



Transforming Our Cities: Best Practices Towards Clean Air and Active Transportation

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Abstract

Purpose of Review By 2050, 70% of the global population will live in urban areas, exposing a greater number of people to specific city-related health risks that will only be exacerbated by climate change. Two prominent health risks are poor air quality and physical inactivity. We aim to review the literature and state the best practices for clean air and active transportation in urban areas.

Recent Findings Cities have been targeting reductions in air pollution and physical inactivity to improve population health. Oslo, Paris, and Madrid plan on banning cars from their city centers to mitigate climate change, reduce vehicle emissions, and increase walking and cycling. Urban streets are being redesigned to accommodate and integrate various modes of transportation to ensure individuals can become actively mobile and healthy. Investments in pedestrian, cycling, and public transport infrastructure and services can both improve air quality and support active transportation. Emerging technologies like electric and autonomous vehicles are being developed and may reduce air pollution but have limited impact on physical activity. Green spaces too can mitigate air pollution and encourage physical activity.

Summary Clean air and active transportation overlap considerably as they are both functions of mobility. The best practices of clean air and active transportation have produced impressive results, which are improved when enacted simultaneously in integrated policy packages. Further research is needed in middle- and low-income countries, using measurements from real-world interventions, tracing air pollution back to the sources responsible, and holistically addressing the entire spectrum of exposures and health outcomes related to transportation.

Keywords Cities · Air pollution · Active transportation · Clean air · Physical activity · Best practices · Public health

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Introduction

Ambient air pollution (PM_{2.5}) was the fifth-ranking mortality risk factor in 2015 (after high systolic blood pressure, smoking, high fasting plasma glucose, and high total cholesterol), causing 4.2 million premature global deaths (7.6% of all deaths) [1, 2]. Over 90% of ambient air pollution fatalities occur in low- and middle-income countries, mainly in Asia, Africa, and the Eastern Mediterranean region [1]. Those aged 50 and older are the most susceptible; a trend that is particularly relevant as lifespans continue to lengthen and adults aged 60 and older represent an increasing proportion of the global population [1, 3]. Additionally, the associated premature mortality and morbidity reduces countries' labor incomes and gross domestic product (GDP) growth. In 2016, for example, the cost associated with the burden of disease from ambient PM_{2.5} worldwide was USD\$5.7 trillion: 4.4% of the global GDP [4].

Worldwide, trends of motor vehicle dependency have contributed to the emission of greenhouse gases (GHGs) and air pollutants, which adversely impact urban air quality. GHGs produced by motor vehicle traffic further contribute to global warming and climate changes that can independently exacerbate poor air quality and public health outcomes [5, 6]. Motor vehicle dependency has also resulted in physical inactivity for many, incurring a significant burden of disease which is responsible for 3.2 million deaths (6% of all deaths) per year [7, 8]. With these emerging impacts and concerns, more transportation planners and public health officials have been collaborating to integrate physical activity and active travel, in what is known as active transportation, to reduce physical inactivity. Active transportation decreases the risk of type 2 diabetes, weight gain, respiratory disease, cardiovascular disease, cerebrovascular disease, dementia, depression, obesity, cancer, and impaired mental health all resulting in an increased risk of premature mortality [9]. Active transportation could provide means to integrate physical activity habits into daily routines and can improve ambient air quality if modal shifts from motor vehicles occur at a sufficient scale [10].

The mortality and disease burdens associated with ambient air pollution and physical inactivity can have profound effects on the quality of life and the social and economic progression of cities and their citizens. The global urban population is expected to grow by 2.5 billion people before 2050 (90% of which will be in Asian and African cities), exposing more people to the health burdens associated with urban air pollution and physical inactivity [11]. In this paper, we first overview the current status of air quality and active transportation in cities and countries around the world alongside relevant standards and recommendations. We then review the best practices of clean air and active transportation to highlight current interventions addressing poor air quality and physical inactivity in cities. Most of the literature we source was published within the last 5 years. Existing literature about clean air and active transportation, however, is based on research from Western countries. Many middle- and low-income countries do not have extensive data sets on air quality; therefore, literature from these regions is currently sparse [12]. For this reason, we mainly focus on Western countries, even though the greatest urban growth and health risks are concentrated in Africa, Asia, and Eastern Mediterranean countries [1, 8, 13].

Air Pollution

The Current State of Air Quality and Health Effects

In 2017, over 80% of the world's urban population was exposed to air pollution levels that exceeded World Health Organization (WHO) recommendations [1]. Ninety-seven percent of cities with populations greater than 100,000 in

middle- and low-income countries do not meet the WHO air quality guidelines [14]. Globally, there is high variability in air pollution levels across different cities, as shown in the WHO air quality database which stores the most recently recorded annual particulate matter (PM) means. In 2017, Bakersfield, California, had the highest annual PM_{2.5} mean—18.2 µg/m³—in the United States (U.S.) [15]. In 2016, the highest annual PM_{2.5} means for the European Union (EU) were all from Polish cities, ranging between 35 and 38 µg/m³ [14]. Similarly, the ten most polluted cities in Asia were in India and had annual PM_{2.5} means ranging from 113 to 173 µg/m³ in 2016 [16]. Most middle- and low-income countries have just begun measuring urban air quality while high-income countries have spent decades exploring a variety of methods to measure and reduce air pollution. Air pollution in low-income countries has been increasing while Western countries have seen gradual decreases in air pollution, due, in part, to clean air programs and policies that can provide insight on the best practices to expedite air pollution reductions in areas with worsening air quality.

A key contributor to ambient air pollution is road transportation. Motor vehicles are responsible for air pollution that degrades urban air quality, specifically PM_{2.5}, PM₁₀, black carbon (BC), ultrafine particles (UFP), nitrogen oxide (NO_x), and carbon monoxide (CO), each detrimental for human health [17–19]. These pollutants are released into the air via exhaust pipes, physical decomposition of vehicle and road parts, and resuspension caused by motor vehicle traffic. With the placement of roads near homes, offices, and schools, an increasing proportion of the population is near busy highways and urban roads. Further, the number of registered vehicles and vehicle miles traveled is increasing which results in more people being exposed to air pollution and the risk of numerous adverse health effects [20].

In conservative estimates, motor vehicle-related air pollution causes 1% (184,000 deaths) of all air pollution-related deaths worldwide. Ambient air pollution exposure has been linked to premature mortality and cardiovascular disease [21], stroke [22], respiratory diseases [21] and inflammations including lung cancer [23], pneumonia [24], childhood asthma [25], and chronic obstructive pulmonary disease [26], as well as congenital anomalies [27], deep vein thrombosis [28], type 2 diabetes [29], obesity [30], autism and child behavior problems [31], dementia [32], and pregnancy complications [33]. Road transportation in Europe is responsible for 19% of CO, 36% of NO_x, and 10% and 8% of PM_{2.5} and PM₁₀ emissions, respectively, and 30% of NO_x, 10% of total PM, 54% of CO, and 14% of CO₂ emissions worldwide, although the contribution of road transportation to overall air pollution will vary depending on traffic characteristics, site layout, and the pollutant studied [17, 34–36]. It is difficult to tease out the contribution of traffic-related air pollution to overall

ambient air pollution and associated health effects, but some studies have attempted doing so in various ways. For example, some studies use (proximity to) traffic flow in a GIS to examine the health of individuals living in low versus high traffic intensity areas [37, 38]. Others used dispersion modeling to explicitly model the contribution of traffic to the overall air pollution and associated health effects [39, 40]. Similarly, source apportionment methods have been used to identify the contribution of traffic to overall air pollution and associated health effects [41, 42]. Other studies consider certain pollutants, such as NO₂, as markers of traffic-related air pollutants. In comparison to the literature on the health effects of overall ambient air pollution, studies specifically investigating the contribution of different air pollution sources to specific health effects are less available. Looking forward, the specific assessment of health effects of traffic-related air pollution is important for policy decision-making as it can inform effective mitigation policies [43].

Air Quality and Vehicle Emission Standards

Air Quality Standards

Periodically, the WHO will assemble a group of experts from a variety of fields and institutions to review the latest literature concerning the status of air quality and health effects of air pollution and produce international guidelines that aim to reduce air pollution levels to ensure healthy living environments. The latest guidelines were

published in 2005 and are detailed in Table 1. Currently, over 80% of the global population lives in areas where these guidelines are not met, which combined with emerging evidence suggesting that there are health risks from PM and ozone (O₃) exposure at levels below the WHO guidelines has prompted revision to the guidelines that are expected to be published in 2020 [14, 44–46]. The WHO guidelines are stricter than air pollution standards in the U.S. or EU, where the most progressive air quality standards are in place [47, 48]. For this reason, we consider the WHO air quality guidelines as the best available standards that all countries should aim for. In line with the context of this paper, we next specifically discuss vehicle emission standards and how they contribute to overall air pollution reductions and compliance with the WHO air quality guidelines.

Vehicle Emission Standards

Vehicle emission standards are in various stages of development around the world. A recent review of the 19 G20 countries revealed how developing and underdeveloped countries are lagging behind in their efforts to regulate GHG emissions produced by motor vehicles [49]. Six of these countries—Australia, Brazil, China, India, Mexico, and Russia—currently employ outdated vehicle emission standards, while adopting EU vehicle emission standards could reduce tailpipe PM_{2.5} emissions by 67% [49].

In Europe, vehicle emission regulations are based on the Euro Standards that began in 1992. Since then, there have been six updates, each more stringent on emissions [50]. Although there has been significant progress in limiting transportation emissions throughout Europe, about 90% of European city dwellers were still exposed to pollution levels above WHO air quality guidelines in 2017 [51]. Vehicle emissions can be widely dispersed in the air becoming a transboundary issue requiring collaboration among neighboring countries and states. Following the recent Volkswagen emissions scandal, a study found that nine other vehicle manufacturers in Europe had been selling diesel cars that produced more tailpipe emissions of NO_x on the road than their laboratory tests reported [52]. The volume of excessive NO_x emissions ranged from 14 gigagrams (Gg) in Sweden to 140 Gg in Germany and France, causing a substantial health burden [52].

On the other hand, the U.S. Environmental Protection Agency enforced The Clean Air Act (CAA) of 1970 to address the entire spectrum of air pollution sources. The CAA has produced automobile-specific standards to regulate vehicle emissions in the U.S. which are currently in the “Tier 3” phase that is set to last until 2025 [53]. A comparison of vehicle emissions regulation in the U.S. versus Europe is shown in Table 2.

Table 1 WHO air quality guidelines

Pollutant	WHO guidelines
PM _{2.5}	10 µg/m ³ per cubic meter annual mean
	OR
PM ₁₀	25 µg/m ³ 24-h mean
	20 µg/m ³ annual mean
	OR
O ₃	50 µg/m ³ 24-h mean
	100 µg/m ³ 8-h mean
Nitrogen dioxide (NO ₂)	40 µg/m ³ annual mean
	OR
	200 µg/m ³ 1-h mean
SO ₂	20 µg/m ³ 24-h mean
	OR
CO	500 µg/m ³ 10-min mean
	30 mg/m ³ 1-h mean
	OR
	10 mg/m ³ 8-h mean

Source: [37]

Table 2 Comparison of vehicle emission regulations per pollutant

Vehicle emission pollutants	USA	European Union
Nitrogen oxide (NO _x)	0.04 g/mi	0.06/0.08* g/mi
Carbon monoxide (CO)	2.61 g/mi	1.0/0.5* g/mi
Carbon dioxide (CO ₂)	155 g/mi	130 g/mi
Particulate matter (PM)	0.003 g/m	0.008 g/mi
Non-methane organic gases	0.06 g/mi	0.07/na* g/mi

Sources: [39, 41]

*Petrol/diesel fuels

Active Transportation

The Current State of Active Transportation

Walking and cycling are the most common forms of active transportation, but public transportation can be considered active transportation as walking or cycling typically bookend public transportation trips [54]. Overall, the built environment can dictate the suitability of various transportation modes in a city. Key aspects of the built environment that are conducive to active transportation are infrastructure separated from motor vehicle traffic, short travel distance, density, parks and recreational space, and overall accessibility [55]. However, a defining characteristic of urban growth over the past several decades is sprawl. Urban sprawl describes the outward expansion of cities and increases the distance between destinations, reinforcing reliance on private motor vehicles. Sprawl is antithetical to high-density development which is instrumental in the utilization of active transportation [56]. Beyond the built environment, other factors such as price, comfort, and timeliness are conducive to active transportation use [57, 58].

Active Transportation Guidelines and Policies

As previously mentioned, physical activity can be routinely attained via active transportation. The WHO recommends at least 150 min of moderate-intensity physical activity throughout the week, or at least 75 min of vigorous-intensity physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activities, for adults, to reduce serious health risks [7]. The attainability of this recommendation varies around the globe: South East Asia hosts the lowest percentage of physically inactive adults (15% of men and 19% of women), while 50% of women and 40% and 36% of men fail to meet physical activity recommendations in the Americas and Eastern Mediterranean regions, respectively [8]. Globally, 31% of adults are not physically active for 150 min/week [8].

Because the built environment, and its respective transportation infrastructure, largely dictate transportation mode choices, active transportation rates reflect the urban planning

and design policies that mold the built environment. There are four levels of policy interventions that influence active transportation: society-level policies (reducing speed limits, restricting car use, or limiting parking spaces to discourage motor vehicle travel), city-level policies (land use design changes to increase density and walking and cycling), route-level policies (providing the required infrastructure to enable active transportation), and individual-oriented policies (educational initiatives to encourage changing travel behaviors). To elicit significant behavioral change, interventions must be made in each of these areas [59].

Intersection Between Active Transportation and Clean Air

Clean air and active transportation overlap considerably as they are both functions of mobility. Shifting from pollution-intensive energy generation and transportation modes to active transportation will result in air quality and physical activity benefits that contribute to healthier urban environments [45]. A systematic review evaluating Health Impact Assessments (HIA) of transportation mode shifts reported overall air quality benefits due to reduced motor vehicle use but also found increased risk from air pollution exposure during active transportation [60]. However, these results can be context specific, as described below.

Risk-Benefit Trade-off

Many studies addressed the risk-benefit trade-off of additional air pollution exposure due to active transportation. Two studies concluded that the benefits of physical activity from active transportation outweigh the risks of air pollution exposure in most scenarios [9, 61]. Less than 1% of cities globally have ambient PM_{2.5} levels (95 µg/m³) high enough to offset the physical activity benefits of cycling for 30 min a day, according to the WHO air quality database [61]. One of the most polluted cities in the database was Delhi (153 µg/m³ PM_{2.5}) where an individual could bike for up to 45 min each day before air pollution exposure health risks surpassed physical activity benefits [61]. At the global annual urban background PM_{2.5} mean (22 µg/m³), individuals could walk or cycle for 16 and 7 h each day, before they no longer receive physical activity benefits due to air pollution exposure [61].

Differences in Transportation Mode Exposure

A study of air pollution exposure based on transportation mode in cities in the UK, Belgium, Netherlands, Spain, Ireland, and Switzerland concluded that motorists are exposed to more PM_{2.5}, BC, and CO than both cyclists (20%, 70%, and 90%) and pedestrians (40%, 300%, and 300%)—who are the

least exposed [62]. However, a study of Sacramento, California, found that cyclists have the greatest exposure to PM_{2.5}, BC, and UFP per mile [63]. The results from these studies highlight the importance of study context as air pollution exposure varies considerably between transportation microenvironments and between regions/cities. [64•] reviewed 39 studies that investigated the relationship between transportation mode and air pollution exposure and concluded that motorists consistently experience the highest exposure to air pollutants including CO, NO₂, BC, and PM. However, active transportation users, mainly cyclists, have greater ventilation rates than motorized transportation commuters and therefore inhale more air pollutants. Despite inhaling more air pollution, a study of air pollution exposure in Montreal concluded that cyclists burn 3.63 times as many calories as motorist and reap physical activity benefits [65].

An important determinant of air pollution exposure for active transportation users is the time of day and route chosen to travel. In Sacramento, California, 15–75% of air pollution exposure was influenced by the time of day and route choice [63]. In Boston, Massachusetts, BC and NO₂ concentrations were 33% higher near street bike lanes compared to bike lanes that were distanced from motor vehicles, with a reduction of BC and NO₂ concentrations by 3.4% and 11.6%, respectively, as vegetation density increased [66]. Urban background sites in many major European cities consistently presented lower air pollution concentrations than main traffic arteries, with fluctuations recorded at different day times [62].

Best Practices

The status of air quality and active transportation in cities and countries around the world, as well as their overlap, has been summarized in the previous sections. The policies and practices detailed in the subsequent sections are considered the best practices for achieving clean air and improved active transportation, each being identified from literature published within the last 5 years. These practices—car-free policies, vehicle technologies, urban design interventions, green space provision, and public transportation provision—are rarely mutually exclusive and can make significant additive improvements when enforced simultaneously.

Car-Free Policies

Car-free policies aim to restrict the use of motor vehicles in cities. Some policies ban the use of motor vehicles in certain areas, while others may temporarily close streets so that only pedestrians and cyclists can use them. Other methods to restrict the use of cars include road pricing, environmental zones, and taxation which are meant to disincentivize the use of motor vehicles. The intentions of these policies vary

as some are designed to reduce specific pollutants, while others may focus on reducing GHGs or limiting traffic congestion. While the air quality effects of these policies inherently overlap, their success is variable and the extent to which they encourage active transportation also fluctuates, as will be overviewed next.

The idea of a “car-free city” is revolutionary considering how drastically automobiles have altered the urban landscape, yet several European and Asian cities aim to achieve a car-free city [67]. The C40 Cities Climate Leadership Group has produced a pledge to transition to zero emission vehicles while developing cities in a way that reduces the use of vehicles overall [68]. As a member of the C40 initiative to reduce fossil fuel reliance and the Carbon Neutral Cities Alliance, Oslo, Norway, expects to boast a car-free city center within the next year and hopes to achieve a 95% reduction in GHG emissions by 2030 [69, 70]. The removal of private vehicles in Oslo could eliminate a significant portion of GHG (60% of GHG emissions in Oslo are produced by road transportation) and other air pollutants, as seen in several European cities already [70]. For example, NO₂ concentrations decreased by 40% on a car-free day in Paris and 20% in Leeds during a leg of the Tour de France [67]. Other cities have already successfully implemented various degrees of car restrictions. Copenhagen and Brussels are home to the first and second largest car-free areas in Europe while Basel has its historic medieval city center car-free [71]. Paris and Madrid have made permanent bans on diesel vehicles and placed other restrictions on private vehicles [71]. Berlin and other German cities have utilized low-emission zones that restrict the use of vehicles which do not attain specific emission standards in certain areas. Mexico City has been enforcing car-free days, a method that Nairobi, the world’s second most congested city, has proposed as a solution to its traffic and air pollution problems [71, 72]. London is preparing to enlist a ban on diesel vehicles starting in 2020 and San Francisco is converting one of its busiest streets into a car-free space [71].

Other car-free policies may be more restricted in their spatial and temporal coverage but can nevertheless improve air quality and serve as a first step in an incremental process for change and public acceptance. In Bogota, Colombia, 75 miles of roads, in addition to the existing 200 miles of bike-only lanes, are closed to cars weekly in an event known as *Ciclovía*. Participants in *Ciclovía* are three times as likely to meet physical activity requirements compared to the rest of the population in Bogota, when measuring leisure time physical activity [73]. There are now over 400 *Ciclovías* around the world due to the initial success of the event in Bogota [74]. In Los Angeles, California, on-road UFP and PM_{2.5} concentrations were decreased by 21% and 49%, respectively, during CicLAvia 2014 [75]. Alternatively known as “open street” events throughout the U.S., the physical activity and health benefits of bike-only activities are typically limited due to

their sparse occurrence throughout the year due to funding and permitting issues [76]. Such events show promise and their popularity has grown with 75% of open street programs in the U.S. being conceived after 2010 and average several thousand participants [76].

In addition to car-free policies, there are interventions that can reduce car usage without explicitly banning the use of motor vehicles. Berlin, Germany, has established an “environmental zone” that is only accessible by low-emission vehicles [71]. Cities across Germany have established environmental zones, some of which were studied and found to decrease measured annual mean PM_{10} by an additional $2 \mu\text{g}/\text{m}^3$ compared to the reductions in PM_{10} outside the environmental zones [77]. These environmental zones, however, were typically focused on reducing concentrations of PM. Their effect on other pollutants, like NO_2 , has largely only been modeled, so while reductions in vehicle emissions can be expected, the extent of real-world vehicle emission reductions is relatively unclear [67].

Road pricing is another measure implemented in cities across Europe and throughout other regions of the world to deter the use of motor vehicles. There are different methods of road pricing, notably Congestion Charge Zones (CCZ) and distance-based road pricing. The effects of each method can vary and are influenced by the tax levied, but there are measurable reductions in air pollution [78]. A CCZ in London successfully reduced CO_2 emissions by 19%. Distance-based road pricing is less common but was estimated to produce larger CO_2 emission reductions (36%—Cambridge, UK) [78]. A modeled CCZ in Beijing could reduce CO and NO_x emissions by 60% and 35%, respectively [79].

While road pricing aims to discourage travel, parking pricing aims to increase the efficiency of traffic flow. Estimates attribute 30 to 50% of vehicle traffic in urban downtowns to vehicles cruising for parking [80]. This activity not only contributes to traffic congestion and longer travel time but increases vehicle miles traveled and the pollution footprint of motor vehicles as well. In San Francisco, *SFpark* is a parking pricing system that manages the availability of on-street parking spaces. As the occupancy of on-street parking spaces increases, so does the price per hour whereas if parking spaces are considerably unoccupied, the price per hour decreases. After monitoring 256 street blocks for a pilot period of 2 years, the adjusted parking rates managed to keep parking occupancy below 80%, reducing cruising by more than 50% [80]. Pay-to-park schemes that enable smoother traffic flow can provide air quality benefits and also open streets to active transportation modes.

A third financial tool that has successfully improved air quality is taxation. In 2007, Norway reformed its vehicle tax structure [81]. The tax was based on the level of CO_2 emissions per kilometer, instead of engine size. This incentivized the purchase of cars that were more fuel efficient and resulted

in a shift away from high-polluting vehicles. Overall, this tax reform decreased the market share of high-pollution vehicles by 12% and the CO_2 intensity per vehicle was reduced by $6 \text{ gCO}_2/\text{km}$ [81]. Taxes can also be applied to fuels, as was modeled in a study of the EU in 2015. By increasing excise taxes for diesel vehicles to equal excise taxes for petrol vehicles, CO_2 , NO_x , and $PM_{2.5}$ could be reduced by up to 14%, 17%, and 22%, although the impact of this scheme depends on the disparity between diesel and petrol excise taxes [82]. If a tax was levied based on CO_2 content of fuels ($50\text{€}/\text{tCO}_2$), reductions are more evenly spread and CO_2 , NO_x , and $PM_{2.5}$ were decreased by an average of 8.5%, 9%, and 10% across the EU [82]. Taxation is a tool that is largely dependent on public and political support, however, which in the past has proven to be an obstacle for vehicle and fuel tax advocates [82].

Vehicle Technologies

Vehicle technologies can also play an important role in improving urban air quality, although there is evidence that the scale of adaptation needs to be wide for benefits to occur [83]. This section overviews emergent and disruptive technologies that may make an impact on air quality and active transportation in urban areas. Specifically, this section discusses electric and autonomous vehicles and how they might change transportation systems and emissions.

Regarding urban air quality, the benefits of electric vehicle (EV) and autonomous vehicle (AV) technologies are more specific to GHG. Studies modeling EV market penetration have projected reduced on-road emissions of CO_2 in China by 20%, CO and NO_x in Taiwan by 85% and 27%, CO in Ireland by 14%, and NO_2 and NO_x in Milan by 5.5% and 14.1%, respectively [17]. Many models, however, do not address the health impacts of these reductions, and the GHG reductions that EVs provide by replacing motor vehicles will be offset by the GHGs that result from increased electricity generation rendering little, if any, change in air quality and health outcomes [84]. This zero-sum reality of GHG reductions associated with EVs is reliant on how electricity is derived [17]. In the U.S., electricity generation produces 28% of all GHG emissions and to meet the energy demand of a large EV fleet would likely result in shifting the current burden of GHG emissions from the transportation sector to the energy sector [85]. However, there are countries leading the way in producing clean energy to electrify their vehicle fleet. EVs compose 19% of the passenger vehicle market in Norway, the largest market share in the world. This was achieved through a variety of financial incentives like limiting road taxes and tolls and exempting EVs from purchase and parking fees [86]. Norway can also rely on clean hydroelectric energy as all 70,000 EVs are powered almost exclusively by hydroelectricity (responsible for 96% of Norway’s electricity) [87].

While tailpipe emissions can be reduced with the above technologies, non-exhaust emissions, in the form of PM (road surface, brake, and tire wear) and the production of batteries, have been suggested to increase upon adoption of EVs [88, 89]. Overall, the effects of EVs on air quality are understudied and non-exhaust pollutants could potentially worsen the situation, despite *potentially* reducing transportation GHG emissions [6].

On the other hand, AVs propose an alternative future for transportation and city planning. Currently, there are limitations to the deployment of AVs, but there is potential for reduction in vehicle emissions upon AV integration. A systematic review of the potential air pollution and public health implications of AVs estimates fuel consumption reductions ranging from 11 to 47% based on differing systems of optimal acceleration and deceleration, connected vehicle-to-infrastructure technology, road designs, and AV penetration in the vehicle fleet [90•]. An integration model of battery-powered AVs shows GHG emission reductions of ~90% and ~75% per mile when replacing internal combustion motor vehicles and hybrid EVs due to the reduced GHG intensity of battery-powered vehicles [90•]. These scenarios, however, are quite optimistic, and the adoption of both technologies (EV and AV) are likely to lag in underdeveloped and rural areas, resulting in differential impacts, potentially by socioeconomic status. Further, the impact of vehicle technologies on physical inactivity is limited and understudied.

Urban Design Interventions

An important influence on active transportation and the resulting physical activity is the built environment. In many Western countries, sprawl and suburbanization occurred after World War II. As the economy boomed in the U.S., private vehicles became more widely available, families moved to suburbs, and low-density development followed as extensive networks of highways allowed longer commutes. In Europe, vehicles and highways provided a similar result to that in the U.S. European cities that were rebuilding after World War II replaced their dense pre-automobile cores with spacious urban designs conducive to automobiles that limited active transportation. The following paragraphs about urban design interventions will discuss how land use policies and infrastructure development influence transportation mode choice, physical activity, and air quality.

The legacy of sprawling development can be seen in Europe where 50% of passenger car trips are shorter than 5 km, many of which could be shifted to active transportation modes if densification, road safety, and accessibility improve [91]. A study of 14 cities in ten countries concluded that up to 89 min of physical activity per week (60% of the WHO recommendation for weekly physical activity) can be attributed to the built environment design [92•]. In Melbourne,

Australia, built environment characteristics that influence active transportation behavior were identified. A housing density of >20 dwellings/ha reduced the likelihood of taking a private vehicle trip by 45%. Mixed land use and a connected street network that provided access to at least nine local living destinations decreased the use of motor vehicles by more than 50%. Living within 500 m of a supermarket alone reduced the use of motor vehicles by more than 25% [93].

Infrastructure improvements that focus on safety and accessibility were also reasoned to encourage active transportation in six European cities that were included in a HIA that focused on the health benefits derived from increased active transportation [94•]. The health benefits of walking and cycling in Paris, Basel, Barcelona, Prague, Copenhagen, and Warsaw were modeled based on improved walking and cycling rates. The improved rates used were equivalent to the highest rates of walking and cycling among the six cities: 50% of trips by walking in Paris and 35% of trips by cycling in Copenhagen. Shifting 35% of trips to cycling resulted in 113 (Warsaw) to 5 (Basel) less annual deaths, while reductions in mortality due to shifting 50% of trips to walking ranged from 19 (Warsaw) to 3 (Barcelona) annual deaths. These mode shifts also produced cumulative GHG reduction co-benefits ranging from 2503 (Basel) to 26,423 (Warsaw) tons of CO₂ emissions avoided in each city annually [94•]. Furthermore, a HIA of 167 European cities finds that there is a positive correlation between the expansion of cycling networks and ridership. By expanding the cycling network to 315 km/100,000 people, cycling could account for 24.7% of all trips, preventing 10,000 premature deaths, with the greatest benefits occurring in cities that had underdeveloped cycling infrastructure [95].

While both modeled HIAs have calculated the health impacts of modal shifts, the method of urban design to encourage such a shift is a separate issue that needs to be addressed. To encourage active transportation in metropolitan Barcelona, the development of superblocks has made walking and cycling safer for residents [96]. Superblocks are proportioned city blocks oriented in a 3 × 3 grid meant to improve the environmental quality of neighborhoods. Main roads that allow a maximum speed of 50 km/h form the perimeter of superblocks, while the interior roads that dissect the grid into nine blocks do not allow vehicles to travel across superblocks and restrict speeds to 20 km/h. Reduced traffic speed and overall congestion has decreased vehicle emissions and noise levels within superblocks. Since 2007, measurements of walking and cycling have shown increases of 10% and 30% while traffic within superblocks has dropped off by 26% in the Barcelona neighborhood of Gracia and Vitoria-Gasteiz [97]. The superblocks are part of a larger Urban Mobility Plan in Barcelona, which aims to reduce motor vehicle traffic by 21% in order to achieve a 40% reduction of CO₂ emissions by 2030 [98].

By increasing infrastructure to encourage the use of active transportation, integrating transportation modes becomes more feasible and can further increase accessibility. In the U.S., “complete streets” are being implemented to redesign the built environment in a way that is amenable to diverse mobility. Over 1200 complete street policies have been adopted and their success increases as the programs grow. Ninety-five percent of all complete street policies in the U.S. were designed to be accessible by all abilities and ages via walking, cycling, and public transportation [99]. Public transportation use increased 35% on a redesigned complete street in San Francisco while a repurposed road in Seattle has accommodated 35% more cyclists [100]. Proximity to a complete street in Salt Lake City, Utah, has a positive correlation to participation in active transportation with those living closest to the complete street, engaging in 50% more walking trips than subjects who lived further [101]. A comparative study of six streets in Los Angeles showed UFP and PM_{2.5} concentrations were decreased by 7% and 2%, respectively, in complete street environments due to decreased motor vehicle traffic [102].

Green Space Provision

Green spaces, land that contains parks, forests, nature reserves, and/or waterbodies, have been associated with physical activity, reductions in air pollution, and overall health benefits [103–105]. This section discusses how cities have managed and placed green spaces to benefit air quality, physical activity, and active transportation by providing healthy and safe places for transportation and recreation.

While the effect of green spaces on concentrations of gaseous pollutants is often limited, the removal of PM is considerable [106]. In Strasbourg, France, green spaces remove about 7% of PM₁₀ emissions in the city annually [107]. A study of various green infrastructure interventions determined that trees provided the greatest reprieve of ambient air pollution in Melbourne, Australia, when compared to green walls and green roofs. When increasing the density of trees to 80 trees per hectare, the annual uptake of NO₂ (964 kg), SO₂ (125 kg), PM₁₀ (1474 kg), PM_{2.5} (43 kg), CO (10 kg), and O₃ (1885 kg) was increased [108]. A systematic review of studies on the effect of trees on PM_{2.5} removal concluded there is a reduction of 5 µg/m³ of PM_{2.5} for 10.2 million people throughout the 245 cities included in the review [109]. In Hamburg, Germany, 16.8% of the urban area consists of parks, recreation areas, or woodland justifying its claim as one of the greenest cities in Europe. There are plans to expand green space to cover 40% of Hamburg, accessible by foot and bike exclusively, by 2035 to reduce motor vehicle accessibility and the city’s CO₂ footprint by 80% in the next 30 years [67].

For urban dwellers, green space offers a retreat from the clamor of cities [110]. There is an emerging field of study on the mental health benefits of commuting through green spaces. A positive correlation between active transportation through green spaces and self-reported mental health was identified by one study, but further research is needed to corroborate these findings [105]. However, associations between green spaces and public health are not a simple causal relationship, but are products of a matrix consisting of functionality, size, location, and aesthetic [110]. Green space has been shown to encourage active transportation only if the appropriate infrastructure is in place and safety is perceived [111]. Several studies have shown that the quality (aesthetics and amenities) determines the utility of green space more than the sheer quantity (placement) [110, 112].

Public Transportation

As mentioned at the outset of this paper, public transportation often entails active transportation due to the likelihood that individuals walk or cycle to fulfill the first- and last-mile portions of their travel. The practices and policies contained in this section focus on the physical activity and air quality benefits of improved public transportation provision and utilization.

A study in the UK shows that a higher percentage of public transportation users (almost four times as high) met public health physical activity guidelines than car commuters [113]. In Montreal, public transportation users burn 1.73 as many calories during commute than car commuters [65]. Public transportation users in England average 16 (bus users) to 28 (train users) min of physical activity daily, and one-fifth (bus users) to a half (train users) of these users achieve 30 min of physical activity daily [114]. Two studies in the UK focused on changes in body mass index (BMI), an increase of which poses a risk of heart disease, diabetes, and certain cancers due to shifts from active and public transportation to private vehicles and vice versa [115, 116]. In both studies, BMI increased by ~0.33 kg/m² for those who reduced active and public transportation usage while BMI decreased ~0.31 kg/m² for those who adopted new active and public transportation commuting habits.

The benefits of public transportation utilization go beyond physical activity as air quality benefits can result from the reduced motor vehicle usage [117]. A new public transportation system in Thessaloniki, Greece, was shown to reduce air pollution-related deaths by 20% due to the reduction of mobile air pollution sources [84]. In the U.S., heavy rail systems, light rail systems, and buses produce 76%, 62%, and 33% less GHG per passenger mile than a single occupancy vehicle [118]. A study of public transportation strikes in Barcelona on 208 days between 2005 and 2016 showed a 4.1% and 7.7% increase in NO_x and BC concentrations, respectively,

in the absence of public transportation [119]. A similar study observed 71 public transportation strikes in Germany from 2002 to 2011 and found a 14% and 4% increase of PM₁₀ and NO₂ air pollution concentrations on the days with strikes [120].

Integrated Policy Packages

This final section focuses on policy packages that incorporate different interventions from the previous sections. By enacting a variety of policies simultaneously such as improved vehicle technologies, restricted vehicle use, improved active and public transportation infrastructure, air pollution and physical inactivity are addressed more holistically and effectively than if they were being addressed with a single policy tool and greater health benefits are expected.

A study of over 20 policies enacted in California between 1993 and 2012 to reduce emissions from transportation and other sources showed considerable success. Emissions of NO_x were reduced by 54%, PM_{2.5} by 21%, and PM₁₀ by 15%, despite a 22% and 37% increase in population and motor vehicle miles traveled, respectively [121]. In 2008, Beijing installed several control measures to improve air quality for the Olympics. These included updating vehicle emission standards, reducing the number of government vehicles driven, banning all diesel and heavy-duty trucks from operating in Beijing, license plate bans, closing gas stations, and improving public transportation service. The mean concentration for each targeted pollutant was substantially reduced: SO₂ by 60%, CO by 48%, PM_{2.5} by 27%, and NO₂ by 43% [122].

Another city that is altering its transportation landscape by enacting integrated policy packages is Copenhagen, Denmark. Copenhagen has reduced carbon emissions by 40% since 1990, despite a population increase of 50%, and aims to be carbon neutral and fossil fuel free by 2050 [123]. This progress has been achieved through a combination of car-free policies and investment in active transportation infrastructure. A bike share system, segregated biking lanes, adequate bike parking facilities, and a “Green Wave Route” (cyclists traveling 12.4 mph will hit all green lights) have resulted in 35% of trips taken by bicycle within the city. Almost 50% of all trips are completed via active transportation and further development of bicycle-exclusive lanes are expected to increase cycling by another 15–20% [124].

Finally, Woodcock et al. set up a model of health impacts of various urban transportation scenarios in London and Delhi. Using a comparative risk assessment, the change in physical activity, exposure to air pollution, and risk of traffic injury in each scenario were used to quantify health benefits in both cities [125]. The authors investigated three scenarios: lower-carbon-emission motor vehicles, increased active travel, and a combination of the two. The results showed that the third scenario (the combination of active travel and lower-

emission motor vehicles) would yield the largest health benefits preventing 7439 disability-adjusted life years in London and 12,995 in Delhi, mainly from a reduction in the number of years of life lost from ischemic heart disease (10–19% in London, 11–25% in Delhi) [125]. Alone, the increased use of lower-emission motor vehicles scenario resulted in the least health benefits [125].

Conclusion and Future Research Directions

The attempt to curtail air pollution has been an evolving issue. Despite air quality improvements, road networks are still expanding, and car ownership is increasing globally, exacerbating air pollution and physical inactivity in cities. The necessity for interdisciplinary collaboration to ensure that future city expansion is done sustainably has become an important focus area of recent research and practice. Some cities are trying to reduce urban air pollution by making active transportation more accessible and feasible for citizens while others have undertaken projects to alter the built environment to be amenable for pedestrians and cyclists through increased safety and accessibility measures. Several more cities have enlisted bans or taxes on vehicles and fuels to improve air quality and encourage modal shifts to walking, cycling, or public transportation (the entire list of policies discussed in this paper are outlined below in Table 3). The positive health impacts of these measures can be maximized by their integration (or bundling in policy packages) but will not be immediate and may take years to be fully realized. Their successes, however, will add momentum to a global movement to reduce car dependency and make cities healthier and more active.

Future research can usefully focus on addressing the following gaps in the literature:

- There is a lack of research in middle- and low-income countries on air pollution and physical inactivity. Ninety percent of future urban growth will be in Asia and Africa, necessitating research in these regions.
- There are no global guidelines for active transportation like there are for air pollution. Accountability studies have been published regarding air pollution policies, but accountability studies focusing on active transportation practices could encourage improvements in active transportation and provide a base for active transportation guidelines.
- There is an overall lack of measurement studies that quantify the active transportation impacts of green space provision. Understanding the relationship between the two could allow for more informed land use decisions and provide health benefits.
- The air quality impacts of complete streets are not extensively researched. Understanding the air quality impacts

Table 3 Examples of practices to improve air quality and support active transportation in cities

Policy	Primary target	Improves air quality?	Supportive of active transportation?	Overall impact
Air quality and vehicle emission standards WHO air quality standards [32]	To set a universal standard for air quality to protect public health.	Yes	No	Recommendations for urban air quality regarding specific pollutant concentrations.
Vehicle emission standards [35]	Limiting emissions from motor vehicles to protect the environment and public health.	Yes	No	Reduced air pollution from motor vehicle traffic.
Clean Air Act of 1970 [35]	Legislation in the USA that focused on researching and reducing air pollution.	Yes	No	Reduced air pollution from motor vehicle emissions in the USA.
Active transportation guidelines WHO physical activity guidelines [4]	To set a universal standard for physical activity levels.	Maybe	Yes	The WHO set forth physical activity guidelines to encourage healthy behaviors in individuals. This can overlap with active transportation invoking air quality benefits simultaneously.
Car-free policies Car-free policies [51]	To reduce motor vehicle activity.	Yes	Yes	Restricting motor vehicle travel in specific areas within a city reduces vehicle emissions and promotes walking, cycling, and public transportation use.
Ciclovia [53]	To promote cycling within a community.	Yes	Yes	Closure of streets to motor vehicles 1 day each week in Bogota, Colombia, promotes cycling and reduces air pollution.
Modal shifts [42]	Provide an alternative mean of transportation to a motor vehicle.	Yes	Yes	Benefits of physical activity from active transportation outweigh the risks of air pollution exposure in most scenarios and can reduce the use of motor vehicles.
Open streets [106]	Close road access to cars to encourage individuals to walk and cycle for transportation.	Yes	Yes	Closing urban roads to motor vehicle traffic and encouraging travel by walking and cycling provides health benefits through physical activity and air quality improvements.
Environmental/low emission zones [52]	Restricting the use of highly polluting vehicles.	Yes	No	Restricting access to specific areas of the city to motor vehicles that do not meet stringent emission standards.
Road pricing [60]	A financial disincentive for traveling via motor vehicle.	Yes	Maybe	Operational tax for motor vehicles driving on designated roadways which can reduce personal motor vehicle use and increase active and public transportation use.
Parking pricing [62]	A financial disincentive for traveling via motor vehicle.	Yes	Maybe	Pay-to-park schemes managed on-street parking availability, reducing the amount of time spent cruising for parking which accounts for a significant portion of motor vehicle traffic in dense urban areas. Can reduce personal motor vehicle use and increase active and public transportation use.
Vehicle or fuel taxation [63]	A financial disincentive for traveling via motor vehicle.	Yes	No	Levying taxes that apply to GHG emission-intensive vehicles to incentivize the purchase of fuel-efficient vehicles. Additional taxation may occur based on the CO ₂ content of fuel.
Vehicle technologies Electric vehicles	To eliminate motor vehicle exhaust pollution.	Maybe	No	Reduce tailpipe emissions and associated air pollution but scale of adaptation needs to be wide and energy sources need to be clean for benefits to occur. Non-exhaust emissions might increase.
Autonomous vehicles	Optimize driving styles for fuel efficiency.	Maybe	No	Efficient driving patterns may increase fuel efficiency and could reduce the number of vehicles on the road.
Urban design interventions Built environment design [74, 126•]		Maybe	Yes	

Table 3 (continued)

Policy	Primary target	Improves air quality?	Supportive of active transportation?	Overall impact
	To make active modes of transportation more safe and sustainable.			Dense and mixed-use development is conducive to improved access to nearby destinations, increasing the utilization of active transportation modes to travel.
Investment in infrastructure to improve safety and accessibility by walking and cycling [106]	Promote active transportation.	Yes	Yes	Perceived safety and appropriate accessibility increase the ease of shifting travel to active modes instead of motorized transportation.
Segregated travel routes for pedestrians and cyclists [47]	Make active transportation safer and more convenient.	Yes	Yes	Distance between motor vehicle traffic and active transportation users improves safety and decreases personal air pollution exposure.
Superblock development [77]	To reduce traffic flow in residential areas.	Yes	Yes	Superblocks can reduce motor vehicle traffic and enable individuals to travel by walking and cycling easier than by motor vehicles to nearby destinations.
Expanding cycling networks [81]	Improves access and ease of travel for cyclists.	Maybe	Yes	Expanding cycling networks correlates with higher cycling rates and potentially modal shifts from motorized transportation
Bike share system/green wave route [79, 80]	Promote access and convenience of cycling.	Yes	Yes	Increasing the accessibility to active modes of transportation improves active transportation utility and correlate with a decrease in motor vehicle usage improving air quality.
Complete streets [83, 122]	To provide infrastructure that enables alternative modes of transportation.	Yes	Yes	Redesigning streetscapes to accommodate multiple modes of travel increases physical activity and decreases use of motor vehicles improving air quality.
Green space provision				
Green space provision [87, 93]	Offer urban spaces that provide recreational and health-promoting opportunities.	Yes	Yes	Vegetation can remove pollutants and can provide a more accommodating transportation environment for active transportation users or leisure-time physical activity.
Increasing tree density [89, 90•]	Remove pollutants from the air.	Yes	No	Removes air pollution, mainly PM, from the air.
Outfitting green spaces with active transportation infrastructure [92•]	Provide quality spaces for individuals to be active.	Yes	Yes	The quality of a green space is a greater determinant of active transportation than the simple provision of green space
Public transportation				
Improving public transportation [94•, 95–100, 123, 124]	Promote (modal shifts to) active transportation.	Yes	Yes	Using public transportation typically requires walking or cycling to public transportation hubs. The removal of low/single-occupancy vehicles due to public transportation and/or “ride sharing” decreases GHG and traffic emissions.

of complete streets could allow for more informed land use decisions and provide health benefits.

- There is a lack of full chain models and source-apportionment studies that trace back air pollution levels and potential changes to the actual sources responsible.
- The health impacts at low levels of air pollution are unknown and may challenge the wisdom that air quality guidelines represent safe levels.
- There is a lack of work holistically addressing the entire spectrum of exposures and health outcomes due to transportation. A paper currently in progress has identified 12 additional pathways, besides air pollution and physical inactivity, that describe the relationship between public health outcomes and mobility habits in urban areas [127].

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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