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Comprehensive Transportation Emission Reduction Planning

Guidelines for Evaluating Transportation Emission Reduction Strategies

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Most current emission reduction plans devote most resources to electric vehicle subsidies and little to vehicle travel reduction strategies, despite their large potential benefits. That is inefficient and unfair.

Abstract

Many jurisdictions have ambitious greenhouse gas emission reduction targets and are developing plans to achieve them. These include clean vehicle (hybrid, electric and hydrogen) adoption, and vehicle travel reduction strategies such as transportation demand management (TDM) incentives and Smart Growth development policies. This study identifies various factors that should be considered when evaluating and prioritizing emission reduction strategies and investigates whether they are considered in typical plans. Emission reduction analysis should consider embodied emissions, rebound effects, implementation costs and subsidies, realistic clean vehicle adoption rates, leverage and synergistic effects, integrated strategies, indirect costs and co-benefits, cost efficiency, latent demand for non-auto travel, and use state-of-art predictive models. This review finds that most plans overlook or undervalue many of these factors in ways that tend to exaggerate clean vehicle benefits, and undervalue vehicle travel reduction strategies. Previous publications identify some of these biases, but this study is more comprehensive and systematic. This study recommends more comprehensive evaluation methods. It concludes that efficient, equitable transportation emission reduction plans should rely at least as much on vehicle travel reductions as on clean vehicles, with particular emphasis on "quick win" strategies.

Introduction

Many jurisdictions have ambitious greenhouse gas (GHG) emission reduction targets and are developing plans to achieve them (ACEEE 2019; Klein 2019; Litman 2022). Since transportation is one of the largest emission sources, it is a major component of such plans.

There are many possible ways to reduce transportation emissions. These include *clean vehicle* strategies that reduce emission rates per mile or kilometer of travel, and transportation demand management (TDM) and Smart Growth policies that reduce total vehicle travel, as summarized below.

Table 1 **Examples of Emission Reduction Strategies** (IEA 2021; ITF 2021; Litman 2021; SUM4All 2019; TfA and SGA 2020; TUMI 2020)

Clean Vehicles	Vehicle Travel Reductions
Technologies and policies that reduce emission rates per vehicle-mile	*TDM and Smart Growth policies that reduce total vehicle travel*
• Shifts to more efficient and alternative fuel vehicles (e.g., hybrid, electric and hydrogen). • High emitting vehicle scrapage programs. • Efficient driving and anti-idling campaigns. • Switching to lower carbon and cleaner fuels. • Inspection and maintenance programs. • Resurface highways. • Roadside "high emitter" identification.	• Multimodal planning (improve walking, bicycling, public transit, ridesharing, etc.) • Transportation Demand Management programs (commute trip reduction, freight transport management, etc.). • Efficient road, parking and vehicle pricing. • Smart Growth policies that create more compact and multimodal communities. • Parking policy reforms.
• Increase fuel prices by reducing subsidies and increasing taxes (encourages both types of strategies).	

"Cleaner vehicles" reduce per-mile emission rates. Vehicle travel reductions reduce total motor vehicle travel. Fuel price increases help achieve both.

Which emission reduction strategies are best? Should emission reduction plans invest in hybrid and electric vehicle subsidies, active and public transit improvements, vehicle travel reduction incentives, or others? Which strategies are most effective and beneficial overall? That depends on how they are analyzed, including the scope of impacts considered and the methods used to predict those impacts. This study identifies factors to consider when evaluating and prioritizing potential transportation emission reduction strategies, and evaluates the degree that they are currently considered in emission reduction planning.

This is an important and timely issue. Large, rapid emission reductions are needed to protect the world's environment and significant policy changes and investments are being considered to achieve those goals. These decisions have many economic, social and environmental impacts; it is important that emission reduction planning be comprehensive, accounting for all significant effects. This report provides guidance for doing so.

This research should be of interest to transportation and land use planners, policy makers, environmental planners and advocates, and anybody who wants to maximize the value to society of emission reduction plans.

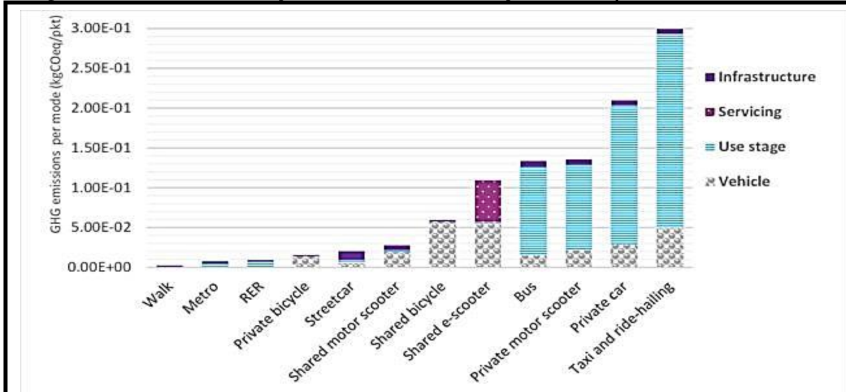
Factors to Consider in Emission Reduction Analysis

This section describes ten often-overlooked factors to consider in transportation emission reduction analysis, particularly when comparing clean vehicle and vehicle travel reduction strategies.

Embodied and Non-Tailpipe Emissions

Embodied (also called *upstream*) emissions occur during vehicle, infrastructure and fuel production, as opposed to the *tailpipe* emissions that occur during vehicle operation. *Lifecycle analysis* calculates total emissions (Buberger, et al. 2022; ITF 2023; Shaffer, Auffhammer and Samaras 2021). Embodied emissions typically represent 10-50% of total emissions, depending on vehicle type and conditions. Some studies compare lifecycle emissions for various modes including bicycling, automobile and public transit (ITF 2020). Electric vehicles typically reduce emissions 43-48% compared with comparable gasoline vehicles (Reichmuth, Dunn and Anair 2022). The figures below illustrate one such comparison.

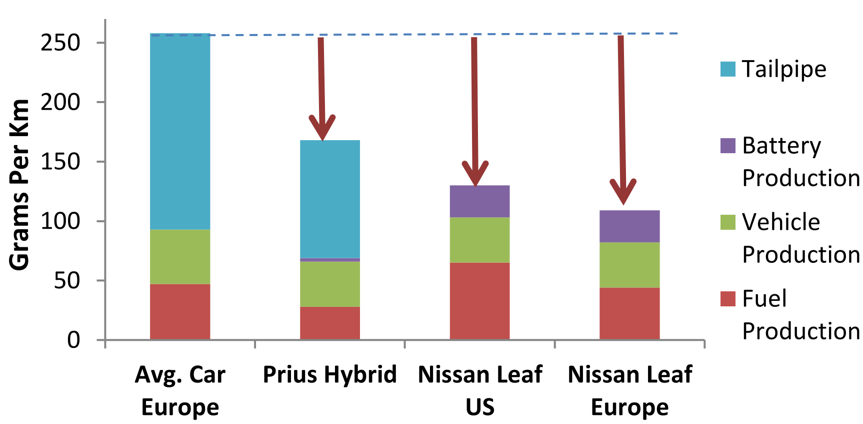
Figure 1 **Lifecycle Emissions by Mode** (de Bortoli and Christoforou Zoi 2020)



This figure compares estimated lifecycle emissions per passenger-kilometer for various modes taking into account their infrastructure, servicing, use and vehicle production. Non-auto modes produce an order of magnitude lower lifecycle emissions than automobile travel.

Hybrids typically reduce lifecycle emissions by a third and electric cars by two-thirds compared with comparable fossil fuel vehicles (Bieker 2021; Noussan, Campisi and Jarre 2022), as illustrated below. This is good, but it is inaccurate to call them *zero emission* vehicles. Large EVs produce emissions equivalent to small fossil fuel cars (Huether 2022). Because of their extra weight, electric vehicles increase tire and road wear particulates by 20-50% (Morris 2023). By inducing more vehicle travel and sprawl, clean vehicles also increase embodied infrastructure emissions (Nunes, Woodley and Rossetti 2022).

Figure 2 **Life-cycle GHG Emissions** (Hausfather 2020)



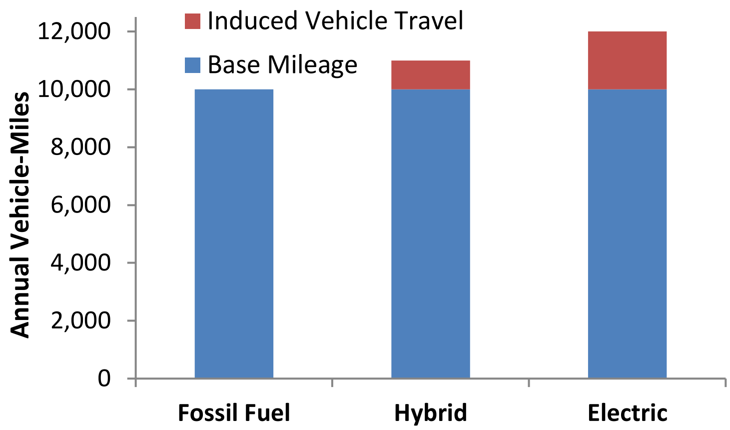
Total life-cycle emissions vary depending on vehicle, fuel source and driving conditions.

Hybrids typically reduce emissions by a third and electric cars by two-thirds compared with comparable fossil fuel vehicles. It is an exaggeration to call them "zero emission vehicles."

Rebound Effects

The *rebound effect* refers to the additional vehicle-travel and larger vehicle sizes that occur when cleaner vehicles have lower operating costs. For example, hybrids typically cost a third less and electric vehicles about half as much per vehicle-mile as comparable fossil fuel vehicles, which typically increases their annual vehicle travel 10-30% (Moshiri and Aliyev 2017; Orsi 2021). The figure below illustrates this. This additional travel adds emissions and increases infrastructure, congestion, crash, and sprawl-related costs. Electric vehicles are also heavier than fossil fuel vehicles (batteries typically add 500 to 1,500 pounds), which increases particulate emissions and crash risks (Shaffer, Auffhammer and Samaras 2021). Ignoring these effects exaggerates clean vehicle benefits (Haghani, Ghaderi and Hensher 2024).

Figure 3 **Rebound Effects**



Clean vehicles' lower operating costs cause owners to drive more annual miles and choose larger vehicles, called rebound effects. The additional vehicle-miles are "induced travel."

Hybrid vehicles typically cost a third less, and electric vehicles two-thirds less, per vehicle-mile, and so are typically driven 10-30% more annual miles, increasing traffic problems. To avoid these costs clean vehicles should be implemented with vehicle travel and sprawl reduction strategies.

Costs and Subsidies

Emission reduction planning should consider and compare total implementation costs and subsidies. Hybrid and electric vehicles are currently expensive and their batteries must be replaced every 80,000 to 160,000 miles, costing $5,000 to $15,000, which averages about 5¢ to 15¢ per vehicle-mile (Argue 2020). Although battery costs per kWh are declining, their sizes are increasing to improve range and performance so electric vehicles will probably be more expensive than comparable fossil fuel vehicles for many more years. They also require charging networks. Residential systems typically cost $1,000 to $2,500 for equipment and installation, and public charging stations cost more. Electric vehicles currently receive various public subsidies as summarized below. These subsidies may decline in the future, but until electric vehicles are charged a special road user fee they will continue to receive approximately $300 annual subsidy in avoided road user taxes, representing approximately $60 cost per ton of emissions reduced.

Table 2 **Typical Electric Vehicle Subsidies** (Litman 2021)

Subsidy	Annual Value
Corporate Average Fuel Economy (CAFE) credits ($4,700 over 15 years)	$313
Purchase subsidy ($5,000 over a 15-year vehicle life)	$333
Electric vehicle recharging stations (zoning code mandates and cash subsidies)	$125
Road user fee exemption (12,500 annual miles, 20 mpg, 50₵ tax per gallon)	$310
Total Annual Subsidy	*$1,081*

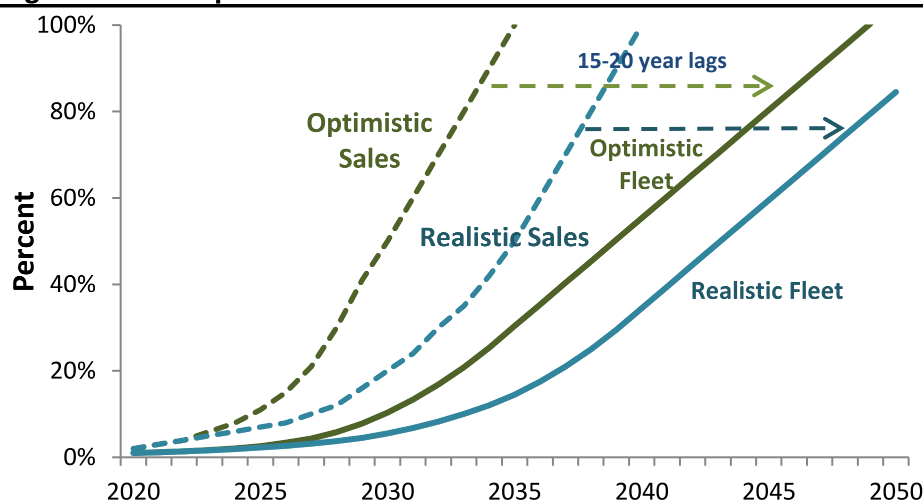
Electric vehicles receive various subsidies that currently total more than $1,000 per year.

Clean Vehicle Adoption Rates

Planning should apply realistic estimates of clean vehicle adoption rates. Motor vehicles are expensive and durable. In 2020, 15 million new light vehicles were purchased in the U.S., representing about 6% of the 250 million fleet (ORNL 2022, Table 3.3). At this rate it takes decades for new technologies to penetrate a fleet unless many functional vehicles are prematurely scrapped.

Adoption rates are slow because new electric vehicle are current relatively expensive and limited in range and charging infrastructure. Hybrid and electric vehicles represented about 3% of 2021 vehicle sales (ORNL 2022, Table 6.2), and these are mainly cars due to slower development of electric SUVs, light truck and vans. Optimistically, half of new vehicles could be electric by 2030 but realistically it will take longer, and the remaining fossil fuel vehicles will skew to low fuel economy (ICF 2021). With current policies, the fleet is unlikely to be fully electric by 2050, as illustrated below.

Figure 4 **Optimistic and Realistic Electric Vehicle Sales and Fleet Adoption**



Optimistically, half of new vehicle sales could be electric by 2030, but realistically it will probably take longer, and since only about 6% of vehicles are replaced each year, it takes 15-20 years before a percentage of vehicle sales are reflected in the fleet. With current policies it is unlikely that the fleet will be fully electric before 2050.

Leverage and Synergistic Effects

Commonly-used transportation statistics imply that walking, bicycling and public transit improvements can only provide small vehicle travel and emission reductions. For example, the U.S. Census indicates that only 0.6% of commuters bike, 2.8% walk and 5.2% use public transit, and these are relatively short trips, implying that improving these modes can only reduce emissions by a few percent. However, more comprehensive data indicate that these modes actually serve 10-15% of trips, their potential is much higher, and improving them can leverage larger reductions in vehicle travel, so each additional mile of walking, bicycling and transit travel reduces more than one vehicle-mile of travel, for reasons summarized in the box on the next page (Litman 2023a).

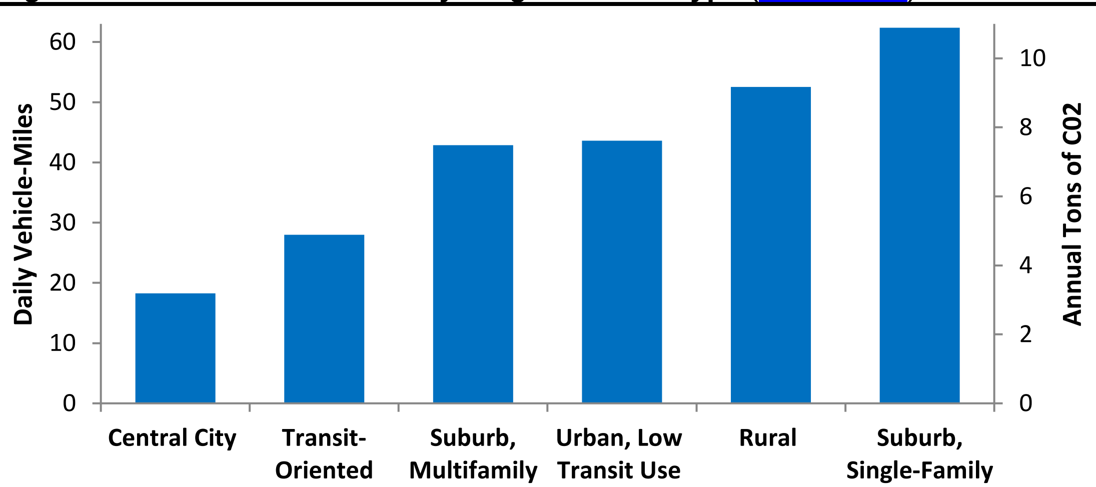
Vehicle travel reduction strategies tend to have synergist effects: they become more efficient and cost effective if implemented together. For example, simply improving public transit might reduce affected automobile trips 10%, and a TDM program to encourage transit travel might reduce affected automobile trips 10%, but together they reduce vehicle trips by 30% because they give travellers both positive and negative incentives to reduce driving. As a result, their impacts tend to be much larger than predicted by conventional models that consider vehicle travel reduction strategies individually.

Box 1 Leverage Effects (Litman 2023; McGraw 2021)
Non-auto improvements often leverage additional vehicle travel reductions in these ways:

- *Shorter trips.* A shorter active trip often substitutes for longer motorized trips, such as when people choose a local store rather than driving to more distant shops.
- *Vehicle ownership reductions*. Improving alternative modes allows some households to reduce their vehicle ownership, for example, from two to one car, or to become car-free. When households no longer have a vehicle available at any time, they tend to significantly reduce their total vehicle travel.
- *Complementary.* Most public transit trips include walking and bicycling links, so improving walking and bicycling conditions around transit stops and stations increases both active and public transport travel.
- *Reduced chauffeuring*. Poor walking and bicycling conditions often cause motorists to chauffeur non-drivers which generates empty backhauls (trips with no passenger). For such trips, a mile of walking often reduces two vehicle-miles of travel.
- *Lower traffic speeds.* Active travel improvements often involve reducing urban traffic speeds. This makes non-auto travel safer, more pleasant and more time-competitive with driving.
- *More compact development with reduced parking subsidies*. Reduced vehicle ownership and use reduces the amount of land required for roads and parking facilities, reducing subsidized parking and allowing more compact development, which further reduces vehicle trips and travel distances.
- *Social norms.* As non-auto travel becomes more common it becomes more socially acceptable.

The report, *Quantifying the Effect of Local Government Actions on VMT*, used sophisticated analysis of travel survey data to measure how local conditions affect residents' vehicle travel and emissions. It found that households in compact multimodal neighborhoods drive less than half as much as in automobile-oriented, sprawled areas, , as illustrated below, reflecting the synergistic effects of multimodal planning, incentives such as more parking fees, and increased density. This indicates that integrated programs of non-auto mode improvements, TDM incentives and Smart Growth development policies can reduce vehicle travel and emissions by 30-60%. Conventional analysis, which considers strategies individually, tends to overlook these effects and therefore potential benefits.

Figure 5 **Household VMT by Neighborhood Type** (Salon 2014)



Household vehicle travel varies significantly depending on neighborhood design, reflecting the synergistic effects of various transport and land use factors.

Indirect Impacts and Co-Benefits

Emission reduction strategies vary significantly in their indirect impacts and co-benefits. TDM and Smart Growth policies that encourage travelers to use the most efficient option for each trip, and create more compact, accessible communities help achieve man planning objectives, as illustrated below.

Table 3 **Comparing Impacts** (Litman 2021)

Planning Objectives	TDM and Smart Growth	Clean Vehicles
Vehicle Travel Impacts	*Reduced*	*Increased*
Congestion reduction	✓	×
Roadway cost savings	✓	×
Parking cost savings	✓	×
Consumer savings and affordability	✓	Higher purchase, lower operating
Traffic safety	✓	×
Improved mobility for non-drivers	✓	×
Fossil fuel conservation	✓	✓
Pollution reduction	✓	✓
Physical fitness and health	✓	×
Strategic development objectives (reduced sprawl)	✓	×

(✓= Achieve objectives. ×= Contradicts objective.) Vehicle travel reductions and more compact development help achieve a wide range of planning objectives. Cleaner vehicles help conserve fossil fuel and reduce pollution but provide few other benefits and, by inducing more vehicle travel, contradict many objectives.

Comprehensive Vehicle Travel Reduction Strategies

There are many cost-effective TDM strategies (CARB 2010-2015; *EPOMM Case Studies*; Litman and Pan 2024), but few emission reduction planners are familiar with the full range of TDM strategies, and so tend to underestimate their potential impacts and benefits (TfA and SGA 2020).

Many current policies encourage motor vehicle travel and sprawl (Shill 2020). These include automobile-oriented planning, parking supply mandates, and limits on development density and mix (STTI 2018). Reforms that correct these distortions can significantly reduce automobile travel in ways that respond to consumer demands and benefits travellers and communities (Litman 2022; Mehaffy, et al. 2022).

For example, according to one study, active transportation improvements can reduce transportation emissions 24%. By reducing local pollution and increasing physical activity, this could avoid 167,000 deaths, providing $1.6 trillion in monetized health benefits (Maizlish, Rudolph and Jiang 2022). A detailed study, *Travel Demand Management: An Analysis of the Effectiveness of TDM Plans in Reducing Traffic and Parking in the Minneapolis-St. Paul Metropolitan Area*, found that office buildings with TDM plans generate third less traffic and need a fifth fewer parking spaces than conventional developments (Spack and Finkelstein 2014). A Fairfax County, Virginia study found that suburban-area residential and commercial developments with TDM programs generate about half as many trips as their peers (Galdes and Schor 2022). In the Puget Sound region, an integrated program of non-auto mode improvements, commute trip reduction programs and Smart Growth development policies reduced total per capita vehicle travel about 5% between 2010 and 2018, significantly increased active and public transport travel, and reduced affected automobile commute mode shares by a quarter (Peterson 2017; PSRC 2019). The report, *The Missing Key to Climate Action Strategies for Lowering Emissions (*Holland, et al. 2023) found that Smart Growth policies can reduce VMT up to 13%, building energy use by up to 16%, and local greenhouse gas emissions by up to 14% relative to business-as-usual development.

The table below summarizes typical travel reduction impacts. This suggests that an integrated package of cost-effective TDM strategies can reduce affected vehicle travel by a quarter to half (Litman 2021).

Table 6 **Vehicle Travel Reduction Strategies** (CARB 2015, Kuss & Nicholas 2022**,** VTPI 2020)

Strategy	Elements	Travel Impacts
Efficient parking pricing and management	Charge motorists cost-recovery parking fees, reduce parking supply and manage parking facilities for efficiency.	5-15% reduction in vehicle ownership and 10-30% reduction in affected vehicle trips.
Active (walking and biking) and micro (e-bikes and e-scooters) modes	Improve walking and bicycling conditions, and encourage use of these modes. Create more compact, walkable neighborhoods.	Active and micro mode improvements increase their use 50-100% and reduce driving 5-15%. Residents of compact, walkable neighborhoods drive 20-60% fewer annual miles.
High quality public transit	Frequent, fast, convenient, comfortable transit services. Amenities such as free wifi, and improved payment systems.	Service improvements increase affected transit travel 20-50%, and reduce auto travel 5-15%, and sometimes more.
Smart Growth, New Urbanism, Transit-oriented development	Develop compact, mixed-use neighborhoods around high quality public transit.	Residents tend to walk, bike and use public transit 20-100% more, and drive 20-60% fewer annual miles.
Commute, school and campus transport management programs	Improve non-auto travel options and encourage their use with financial incentives (parking pricing and cash out).	Programs that only use persuasion reduce driving 5-15%, those that provide financial incentives reduce 10-30%.
Roadway redesigns to favor sustainable modes	Widen sidewalks, add bike- and bus lanes, and reduce traffic speeds.	Non-auto travel typically increases 20-100%, and auto travel declines 10-30%.
Efficient road pricing	Motorists pay cost-recovery tolls on urban highways and fees to enter city centers	10-30% reduction in affected road traffic volumes.
Distance-based pricing	Vehicle insurance and registration fees are prorated by average annual mileage.	Up to 15% if total insurance premiums and registration fees are prorated.
Vehicle sharing	Provide car- and bikesharing services in urban neighborhoods.	12-15 private cars replaced by each shared car.
Freight transport management	Require or encourage shippers to use efficient vehicles and logistics.	Can reduce freight vehicle travel and emissions 10-30%.
Limited traffic zone	Only allow service, taxi and residents' vehicles in central city neighborhoods.	10-20% reduction in city-centre cars.
Personalized travel planning.	Encourage residents to use non-auto modes. Provide transit fare discounts.	6-12% reduction in vehicle travel use among residents.
Sustainable mobility app.	Rewards for achieving non-auto travel targets.	73% of app users earn rewards.

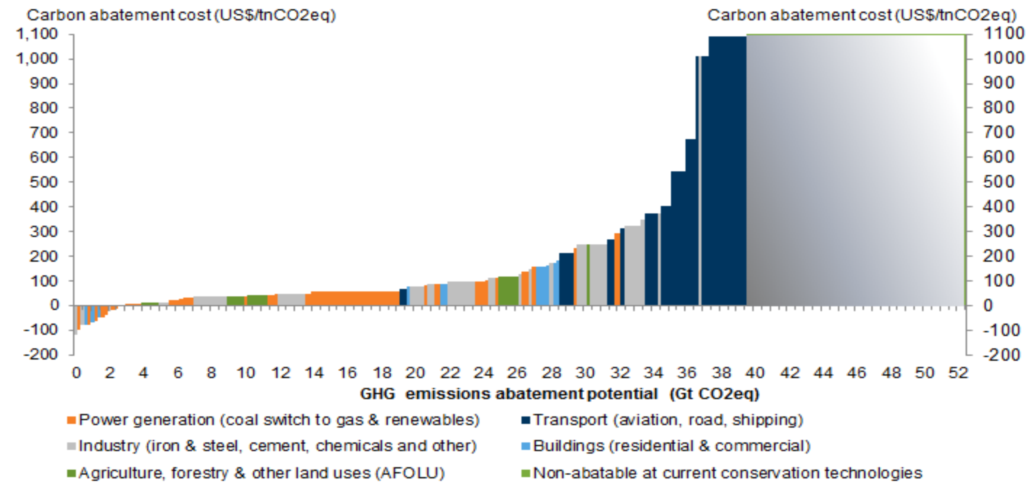
Vehicle travel reduction strategies can significantly increase non-auto travel and reduce driving. Impacts vary depending on design and conditions. These strategies tend to have synergistic effects: they become more effective if implemented as an integrated program that includes a combination of resource-efficient mode improvements, automobile travel disincentives (particularly efficient road, parking and vehicle insurance pricing), and development policy reforms to create more compact, multimodal neighborhoods.

Cost Efficiency

Cost efficiency measures unit costs, such as dollars per tonne of emissions reduced. This is a useful way to compare emission reduction strategies. Several studies estimate these costs, including the Environmental Defense Fund's *Marginal Abatement Cost Curves for U.S. Net-Zero Energy Systems* (Farbes, Haley and Jones 2021), the Global Commission on the Economy and Climate's, *Quantifying the Multiple Benefits from Low-Carbon Actions in a Greenhouse Gas Abatement Cost Curve Framework* (NCE 2015), and the Goldman Sachs report, *The Economics of Climate Change: A Primer* (Hatzius, et al. 2020).

These studies vary widely in their scope and methods. Most only consider direct incremental production and infrastructure costs; they seldom account for induced vehicle travel costs or co-benefits provided by vehicle travel reductions. They generally find that clean vehicle emission reductions are relatively expensive with costs that generally exceed $50 per tonne, and often much higher, as illustrated below.

Figure 7 **Emission Abatement Supply Curve** (Hatzius, et al. 2020)

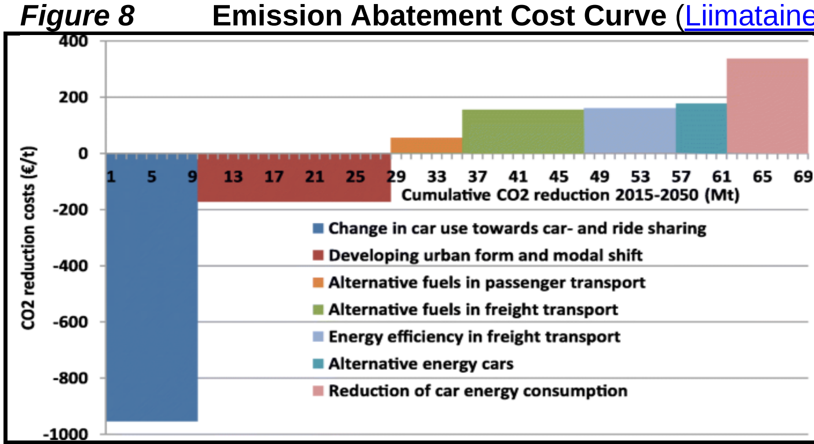


This study estimated unit costs for various emission reduction strategies. The height indicates costs per tonne, the width indicates number of tonnes that strategy can reduce.

Clean vehicle strategies (dark blue) tend to have higher costs than most other sectors.

Considering all impacts, vehicle travel reduction strategies often have negative costs; their total benefits are greater than their total costs, making them no-regrets strategies that are justified regardless of their emission reduction impacts. The figure below shows the large negative costs of vehicle travel reduction strategies, compared with the relatively high costs of clean vehicles.

Figure 8 **Emission Abatement Cost Curve** (Liimatainen, Pöllänen and Viri 2018)



This study concluded that vehicle travel reduction strategies, such as car- and ride-sharing, and more compact urban form, have negative costs (they provide net savings, indicated by costs below zero) due to their large co-benefits, while alternative fuels and energy efficient cars tend to have relatively high costs, over 100€ per tonne.

Latent Demand for Non-Auto Travel

Emission reduction plans sometimes assume that most people want to live automobile-oriented lifestyles, so vehicle travel reductions harm consumers and are difficult to implement (Salzberg 2021). For example, the *Clearing the Air* report implies that Smart Growth reduces livability, and mode shifts are difficult and costly to achieve. However, surveys indicate that many North Americans would like to drive less, rely more on non-auto modes, and live in more multimodal communities, provided that these alternatives are convenient, comfortable and affordable (NAR 2020). As a result, vehicle travel reduction strategies that improve non-auto travel options, reward shifts to efficient modes, or improve housing options in walkable neighborhoods directly benefit consumers, in addition to their other benefits.

Many current demographic and economic trends are increasing non-auto travel demands, and therefore the benefits of more multimodal planning and compact development. These include aging population, rising fuel prices, increasing poverty, growing health and environmental concerns, and changing consumer preferences. Vehicle travel reduction strategies help prepare communities for these future demands.

State-of-Art Transportation Models

Emission reduction plans use transportation models to predict how a policy will affect vehicle travel and emissions. Many of these models are outdated and biased in ways that underestimate the emission reductions provided by TDM and Smart Growth.

For example, many models use low elasticity values (typically -0.1), based on U.S. from the 1950-70s when employment and real incomes were growing and fuel prices were relatively low (Hughes, Knittel and Sperling 2006). More recent studies indicate that vehicle travel is two or three times more price sensitive than the older studies indicated (CARB 2015; Kilian and Zhou 2020). These biases can significantly affect analysis results: if an older model predicted that a parking fee will reduce affected vehicle trips by 10%, the actual long-term impact is probably 20-30%. Similarly, if it predicts that electric vehicles will be driven 5-10% more annual miles than comparable fossil fuel vehicles, the true rebound effect is probably 20-30%. Older models tend to underestimate TDM and Smart Growth emission reductions (Galdes and Schor 2022; Schneider, Handy and Shafizadeh 2014; Spack and Finkelstein 2014).

To be comprehensive and accurate models should include these features (Caltrans 2020; STTI 2018):

- Analysis of demographic and economic factors that affect future demands including aging population, rising fuel prices, increasing poverty and affordability concerns, increased health and environmental concerns, and changing consumer preferences.
- Integrated transportation and land use models that account for feedback between transportation and development patterns (such as when highway expansions increase sprawl).
- Comprehensive travel data, including data on non-commute trips, active travel, short trips (within each traffic analysis zone), travel by children and recreational travel.
- Accurate long-term price and service elasticities (typically -0.3 to -0.6) for more than 5-year impacts.
- Ability to account for diverse TDM and Smart Growth policies including improvements to non-auto modes, transportation pricing reforms, TDM programs, and more compact and mixed development patterns, plus the synergistic effects of integrated programs.

Summary

The table below summarizes ten factors that should be considered in comprehensive transportation emission reduction planning. Ignoring them tends to bias planning decisions in ways that exaggerate clean vehicle benefits and undervalue vehicle travel reduction strategies.

Table 4 **Comparing Impacts**

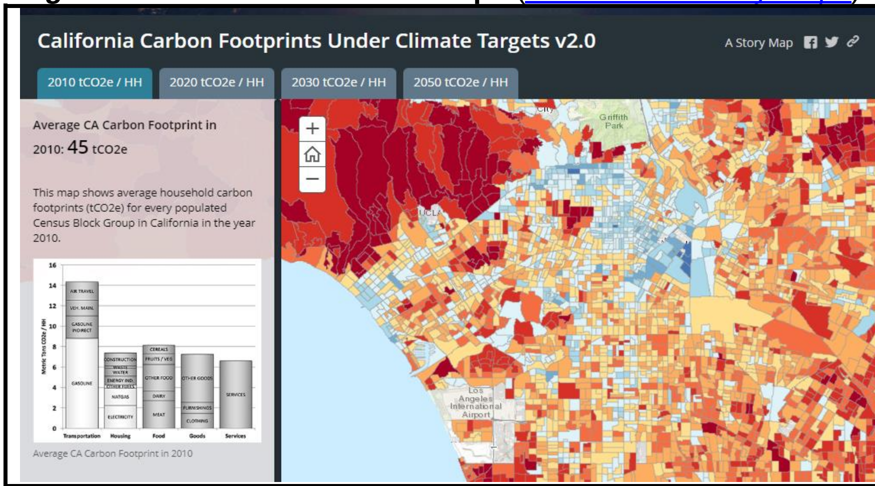
Factor	Description	Methods	Effect if Ignored
Embodied emissions	Emissions from vehicle, battery, fuel and infrastructure production.	Apply lifecycle analysis that accounts for all emissions.	Exaggerates clean vehicles emission reductions.
Rebound effects	Additional vehicle travel and size caused by reduced operating costs, and resulting increases in external costs.	Account for rebound effects and the additional external costs that result.	Exaggerates clean vehicles emission reductions and benefits.
Costs and subsidies	Consider all costs of developing, producing and operating clean vehicles and their infrastructure.	Consider all costs when evaluating and comparing strategies.	Tends to underestimate clean vehicle total costs.
Realistic fleet adoption predictions	The time needed for clean vehicles to penetrate vehicle fleets and travel.	Use realistic predictions.	Optimistic predictions exaggerate clean vehicle emission reductions.
Leverage and synergistic effects	Additional vehicle travel reductions provided by integrated TDM and Smart Growth programs.	Consider leverage and synergistic effects in modelling and analysis.	Undervalues integrated TDM and Smart Growth programs.
Indirect costs and co-benefits	The range of impacts considered, including indirect costs and co-benefits.	Account for all significant impacts, including indirect and long term effects.	Overlooking these impacts tends to undervalue vehicle travel reduction strategies.
Variety of vehicle travel reduction strategies	The variety of TDM and Smart Growth strategies considered in analysis.	Consider all potentially effective TDM and Smart Growth strategies.	Overlooking cost-effective strategies undervalues vehicle travel reduction solutions.
Cost efficiency	Comparison of unit costs, such as dollars per tonne of emissions reduced.	Compare total unit costs between strategies.	Favors clean vehicles over vehicle travel reductions.
Latent demand for multimodal lifestyles	The portion of travellers who want to rely more on non-auto modes and live in more multimodal communities.	Consider future consumer demands for non-auto travel and walkable communities.	Ignoring this factor undervalues TDM and Smart Growth strategies.
State-of-Art models	The quality of models used to predict travel and emission impacts.	Use up-to-date integrated models.	Outdated models tend to undervalue vehicle travel reduction strategies.

These factors should be considered when evaluating transportation emission reduction strategies. Failing to account for them tends to bias emission reduction planning.

Evaluation Tools

New analysis tools can help evaluate the impacts and benefits of emission reduction strategies. For example, the *CoolClimate Policy Tool* (https://coolclimate.berkeley.edu) compares emission by location, and calculates potential emission reductions by various local policies, as illustrated in figures 7 and 8.

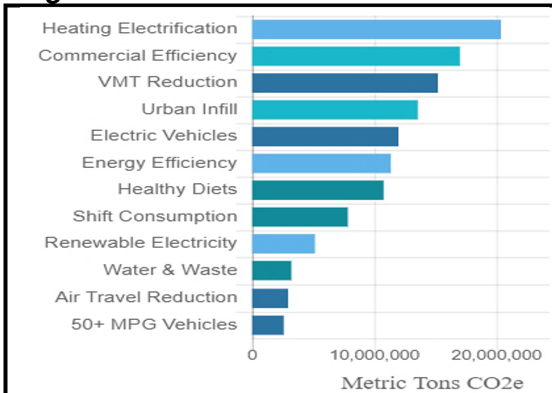
Figure 7 **Emissions Heatmaps** (*CoolClimate Policy Maps*)



Cool Climate maps show average household carbon footprints for every populated Census Block Group in California, taking into account their consumption of transportation, housing, food, goods and services.

Similar maps show average carbon footprints for all U.S. communities.

Figure 8 **GHG Reduction Potential from Local Policies** (*CoolClimate Policy Tool*)



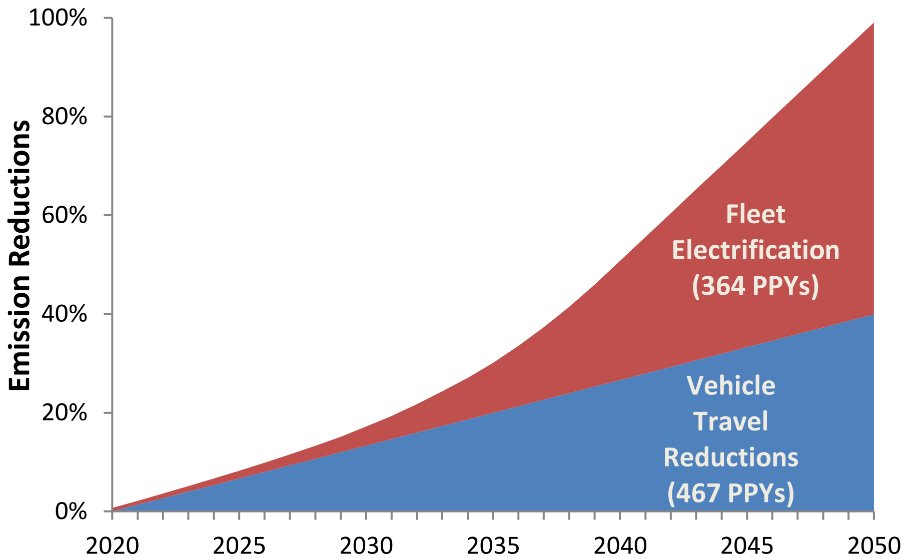
The CoolClimate Policy Tool uses models developed under a comprehensive research program to predict the effectiveness of potential emission reductions policies. This graph shows results for California state. It can be adjusted to predict impacts in a particular community.

It ranks VMT reductions and urban infill among the most effective strategies, providing more emission reductions than fuel efficient or vehicle electrification.

Street Smart (www.thinkstreetsmart.org) clearinghouse provides comprehensive, evidence-based information for integrating climate change, public health, and equity concerns into transportation. *Smart Growth Planning* (www.smartgrowthplanning.org) provides information on methods for evaluating the impacts and benefits of Smart Growth development policies and TDM programs. The *San Francisco TDM Tool* (www.sftdmtool.org) provides guidance for designing and evaluating TDM programs. The California Air Resources Board's *Research on Impacts of Transportation and Land Use-Related Policies* (CARB, 2010-2015) describes how various TDM policies and programs can reduce vehicle travel and emissions. The California Air Resources Board's *Handbook for Analyzing Greenhouse Gas Emission Reductions*, (www.caleemod.com/handbook/index.html) provides detailed guidance for analyzing how a particular policy or program will affect vehicle emissions. The VTPI Mobility Management Evaluation Spreadsheet can be used to evaluate the individual and cumulative impacts of various mobility management strategies on vehicle travel, energy consumption and emissions.

The figure below compares potential emission reductions provided by fleet electrification and vehicle travel reductions. Fleet electrification takes decades and only reduces total vehicle emissions 60-80%. A set of TDM and Smart Growth policies could reduce per capita vehicle travel 20-50%. Many of these strategies can be implemented quickly and provide large co-benefits. This indicates that both fleet electrification and vehicle travel reductions are needed to achieve ambitious emission reduction targets.

Figure 9 **Comparing Emission Reductions**[1]



Considering embodied emissions and rebound effects, electrification typically reduces emissions about 70% compared with comparable fossil fuel vehicles, and takes decades to achieve significant results. Many vehicle travel reductions can be implemented quickly and provide large co-benefits by reducing vehicle traffic and sprawl. As a result, travel reductions generally achieve more percentage point years (PPY) of emission reductions and more total benefits than electrification.

Many experts conclude that clean vehicle strategies are insufficient to achieve emission reduction targets (Alarfaj, Griffin and Samaras 2021; McCahill 2021; Reid 2021; Wilson 2021; Manjoo 2021; Zipper 2023). For example, an academic study, "Electrification of Light-Duty Vehicle Fleet Alone Will Not Meet Mitigation Targets," conclude that current policies cannot achieve targets (Milovanoff, Posen and MacLean 2020). *Our Driving Habits Must Be Part of the Climate Conversation* concludes that vehicle travel must decline 20% to limit global warming to 1.5° (Yudkin, et al. 2021). *The Climate Change Mitigation Effects of Daily Active Travel in Cities*, found that shifts from automobile to active modes provide larger and quicker emission reductions than fleet electrification (Brand, et al. 2022).

Some jurisdictions have established vehicle travel or emission reduction targets. For example, British Columbia, California, Colorado, New Zealand, Washington State, and many cities have targets to reduce vehicle travel by 15% to 25% (Litman 2022). Some jurisdictions have rules requiring that individual policy and planning decisions support those targets (Brown and Casale 2023). To evaluate these impacts and guide planning decisions, some have developed tools for predicting how planning decisions affect vehicle travel emissions, such as California's *Vehicle Miles Traveled-Focused Transportation Impact Study Guide* (Caltrans 2020), and the European Union's *Sustainable Urban Mobility Plans* which identify local vehicle travel reduction strategies (EU 2018).

[1] Based on Figure 4 "Realistic" electrification prediction, assuming electric vehicles reduce emissions 70%, and comprehensive TDM and Smart Growth policies can reduce per capita vehicle travel 40% by 2050.

Emission Reduction Plans Reviewed

This study reviewed the following transportation emission reduction plans.

Accelerating Decarbonization of the U.S. Energy System (https://bit.ly/3mBYh5k) by the National Academy of Sciences. This major study identifies actions to reach net-zero emissions by 2050. Its transportation goals include 50% zero-emission vehicle sales by 2030, more shared vehicle travel, and urban planning changes to facilitate biking and walkability. It ignores rebound effects, and considers a limited set of TDM strategies (no transportation pricing or parking policy reforms).

All Hands on Deck: An Assessment of Provincial, Territorial and Federal Readiness to Deliver a Safe Climate (https://bit.ly/3CRU2sA) by the Pembima Institute. Evaluates Canadian emission reduction policies. It highlights the need to reduce transportation emission growth, and recommends affordable, accessible, low-carbon public transit options, transit-supportive development, active transportation infrastructure, and electrifying passenger vehicles, but no TDM policies.

Aotearoa New Zealand's First Emission Reduction Plan (https://bit.ly/3UduEox), by the Ministry for the Environment. Identifies policies to reduce reliance on cars, encourage active and public transport, adopt low-emitting vehicles, and increase freight transport efficiency. It establishes a target to reduce total light vehicle-kilometres 20% by 2035 providing better travel options and more compact development. It emphasizes the co-benefits of reduced vehicle travel.

Better Access to Urban Opportunities: Accessibility Policy for Cities in the 2020s (https://bit.ly/3mBCf2B) by the LSE Cities and the OECD for the Coalition for Urban Transitions. This report identifies policies to integrate climate emission reduction and social equity goals into pandemic recovery programs by creating more accessible and efficient cities.

Blueprint 2030: An All-In Climate Strategy (www.americaisallin.com/blueprint-2030), by America is All In. Describes a whole-of-society approach to cut emissions 50% by 2030 and 100% by 2050. It recommends land use changes, public transport, safe biking and walking infrastructure, micro mobility, and other vehicle traffic reduction strategies to achieve community livability, public safety and social equity goals. Predicts that these could reduce transport emissions 39% by 2030.

Canada's Net Zero Future: Finding Our Way in the Global Transition (https://bit.ly/3pgk29c) by the Canadian Institute for Climate Choices. Recommends electric vehicle and biofuel development, plus increased use of active and public transport.

Canada's 2030 Emission Reduction Plan (https://bit.ly/3VpADYM), by Environment Canada. Identifies ways to achieve Paris Accord targets. Transportation actions include cleaner public transit, more active transport, more affordable and accessible zero emission vehicles, and cleaner air, marine, and rail travel.

The Closing Window: Climate Crisis Calls for Rapid Transformation of Societies (https://bit.ly/3XCDWxE) Emissions Gap Report 2022, by the United Nations Environmental Programme. Identifies additional policies needed to achieve emission reduction targets. It recommends transportation and urban planning reforms to reduce automobile travel and shift to low-emitting modes and increase freight efficiency.

Decarbonising Transport (https://bit.ly/3t9zsB6) by the UK Department for Transport. Identifies ways that Britain will achieve its target of eliminating climate emissions by 2050. These include shifts from automobile to active and public transport, more efficient goods delivery, fleet decabonization, behaviour change and community-based emission reduction programs.

Driving California's Transportation Emissions to Zero (https://escholarship.org/uc/item/3np3p2t0) by the University of California's Institute of Transportation Studies. Identifies ways that California can achieve carbon-neutral transportation by 2045. Recommends VMT reduction targets and identifies some TDM strategies. States that, "Reducing VMT in California from light, medium, and heavy-duty vehicles is a critical part of reducing transportation system GHG emissions."

Driving Down Emissions: Transportation, Land Use and Climate Change, (https://bit.ly/3tLZBEw) by Transportation for America and Smart Growth America. This report argues that large emission reductions are possible by meeting the demand for housing in accessible, multimodal communities.

Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050, (https://bit.ly/3yiQuwM) by the American Council for an Energy-Efficient Economy. This report identifies ways to halve emissions through government policies and investments. Most transport emission reductions are from efficient and electric vehicles, but it also recommends VMT reduction strategies.

Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity (www.caleemod.com/handbook/index.html), by the California Air Pollution Control Officers Association. Describes methods to quantify emission reductions from various policies and programs. It describes methods for assessing health and equity co-benefits.

Inflation Reduction Act (https://bit.ly/3i7tcH0), by the U.S. Congress. This U.S. federal law is considered the nation's first major investment in climate change mitigation. It focuses on clean vehicles, primarily large subsidies for electric vehicle purchases and charging networks, but exclude micromodes (e-bikes and –scooters), and provide little support for vehicle travel reductions.

Marginal Abatement Cost Curves for U.S. Net-Zero Energy Systems (https://bit.ly/3CkbVAQ) by the Environmental Defense Fund. This report quantifies the costs of various emission reduction technologies including electric and fuel cell vehicles. It concludes that, although some electric vehicle implementation can be achieved at less than zero costs, large reductions will cost more than $100 per tonne and require renewable electricity. It considers no TDM strategies, rebound effects or co-benefits.

The U.S. National Blueprint for Transportation Decarbonization (http://bit.ly/3JcJUjV) by the Department of Energy's Office of Energy Efficiency & Renewable Energy describes how U.S. Federal policies can transition to a decarbonized transportation system that provides more equitable, affordable, and accessible transportation options. It promotes improvements to affordable and efficient modes, including active and public transport, and development policies to create more accessible communities.

Net Zero by 2050: A Roadmap for the Global Energy Sector (www.iea.org/reports/net-zero-by-2050), International Energy Agency. Describes energy production and consumption changes required to achieve net zero by 2050. Relies primarily on fuel shifting and energy efficiency gains, particularly electric vehicles. It concludes that behavior changes, "such as replacing car trips with walking, cycling or public transport, or foregoing a long-haul flight" can only achieve about 4% of emission reduction targets.

Pledges and Progress: Steps Toward Greenhouse Gas Emissions Reductions in the 100 Largest Cities Across the United States (https://brook.gs/3VdCkIY) by the Brookings Institute. Finds that in 2020, approximately 12% of the U.S. population lived in cities with emission reduction targets, but few are achieving their targets, and there are doubts that their current plans will be successful. It suggests that cities have limited ability to implement many strategies, such as regional land use and transport reforms.

Project Drawdown (https://drawdown.org) is an activist-based planning exercise that identifies and evaluates various emission reduction strategies. Its analysis does not account for embodied emissions, rebound or synergistic effects of integrated programs, and uses low price elasticities. It considers active and public transport improvements, but not transportation demand management incentives to encourage mode shifts and reduce total vehicle travel.

State Climate Policy Maps (www.c2es.org/content/state-climate-policy) by the Center for Climate and Energy Solutions. Finds that 24 states have greenhouse gas reduction targets, 36 have electric vehicle purchase and infrastructure subsidies, some have low-carbon fuel (ethanol) requirements, and a few have land use policies and public transit investments to reduce transport emissions.

State of Climate Action 2022 (www.wri.org/research/state-climate-action-2022) by the World Resources Institute and various partners. Evaluates recent progress and gaps in emission reduction efforts. Mentions embodied emissions, rebound effects and co-benefits, but not related to transport. The Transport section (pp. 72-91) recommends shifts from automobile to active and public transit, and evaluates rapid transit and bike lane network development, but focuses on fleet electrification, plus aviation and freight fuel shifting.

Transport and Climate Change Global Status Report (https://tcc-gsr.com), by Sustainable Low Carbon Transportation (SLOCAT). This detailed report evaluates transport's contribution to climate change, ways to reduce emission, and various success stories. It emphasizes the importance of balancing climate action with other development goals, and so advocates *avoid-shift-improve* prioritization which favors vehicle travel reductions over clean vehicle strategies.

Transport Climate Action Directory, (www.itf-oecd.org/tcad-measures) by the International Transport Forum. This website describes over 60 climate mitigation strategies, including their emission reductions, costs and co-benefits. It includes many TDM and Smart Growth policies.

Transport in New Nationally Determined Contributions and Long-Term Strategies (https://changing-transport.org/publication/transport-in-ndcs-and-lts), by Sustainable Low Carbon Transportation. This study evaluates the transport commitments in Nationally Determined Contributions (NDCs). It found that most focus on electric and hydrogen vehicle adoption. Few recognize embodied emissions or rebound effects. Many mention some TDM strategies, but often assume that they have limited potential, high costs and little public support. Few consider indirect impacts or co-benefits. A few apply *avoid-shift-improve* prioritization which favors vehicle travel reductions over other strategies.

Transport Outlook 2023 (www.itf-oecd.org/itf-transport-outlook-2023), by the International Transport Forum, examines the impacts of different policy measures on global transport demand and carbon dioxide emissions to 2050. It identifies a High Ambition scenario that could accelerate transport decarbonisation and help achieve other strategic goals.

Transport Strategies for Net-Zero Systems by Design (https://bit.ly/31Qi1Ll) by the OECD. This report applies a well-being lens to emission reduction planning. It concludes that induced demand, urban sprawl and degraded active and shared transport increase car dependency and emissions. It recommendations strategies that reduce emissions and improve well-being.

Updated NDCs – What Do They Say About Transport? (https://bit.ly/3XWLdIH), by Changing Transport. Found that 57% of national actions to achieve Paris emission reduction targets rely on clean vehicle implementation and only 6% rely primarily on vehicle travel reductions (Taeger 2021).

Zero Carbon Action Plan (ZCAP) for the United States (www.unsdsn.org/Zero-Carbon-Action-Plan) by the Sustainable Development Solutions Network. This major study recommends that 30% of new vehicles be electric by 2030 and vehicle travel be reduced 25% by 2050. To achieve those targets it recommends shifting funds from roadways to resource-efficient modes and more compact development. It states, "Transportation is generally seen as the most challenging sector to decarbonize, but it may also prove one of the least costly—even eventually providing large economic saving. It is also the sector with the greatest opportunity to provide a large number of associated co-benefits to travelers and society and to create a more environmentally sustainable and equitable society."

Below are observations concerning these plans:

- Most plans appear to use simplified analysis methods that incorporate many of the biases identified in this report (most are vague about their analysis details). Most ignore embodied emissions, rebound effects, synergistic effects of integrated programs, and vehicle travel reduction co-benefits. Many use outdated models with low price elasticities. These biases tend to exaggerate clean vehicle benefits and undervalue vehicle travel reduction strategies. Few plans include cost efficiency analysis (estimates of net costs per tonne of emissions reduced) or other indicators of net benefits.
- Although there is no comprehensive accounting, most current national and state plans invest most in clean vehicle strategies, including consumer subsidies and support for technical and industry development. Vehicle travel reduction strategies generally receive far less investments. Many subsidize electric vehicles but not micromodes, such as e-bikes.
- Subsidies for micromodes tend to provide larger emission reductions and total benefits than for electric automobiles because e-bikes are much cheaper, have a higher price elasticity (each dollar of subsidy increases e-bike purchases much more than e-car purchases) and because shifts to e-bikes cause much large emission reductions and greater total benefits than shifts from fossil fuel to electric cars (Bigazzi and Berjisian 2021; Edmondson 2023). Small subsidies can lead to large increases in e-bike sales (Rachal 2023).
- Guidance reports by scientific organizations, such as the National Academy of Sciences and the International Energy Agency, also focus on clean vehicle strategies. Although most mention vehicle travel reduction strategies, they imply that vehicle travel reductions are costly and difficult to achieve, and only provide small emission reductions.
- Some plans imply that vehicle travel reductions depend entirely on active and public transport infrastructure investments, with little attention to TDM incentives to encourage mode shifting, such as efficient road, parking and insurance pricing, and development policy reforms.
- Sustainable development organizations, such as Transportation for America, SLOCAT, the World Resources Institute, and the United Nations Environmental Programme, tend to give more priority to vehicle travel reductions and consider a wider range of TDM incentives and impacts.
- Some jurisdictions, including British Columbia, California, New Zealand, and the United Kingdom, have specific targets to reduce total motor vehicle travel and increase use of resource-efficient modes. These typically aim to reduce per capita motor vehicle travel 15-25% during the next two decades, and approximately double walking, bicycling and public transit travel. Some are developing analysis tools for evaluating specific transportation and land use planning decisions to ensure that they support vehicle travel reduction targets.

Conclusions

Many jurisdictions have ambitious emission reduction targets and are developing plans to achieve them. This study finds that the process used to develop those plans is often biased to favor clean vehicle (e.g., hybrid, electric and hydrogen vehicles, and low carbon fuels) subsidies over vehicle travel reduction strategies such as walking, bicycling and public transport improvements, TDM incentives, and Smart Growth development policies. Previous publications identify some of these biases, but this study is more comprehensive and systematic. It identifies ten common biases and ways to correct them.

Many plans assume that clean vehicle strategies are more cost effective, reliable, and beneficial than vehicle travel reductions. This study challenges those assumptions. Clean vehicle development deserves support, but their net benefits are often smaller than predicted. Considering embodied energy, clean vehicles typically reduce per-mile emission rates by one to two thirds, so it is an exaggeration to claim they have zero emissions; it is more accurate to describe them as “lower-” or “elsewhere-emission” vehicles. Their benefits are further reduced by their induced travel which reduces their benefits and increases their external costs. Currently, clean vehicles have relatively high costs per tonne of emissions reduced and receive large subsidies. Optimistically, half of *new* vehicles could be electric by 2030 but these will primarily be cars; SUV, light trucks and van electrification will take several more years, and unless many functional vehicles are prematurely scrapped many high-emitting vehicles will continue to operate for decades. As a result, clean vehicle programs can provide only modest emission reductions before 2040 and full fleet electrification is unlikely to occur by 2050.

On the other hand, vehicle travel reduction strategies provide large but often overlooked co-benefits including user savings and benefits, plus reductions in external costs. Although few motorists want to give up driving altogether, surveys indicate that many would like to drive less, rely more on alternative modes, and live in more walkable communities, provided that they are convenient, safe and affordable. More multimodal transportation planning and compact community development responds to those demands. Most vehicle travel reductions strategies also reduce traffic and parking congestion, provide infrastructure savings, provide more independent mobility for non-drivers, improve public health and safety, and reduce sprawl-related costs in addition to emission reductions. Many vehicle travel reduction strategies can be implemented quickly. Although their individual impacts may seem small, these strategies have synergistic impacts – their benefits are greater if implemented together. They complement clean vehicle strategies by avoiding rebound effects, preventing hybrid, electric and hydrogen vehicles from increasing traffic problems and sprawl-related costs. An integrated set of TDM and Smart Growth strategies can typically reduce transportation emissions by 30-60% in ways that are cost-effective and beneficial overall.

Vehicle travel reduction solutions require a paradigm shift. The old paradigm assumed that it is desirable to maximize vehicle travel, the new paradigm recognizes that it is possible to satisfy our accessibility needs with significantly less vehicle travel. New technologies and services, such as e-bikes, telework and integrated mobility apps, help make this happen.

This analysis suggests that to be efficient and equitable, transportation emission reduction plans should rely at least as much on vehicle travel reductions as on clean vehicle strategies, with particular emphasis on “quick win” strategies that can be implemented in a few years.

We have an optimistic story to tell: With better analysis we can identify true win-win emission reduction strategies that also help achieve other economic, social and environmental goals. Everybody wins!

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