile as a status symbol), freedom seeking, or lack of trust in others' cooperativeness, are often at play, especially in the developing world, and perpetuate urban transport problems [49]. Moreover, the publicity generated by the car industry is well ahead of sustainable urban transport promotion. In the collective consciousness, private motorized vehicles have been long associated with pleasure, comfort, speed, convenience, power, protection, superiority, individuality, hedonism, and freedom [62].

Several general strategies to raise awareness on sustainable transport policy can be employed (Box 4). A few specific techniques seeking to reduce car use settings have also been developed and tested but generally only in developed countries. These techniques involve the provision of tailored feedback to individuals and households about travel patterns, costs, and the alternatives to current behavior [63,64]. The main aim of these exercises has been to motivate people to consider the consequences of their travel behavior. While the pilots have yielded promising results (up to 10% reduction in car travel), their effects cannot be fully generalized yet. Although cost-effective, they often require large upfront investments [63].

Box 4. General strategies to raise awareness on sustainable transport (based on [49]).

- provision of information, education, communication about risk generation, types and levels of risk resulting from one's transport choices, others' perceptions and intentions, and risk reduction strategies
- social modeling and support, *i.e.*, demonstrating cooperative behavior and the efficacy of others
- changing values and morality (*i.e.*, appealing to conscience, enhancing "altruism" towards others and future generations, and reducing selfishness)

In developing countries, lower-cost activities are likely to be more feasible and constructive (e.g., car-free days, bicycle-to-work days, free-vehicle-inspection days, bicycle film festivals, car-pooling days, free-public-transport days, and media attention). Effective public awareness activities require novel approaches to capture the audience's attention. Also, campaigns must advance specific ideas (e.g., the creation of cycle tracks) rather than vague notions (e.g., transport sustainability in general). Experience suggests that public awareness campaigns need to be targeted and "integrated" (presenting all the urgent urban transport concerns as interconnected and interdependent). Parking policy must be correctly framed as not merely a public order issue but as a crucial tool in restricting demand for car travel and in raising revenues. Public awareness activities must encourage shifts in existing paradigms. For example, bicycles must be presented as the healthy vehicles of the future (*i.e.*, a new status symbol rather than a vehicle for the poor); cars as imposers of high costs on the community (*i.e.*, an antisocial mode); buses as modern and comfortable (*i.e.*, a choice mode rather than a mode of last resort); walkways as a measure of democratization (*i.e.*, pedestrians as part of the transport system).

It is important to select relevant and context-sensitive advocacy activities as locals might not be able to relate to best practice examples from developed cities. Campaign organizers must project an image of professionalism, expertize, vision, creativity, and persistence. Messages sent by groups which appear amateurish are often ignored. Whether awareness campaigns are organized by government and/or civil society, the support of charismatic political leaders is often crucial [65]. Because many urban transport problems are perpetrated and perpetuated by people with higher education, sustainability concepts must be included in university teaching curricula. Successful courses in sustainability engage participants' heads (cognitive domain; academic study and understanding of transport sustainability), hands (psychomotor domain; enactment of theoretical learning through practicing transport sustainability in real life), and hearts (affective domain; enablement of values and attitudes to be translated into travel behavior) [66].

2.7. Pricing Mechanisms

Even in contexts where drivers are well aware of the adverse impacts of car driving in urban areas, the choice of mode is distorted in favor of road transport, particularly private cars, if drivers are not charged the full costs of motorization [27]. The availability of free or underpriced parking also fuels car ownership and use and increases "search-for-parking" traffic [67]. Keeping fuel prices artificially low-through price control, export or quantity restrictions, or political pressure put on oil companies-produces another set of adverse effects, particularly in developing countries. These include flourishing black markets, smuggling, fuel adulteration, illegal diversion of subsidy funds, large financial losses suffered by fuel suppliers, deteriorating refining and other infrastructure, and acute fuel shortages causing economy-wide damage [68].

The idea of financially penalizing drivers by using coercive pricing mechanisms (Box 5) has long been proposed by transport economists as an effective mechanism to contain car use in urban areas. Notwithstanding their theoretical value, all real-world pricing schemes have limitations and there is no guarantee that their benefits will exceed their setup and operating costs. For example, while fuel taxes are administratively simple and discourage the utilization of vehicles in the short-run, in the long run they alter consumers' purchasing behavior, thereby causing them to switch to more fuel-efficient methods (e.g., smaller vehicles, which ultimately do little to alleviate congestion and can increase safety risk). Even in the short-term, most studies find that fuel taxes lead to welfare loss among lower-income drivers, who lack alternative travel options (*i.e.*, in a city where the public transport system is weak).

Box 5. Examples of coercive pricing mechanisms.

- fuel taxes (based on emissions)
- vehicle import/purchase/registration taxes (based on emissions)
- experience rating of car insurance premiums; tradable mobility/emission credits/quotas
- direct road charges (urban drivers are charged by distance travelled based on information collected through electronic plates installed in cars)
- cordon area pricing (charges apply for the right to access or circulate within limited geographical areas, generally city centers, with some degree of time differentiation)
- parking fees (generally paid hourly in city centers and monthly in residential neighborhoods).

Cordon pricing and direct road charges, which outside the developed world have only seen application in Singapore, employ cameras or other electronic devices that observe the license plates of vehicles entering or moving within the cordon, and charge the driver remotely. While cordon pricing has positive impacts on peak-congestion delays, air pollution, and accidents in city centers, it often has few effects on the overall amount of commuter traffic [69].

While megacities with large numbers of private vehicles and severe congestion problems may prefer congestion charges, smaller developing cities might consider fuel taxes. Generally, in developing countries and cities with low administrative capacities, instruments with smaller or no monitoring costs (e.g., fuel taxes and emission-based vehicle taxes) are more effective than those requiring large monitoring or administrative and compliance costs. No single policy fits all conditions. The policy options presented in this article can be enacted at the local, regional, or national level, depending on the governance arrangements that are already in place [70].

The major barriers to charging drivers the full cost of car use are often related to public acceptability and political feasibility. Even the most sophisticated, equitable, efficient, and sensitive policy designs will create losers and generate opposition. This necessitates approaches that can increase public acceptance while maintaining efficiency. For example, earmarking revenues for local public transportation, and possibly for infrastructure for pedestrians and bicyclists and public space improvements, has public support (more so than placing revenues in general funds). These revenues can then be used to reduce other taxes or could be returned uniformly to adult residents or owners of registered vehicles in a designated area. Overall, studies indicate that attitudes toward road pricing improve after programs are implemented–once residents experience their benefits [61,67,69].

Pricing mechanisms also include subsidies for public transport fares (e.g., limited to vulnerable groups), tax subsidies (or exemptions) for the purchase of clean vehicles, and incentives for scrapping old vehicles. They have all been implemented in various developing cities but in a limited way due to their cost.

2.8. Vehicle Access Restrictions

Pricing mechanisms are generally considered to be more effective than regulatory approaches because they offer car users more choice, raise revenues, and can be adjusted according to different conditions [69]. However, blanket command-and-control policies have a role to play as well. Laws and regulations related to driving include limits on car use based on certain criteria, such as emission levels, noise levels, vehicle weight, fuel consumption, occupancy (*i.e.*, bans of single-occupancy vehicles), days of the week, time of the day, area (usually a city center), and license plate number (in pollution-emergency days or permanently), and quotas for distance travelled or number of motorized trips within a given urban area. Other regulatory options include parking restrictions and speed limits.

Several developing cities have experimented with selective car rationing or banning, often reaching for higher achievement than developed cities. These measures are considered politically easier to implement than pricing mechanisms because of the perception that all sections of the population are treated equally [71]. For example, Bangkok made efforts to restrict all newly registered cars to use exclusively in non-rush hours. In Guangzhou only locally registered motorcycles are allowed to circulate. Many other Chinese cities have limited the operation of commercial vehicles in unprecedentedly detailed ways (in terms of days, hours, and localities). During the 2008 Olympics, the City of Beijing imposed a temporary restriction on car owners based on license plate numbers. In Latin America, larger cities including Mexico City, Santiago, São Paulo, and Bogotá have attempted the same approach for some time. While there are no reported examples of large-scale car restrictions implemented in smaller developing cities, many examples of small-scale pedestrianization schemes in historic or commercial centers can be found, especially in some parts of Latin America and Asia.

In the past, some vehicle restriction measures have had unintended consequences. In Mexico City, for example, a vehicle restriction backfired when more than one fifth of the households (the higher income ones) purchased additional cars with alternating plates (usually cheaper, older, and more polluting) in order to circumvent the restriction. In Santiago, the car ban schedule is changed every few months to prevent this possibility, while in Bogotá, the high price of used cars prevented the problem from arising. While traffic restrictions have received public support in Latin America, they have faced opposition from the auto industry and vehicle owners. To be successful, these types of command-and-control measures must be reinforced by other complementary transport policies and promotional measures [71]. Some types of car restrictions, such as speed limits, are not effective without the traffic law enforcement resources to ensure that limits are followed [72].

An indirect way to alleviate peak-hour congestion through regulations is to mandate employers to implement telecommuting, flexible work, and staggered work shift programs, so that employees shift their commute at different times of the day. Reviews that recount the experience of developing cities with work-related policies and their impact on urban travel are still to be assembled. In developed countries, the evidence suggests that, without supportive policies, telecommuting is unlikely to be enough to affect employee commuting patterns [73].

2.9. Control of Land Uses

Generally, public transport and non-motorized modes require high densities and mixed uses in order to be practically and financially feasible. Compact urban development is also often associated with shorter distances and lower use of motorized transport. Therefore, land-use controls have important implications for travel behavior. In smaller cities in particular, the manipulation of urban form (shape, size, density, compactness, intensification, decentralization, land-use type and mix, building layout and type, and green and open spaces) can help to overcome city problems [74]. However, there are many complexities in the relationship between transport and land-use. The desirable degree of compaction of existing settlements is far from clearly understood. Moreover, a wide range of variation in terms of urban form, density, governance, economy, zoning controls, and enforcement capacity, exists in the developing world. Sustainability choices depend on local characteristics, which are briefly reviewed here.

Developing cities often have higher densities than developed cities, especially in the urban core (the densest urban areas in the world are found in developing countries—e.g., Mumbai and Hong Kong). This is due to higher urbanization rates, smaller dwellings, a prevalence of high-rise housing, later advent of the automobile, and lax regulations that allow land and housing subdivisions. However, there is disparity among regions. While Asian cities are often extremely dense, cities in sub-Saharan Africa are some of the world's most spread out, with large squatter settlements. In contrast to the "planned sprawl" of developed cities, sprawl here is mostly unplanned and poses a different set of challenges. Densities are high in North African cities but low in Latin American ones. Many cities are dual, with dense inner areas and peripheral sprawl. Climate variations, as well as cultural factors, play a role in the level of acceptable space consumption and proximity [74]. Evidence to date suggests that there is no single sustainable urban form but uncontrolled low-density sprawl is never the best option.

Some developing cities have strong economies which enable transport investments and land use control, while other are poor and/or have a laissez-faire approach to development and are dominated by the informal sector. However, in most developing-city contexts, land use intensification often occurs in the absence of land use controls. Strict enforcement to avoid sprawl and high public investment to purchase land or development rights (e.g., for the creation of urban green belts, green corridors, or ecological reserve areas) appear to be unlikely here given a past history of loose or patchy enforcement.

In contrast with de-industrialized European cities, the potential for conversion of derelict urban land (brownfield sites) is limited in many developing cities where industrialization has been minimal. In developing cities which are built in naturally hazardous areas (floodplains, seismically active zones, foot of volcanoes, *etc.*), densification has implications for disaster mitigation and management. The densification is a very contentious issue in both overcrowded inner-city shanty towns and low-density peri-urban squatter settlements with large plot sizes but with maximum lot coverage [74].

In terms of functional mix, developing cities are generally characterized by high levels of mixed use, as well as vitality and vibrancy (*i.e.*, the "urban village" notion). This is due to a limited penetration of modernist concepts and loose land use controls rather than specific policies. However, in higher income developing cities, shopping centers, strip malls, wholesale supermarkets, and sometimes high-tech industry clusters, have started to appear in the peripheries, causing traffic congestion. Interest in linear city models, often at a very large scale, is high in Southeast Asia and South Africa. Attempts to manipulate urban form (e.g., towards a classic radio-circular form for smaller cities and a polycentric "concentrated deconcentration" form for larger cities) have been limited due to the shift from comprehensive planning to piecemeal project-based and strategic planning, which has also occurred in developed cities [74].

Given the great diversity of land use approaches, preferences, and constraints in developing cities, it is difficult to come up with a set of recommendations that can apply to all. Experience to date suggests that some degree of success can be achieved if a pragmatic rather than idealistic approach is taken. If an overall dense and compact development cannot be achieved or if densification is not desirable in a given context (*i.e.*, already hyper-dense inner city areas), densification and intensification of land uses can be encouraged around transport nodes and along transport corridors (the transit-oriented development or TOD model at a regional scale) in order to increase access for larger portions of the population. TOD has been successful in a variety of settings, including some developing cities [75]. Compaction efforts can be concentrated on the development of new neighborhoods rather than on modifying existing ones, although this approach could lead to urban sprawl and consequently, the degradation of inner cities. Incentive schemes involving land-sharing arrangements, the transfer of development rights, and public/private partnerships, show some promise. In some cases, small yet significant interventions, either through planning discourse or symbolic development on the ground, can help change public perceptions of sustainable urban form [74].

3. Conclusions

Smaller and medium-sized developing cities, especially ones which are dense and compact, have great potential to develop sustainable transport systems. Low-cost investments and the imposition of modest fees on road users can deliver substantial environmental and lifestyle benefits for these cities. However, no single type of strategy or policy is effective or sufficient to promote more sustainable urban transport. Moreover, different types of measures may be more appropriate for smaller and medium-sized developing cities than megacities (e.g., fuel taxes rather than congestion charges).

Some of the key strategies to be considered in these developing cities include: (1) street conditions conducive to green modes via low-cost interventions such as sidewalk maintenance and speed restraint; (2) pedestrian-only zones in areas with heavy pedestrian traffic; (3) exclusive lanes for busses and bicycles, which are adequately protected from car traffic; (4) reasonable parking fees; (5) more attention to road infrastructure maintenance rather than the construction of new infrastructure; and (6) awareness-raising and education campaigns.

When considering investments in public transportation in medium-sized developing cities, a key priority should be to improve existing bus systems. BRT is more affordable and cost-effective in these cities than many other types of public transportation systems, including LRT. The high capital and operation cost of metros makes them less economically viable in medium-sized developing cities than in megacities. Promoting more sustainable patterns of urban development is also crucial for reducing the environmental impacts of cities but the appropriateness of different forms of development is context-dependent. Uncontrolled low-density sprawl is, however, rarely appropriate. Technological improvements can help to address urban environmental problems but they cannot address all transport-related problems. Moreover, the benefits of technological advances may be offset by rapid transport growth in developing cities. However, inexpensive technologies such as new mobility services via cell phones (*i.e.*, on-demand transport or parking payments) already exist in developing countries and could be utilized more extensively to promote new innovative forms of urban transport services. The social, economic, and environmental impacts of large-scale alternative fuel adoption in developing cities are often uncertain.

There is increasing recognition that combinations (or packages) of measures are necessary [5,76]. Certain combinations of policies can work together and give rise to synergies, leading to impacts greater than the sum of their individual parts. The identification of policy packages is a crucial issue for promoting more sustainable urban transport: packages should maximize potential synergies. It is crucial to consider local factors such as costs, feasibility, and barriers. Finally, caution is advised both in terms of the appropriateness and effectiveness of policy solutions being transferred to smaller and medium-sized cities in developing countries from larger cities and/or from more developed countries.

Author Contributions

Dorina Pojani performed 80% of the work for this article (including research design, analysis, and writing) and Dominic Stead performed 20%. Both authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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