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Comprehensive Evaluation of Transport Energy Conservation and Emission Reduction Policies

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Abstract

Various transportation policies can help conserve energy and reduce pollution emissions. Some, called *cleaner vehicle* strategies in this article, reduce emission rates per vehicle-kilometer. Others, called *mobility management* (also called *transportation demand management* and *VMT reduction*) strategies, reduce total vehicle travel. There is disagreement concerning which approach is most cost effective and beneficial. Some studies conclude that cleaner vehicle strategies are generally most cost effective and beneficial overall, while others favor mobility management strategies. These different conclusions tend to reflect different analysis scope. Analyses that favor clean vehicle strategies tend to overlook or undervalue some significant impacts, including cleaner vehicle lifecycle analysis and rebound effects, and mobility management co-benefits. More comprehensive analysis tends to favor mobility management. This article investigates these issues and provides specific recommendations for comprehensive evaluation of transport energy conservation and emission reduction strategies.

Introduction

In response to concerns about oil dependency, air pollution and climate change risks, many jurisdictions have established energy conservation and emission reduction targets (Pew 2008). Since motor vehicles are major petroleum consumers and pollution emitters, transportation policy reforms are important for achieving these goals.[1] There are many potential transport energy conservation and emission reduction strategies (AASHTO 2009; Morrow, et al. 2010; UKERC 2009). For this analysis they are divided into two major categories: *cleaner vehicle* strategies that reduce fuel consumption and emission rates per vehicle-kilometer, and *mobility management* strategies that reduce total motor vehicle travel, as indicated in Table 1.[2]

Table 1 **Transport Energy Conservation and Emission Reduction Strategies** (VTPI 2011)

Cleaner Vehicles	Mobility Management
Reduce fuel consumption and emission rates per vehicle-kilometer	Reduce total vehicle travel
Anti-idling programs and regulations	Car-free planning and vehicle restrictions
Feebates (special fees on inefficient vehicles and rebates on efficient vehicles)	Commute trip reduction programs
Fleet management and driver training	Distance-based vehicle insurance and registration fees
Fuel efficiency standards (such as CAFE)	Distance-based emission fees
Fuel quality improvements	Efficient parking management and pricing
Fuel tax increases*	Freight transport management
Inspection and maintenance (I/M) programs	Fuel tax increases*
Low emission vehicle mandates	Mobility management marketing
Promote purchase of cleaner vehicles	Non-motorized transportation improvements
Promote motorcycle and small vehicle use	Ridesharing improvements and incentives
Resurface highways	Road pricing
Roadside “high emitter” identification	Smart growth development policies
Scrapage programs	Telework encouragement
	Transit improvements and incentives

This table lists the various types of energy conservation and emission reduction strategies.
(fuel taxes encourage both cleaner vehicles* and *vehicle travel reductions.)*

[1] Since energy consumption produces air emissions they overlap and can generally be considered a single objective.

[2] Mobility management is often called *transportation demand management*, but this is a technical term and the acronym sounds like *tedium*, an unpleasant condition, and so is inappropriate for general audiences. The term *VMT (Vehicle Miles Traveled) reduction* is widely used in the U.S., but is not metric and therefore inappropriate for international audiences. Cox (2011) calls cleaner vehicle strategies *technological strategies* and mobility management *behavioral strategies*, but those terms are inaccurate since many cleaner vehicle strategies involve behavioral change (such as changing vehicle purchase decisions) and many mobility management strategies involve new technologies (to support telework, automate road and parking pricing, improve user information, etc.). For these reasons I consider *cleaner vehicles* and *mobility management* more accurate terms.

There is considerable debate concerning which policies are overall optimal. Some studies conclude that clean vehicle strategies are most cost effective and beneficial overall, based on the assumption that mobility management is difficult to implement and harmful to consumers and the economy (Cox and Moore 2011; Hartgen, Fields and Moore 2011; McKinsey 2007). For example, Moore, Staley and Poole (2010) argue,

> "Attempts to reduce VMT [vehicle miles traveled] typically rely on very blunt policy instruments, such as increasing urban densities, and run the risk of reducing mobility, reducing access to jobs, and narrowing the range of housing choice. VMT reduction, in fact, is an inherently blunt policy instrument because it relies almost exclusively on changing human behavior and settlement patterns to increase transit use and reduce automobile travel rather than directly target GHGs. It also uses long-term strategies with highly uncertain effects on GHGs based on current research. Not surprisingly, VMT reduction strategies often rank among the most costly and least efficient options. In contrast, less intrusive policy approaches such as improved fuel efficiency and traffic signal optimization are more likely to directly reduce GHGs than behavioral approaches such as increasing urban densities to promote higher public transit usage."

Other studies conclude that mobility management strategies can be cost effective and beneficial overall (Litman 2008). Research commissioned by the Transportation Research Board (TRB 2009), the U.S. Department of Transportation (USDOT 2010), and the UK Energy Research Centre (UKERC 2009) all conclude that vehicle travel reductions can provide significant and cost effective energy savings and emission reductions.

These different conclusions tend to reflect different evaluation frameworks, which define the analysis methods and scope. A comprehensive evaluation framework, which considers all significant options and impacts, is necessary to identify truly optimal policies.[3] Comprehensive analysis is particularly important for transport policy analysis because transport decisions tend to have more diverse impacts than most other sectors. For example, increasing building insulation does not generally affect how people live or communities develop, so relatively simple cost effectiveness analysis is adequate to determine optimal building weatherization. However transport planning decisions have many indirect economic, social and environmental impacts, so decisions that affect the quality of transport options, how and how much people travel, require comprehensive analysis that accounts for these additional factors. Although the importance of comprehensive evaluation may seem obvious, it is not always done. Conventional transport policy analysis often considers a limited set of impacts.

This article investigates these issues. It describes the requirements for comprehensive evaluation of energy conservation and emission reduction policies, investigates current evaluation practices, and discusses various factors that should be considered in such analysis.

[3] Various terms are used when evaluating impacts. Undesirable impacts are generally called *problems* in qualitative analysis and *costs* in quantitative analysis. Desirable impacts are often called *planning objectives* in qualative analysis and *benefits* in qualitative analysis. Additional benefits are called *co-benefits* (Kendra, et al. 2007; Leather 2009).

Comprehensive Evaluation Guidelines

This section discusses requirements for comprehensive evaluation of transportation energy conservation and emission reduction strategies.

Options Considered

Comprehensive analysis should consider a diverse range of potential energy conservation and emission reduction strategies, such as those in Table 1. Some strategies have complementary and synergistic effects (total impacts are greater than the sum of their individual impacts). For example, pricing reforms tend to be more effective if implemented with improvements to alternative modes. As a result, comprehensive evaluation should consider integrated packages of complementary strategies. Various information sources can help identify these strategies (AASHTO 2009; Böhler-Baedeker and Hüging 2012; Litman 2007; Morrow, et al. 2010; VTPI 2011) and evaluate their impacts (CARB 2010-11; IDTP 2010; UKERC 2009). Critics sometimes argue that mobility management impacts are unpredictable (Cox and Moore 2011; Moore, Staley and Poole 2010), but such claims tend to ignore current modeling capabilities and examples (*EPOMM Case Studies*; Johnston 2006; VTPI 2011).

Scope of Impacts

Comprehensive analysis should consider all significant impacts. Table 2 indicates various transport impacts and the degree they are considered in conventional transport policy analysis.

Table 2 **Transport Impacts**

Impacts	Degree Considered in Conventional Policy Analysis
Travel speed, convenience and comfort	Travel speed is generally considered, but convenience and comfort are seldom quantified
Consumer costs and affordability (costs to lower-income people)	Vehicle operating costs and fares are generally considered, but vehicle ownership costs are often ignored
Mobility options for non-drivers	Generally considered a special planning issue
Congestion	Generally considered and is often a dominant analysis factor
Direct government costs	Generally considered and is often a dominant analysis factor
Parking facility costs	Seldom considered
Traffic safety	Generally considered, measured per kilometer of travel
Energy consumption	Generally considered, measured per kilometer of travel
Pollution emissions	Generally considered, measured per kilometer of travel
Land use impacts	Sometimes considered
Public fitness and health	Seldom considered, but gaining consideration

Conventional analysis tends to focus on some impacts (government costs, travel speed and delay, vehicle operation, plus accident, fuel consumption and emissions per kilometer) and overlook others (traveler comfort and convenience, vehicle ownership costs, parking costs, public fitness, plus accident, fuel and emission impacts from increased vehicle travel).

Comprehensive analysis should at least apply qualitative analysis that indicates the direction of impacts, and if possible impacts should be *quantified* (measured) and *monetized* (valued using monetary units). Monetized estimates of many of these impacts are now available from various sources (DfT 2006; Litman 2009; Maibach, et al. 2008; NZTA 2010).

Rebound Effects

Rebound (also called *takeback*) *effects* refers to the increased vehicle travel that results from increased fuel efficiency, cheaper fuels, or roadway expansion that increases traffic speeds (Noland and Quddus 2006; UKERC 2009). In a typical situation, about a third of fuel or time savings that result are used for additional vehicle travel, so for example, increasing fuel efficiency 10% increases vehicle travel 3%, leaving 7% net energy savings. This has three impacts to consider: reduced net energy savings, increased vehicle travel external costs, and increased consumer benefits from the additional mobility (Litman 2001).

There is debate concerning the magnitude of this effect. Hymel, Small and Van Dender (2010) found that vehicle travel price elasticities declined to less than -0.1 (a 10% fuel price increase reduced fuel consumption less than 0.1%) in the U.S. between 1970 and 2004, but this was a unique period of increasing travel demand, rising incomes, automobile-oriented planning, and declining real (inflation-adjusted) fuel prices. Recent studies indicate that driving has since become more price sensitive (Litman 2012). Li, Linn and Muehlegger (2011) found a -0.235 fuel price elasticity between 1968 and 2008 (a 10% fuel price increase reduced fuel consumption 2.3%) with higher values for durable price increases. Gillingham (2010) found medium-run (two-year) elasticities of vehicle travel with respect to gasoline price ranging from -0.15 to -0.20, with impacts that increased over time. These studies suggest that rebound effects have returned to more normal levels and will probably rise further if fuel prices continue to increase relative to incomes.

Lifecycle Analysis

When evaluating energy conservation strategies it is important to use lifecycle analysis that considers resource consumption and emissions at all stages of production. For example, electric vehicle evaluation should account for energy and emissions embodied in vehicle, battery and electricity production. Chester and Horvath (2008) estimate that tailpipe emissions represent just 56% of total automobile lifecycle energy inputs, and Michalek, et al. (2011) concluded that hybrid vehicles provide at most only about 20% lifetime energy conservation and emission reductions compared with conventional vehicles.

Additional Energy Savings

Some mobility management strategies provide additional energy savings and emission reductions. Some strategies (pricing reforms and grade-separated transit or ridesharing facilities) reduce traffic congestion and therefore vehicle emission rates in addition to reducing vehicle travel. High quality public transit can leverage additional vehicle travel reductions by providing a catalyst for more compact, transit-oriented development, where residents tend to own fewer vehicles and drive less than they would in more automobile-oriented neighborhoods (Arrington, et al. 2008; ICF 2008; Litman 2011).

Economic Transfers
It is important to account for economic transfers when evaluating price changes and subsidies. For example, a tax or fare increase is a cost to affected consumers but a benefit to the government or organization that collects the additional revenue. The ultimate impacts depend on how revenues are used; even people who pay a fee may benefit overall if it reduces other taxes or finances additional services that they value. Similarly, transit subsidies are costs to governments but provide user savings and benefits.

Consumer Impact Analysis
Transport policy analysis sometimes assumes that any automobile travel reduction increases user costs. However, vehicle travel changes that result from positive incentives, such as improved accessibility options or financial rewards for reduced driving, directly benefit users. For example, if cycling facility improvements cause shifts from automobile to bicycle travel, or smart growth policies allow more households to choose more accessible, multi-modal location, it is incorrect to assume the affected users are worse off, even if the new modes are slower or their new lifestyle is less mobile. The consumer impacts of price changes can be evaluated using the *rule-of-half*, which states that consumer surplus changes (net changes in consumer benefits) are worth half the change in revenue ("Unit 3.5," DfT 2006). For example, if a $1 per trip road toll increase causes annual vehicle trips to decline from 3 million to 2 million, the reduction in consumer surplus is $2,500,000 (<u>$1 x 2 million</u> for existing trips, plus <u>$1 x 1 million x 0.5</u> for vehicle trips foregone).

Summary
Table 3 summarizes factors that should be considered for comprehensive transport policy.

Table 3 **Summary of Comprehensive Evaluation Requirements**

Factor	Effects Of Omitting
Variety of options considered, including various mobility management strategies.	A limited range of options may overlook some cost-effective strategies.
Impacts (costs and benefits) considered in analysis.	Tends to undervalue mobility management strategies.
Rebound effects (additional vehicle travel resulting from more efficient vehicles, cheaper fuels, and roadway expansion).	Exaggerates cleaner vehicle benefits.
Lifecycle analysis (resource inputs and emissions at all states of vehicle and fuel production).	Exaggerates cleaner vehicle energy savings and emission reduction benefits.
Additional energy savings from reduced congestion or leveraged vehicle travel reductions.	Undervalues strategies that reduce congestion and increase non-motorized travel.
Economic transfers (price change costs and benefits)	Often exaggerates the total costs of pricing reforms.
Consumer impacts of changes in transport options and activities.	Conventional analysis often overlooks user benefits and exaggerates costs of mode shifts.

This table summarizes factors required for comprehensive evaluation of transport energy conservation and emission reduction policies, and the effects of omitting these factors.

Qualitative Analysis

This section uses qualitative analysis to evaluate energy conservation and emission reduction strategies. Table 4 compares the planning objectives typically achieved by cleaner vehicle and mobility management strategies. Cleaner vehicles conserve energy and reduce emissions, and usually reduce fuel costs, but this is partly offset by increased ownership costs (due to higher production and battery replacement costs) to achieve a given level of performance. Mobility management strategies generally achieve far more planning objectives.

Table 4 **Comparing Impacts** (Litman 2007)

Planning Objectives	Cleaner Vehicles	Mobility Management
Improved user convenience and comfort		✓
Consumer savings and affordability	✓/✗[4]	✓/✗[5]
Improved mobility options for non-drivers		✓
Congestion reduction		✓
Roadway cost savings		✓
Parking cost savings		✓
Traffic safety		✓
Energy conservation	✓	✓
Pollution reduction	✓	✓
Land use objectives (supports smart growth)		✓
Improved public fitness and health		✓

(✓ = Achieve objectives. ✗ = Contradicts objective. ✓/✗ = Mixed Impacts) Cleaner vehicle strategies tend to achieve fewer planning objectives than mobility management.

If cleaner vehicle strategies induce additional vehicle travel (a rebound effect) they tend to contradict many planning objectives, as illustrated in Table 5.

Table 5 **Comprehensive Evaluation With Rebound Effects** (Litman 2011)

Planning Objective	Cleaner Vehicles	Mobility Management
Motor Vehicle Travel	*Increased*	*Reduced*
Improved travel speed convenience and comfort		✓/✗
Congestion reduction	✗	✓
Roadway cost savings	✗	✓
Parking cost savings	✗	✓
Consumer savings and affordability	✓/✗	✓/✗
Traffic safety	✗	✓
Improved mobility options		✓
Energy conservation	✓	✓
Pollution reduction	✓	✓
Land use objectives	✗	✓
Public fitness and health	✗	✓

(✓ = Achieve objectives. ✗ = Contradicts objective. ✓/✗ = Mixed Impacts). Clean vehicle strategies tend to increase vehicle travel and therefore contradict other planning objectives.

[4] Efficient and alternative fuel vehicles usually have lower operating costs but higher ownership costs.
[5] Some strategies (alternative mode improvements and parking cash out) provide direct user savings. Others (efficient road and parking pricing) increase user costs but their overall impacts depend on how revenues are used.

For more detailed user impact analysis, mobility management strategies can be divided into three major categories, as indicated in Table 6:

- Strategies that improve transport options (walking, cycling, public transit, carsharing, etc.) tend to provide direct user benefits.
- Some pricing reforms (distance-based insurance and parking cash out) provide direct user savings (they are optional so users only reduce vehicle travel if they directly benefit), while others (such as higher road tolls, parking fees and fuel prices) increase user costs but are economic transfers so their overall impacts depend on how revenues are used.
- Smart growth policies, which result in more compact and multi-modal development tend to provide both direct user benefits (improving accessibility and reducing transport costs), and some user costs (increased local congestion and some development costs).

Table 6 **Impacts of Different Types of Mobility Management Strategies**

Planning Objective	Improve Options	Pricing Reforms	Smart Growth
Improved travel speed, convenience & comfort	✓	✓/✗	✓/✗
Congestion reduction	✓	✓	✓/✗
Roadway cost savings	✓	✓	✓/✗
Parking cost savings	✓	✓	✓/✗
Consumer savings and affordability	✓	✓/✗	✓/✗
Traffic safety	✓	✓	✓
Improved mobility options	✓	✓/✗	✓
Energy conservation	✓	✓	✓
Pollution reduction	✓	✓	✓
Land use objectives	✓	✓	✓
Public fitness and health	✓	✓	✓

(✓ = Achieve objectives. ✗ = Contradicts objective. ✓/✗ = Mixed Impacts).

This quantitative analysis indicates that mobility management strategies generally achieve more planning objectives than cleaner vehicle strategies, particularly if cleaner vehicle strategies have rebound effects. Of the various types of mobility management strategies, improving transport options tend to provide the greatest range of benefits because they directly benefit users in addition to their external benefits. Pricing reforms are primarily economic transfers; their ultimate impacts depend on the quality of accessibility options available and how revenues are used. Smart growth policies tend to provide a mix of benefits and costs.

Quantitative Analysis

This section uses quantitative analysis to evaluate energy conservation strategies.

Fuel- and Vehicle-Travel Related Costs

An extensive and growing body of research monetizes transport costs (Litman 2009; Maibach, et al. 2008). Table 7 summarizes monetized estimates of an average automobile's costs divided into those related to fuel consumption and those related to vehicle travel.

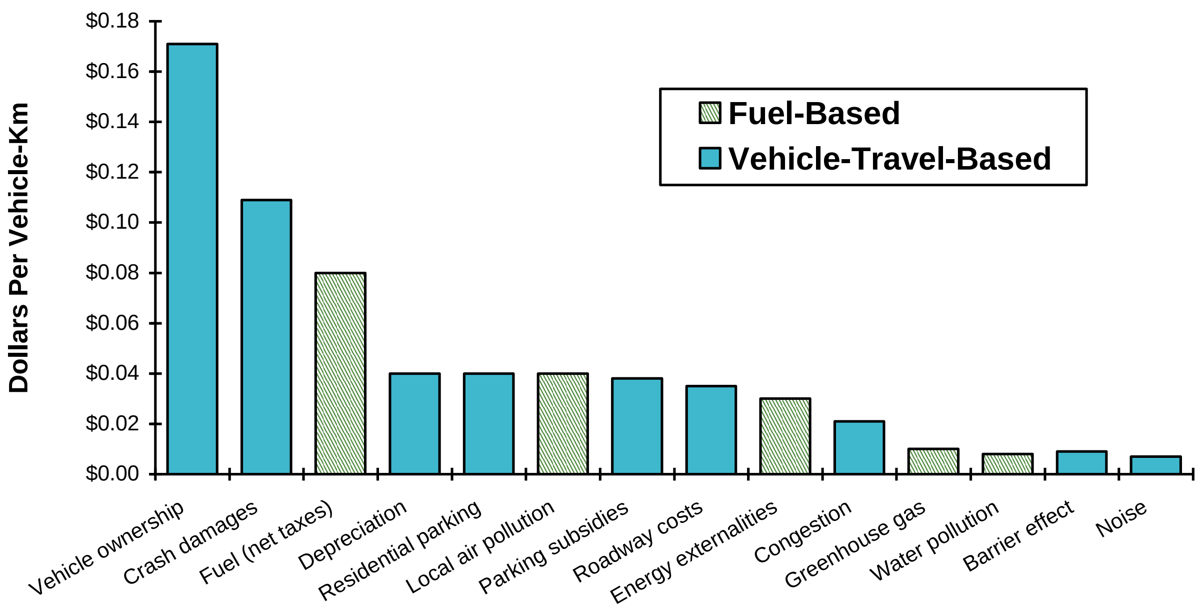
Table 7 **Average Automobile Monetized Costs** (Litman 2009; Maibach, et al. 2008)[6]

Fuel-Related Costs		Vehicle-Travel-Related Costs	
Costs associated with fuel use	*Per Vehicle-Km*	*Costs associated with vehicle travel*	*Per Vehicle-Km*
Fuel purchase (net taxes)	$0.079	Vehicle ownership	$0.171
Petroleum production externalities	$0.030	Crash damages	$0.109
Local air pollution	$0.040	Mileage-based depreciation	$0.040
Climate change emissions	$0.010	Residential parking	$0.040
Water pollution	$0.008	Parking subsidies	$0.038
		Roadway costs	$0.035
		Congestion	$0.021
		Barrier effect	$0.009
		Noise	$0.007
Total	*$0.167*		*$0.470*

Some costs are associated with fuel use, others with vehicle travel.

Figure 1 illustrates the magnitude of these costs.

Figure 1 **Average Automobile Costs** (from Table 7)



This figure shows various costs for an average automobile ranked by magnitude.

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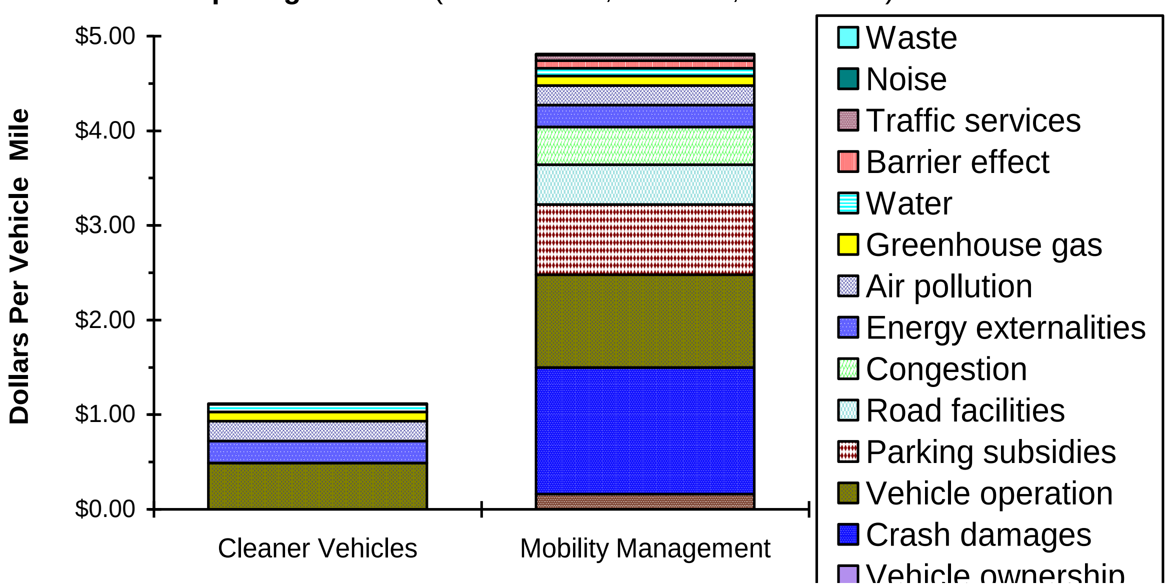
6 *Comprehensive Emission Reduction Evaluation Spreadsheet* (www.vtpi.org/CERE.xls).

This indicates that for typical vehicles, fuel-related costs are much smaller than vehicle-travel-related costs. As a result, a fuel conservation strategy is probably not cost effective if it causes even modest increases in vehicle-travel costs, but is far more cost effective if it also reduces those costs. For example, a policy that doubles fuel economy provides about 8.4¢ per vehicle-km in total benefits, of which 4.4¢ are external benefits. That is probably not cost effective if it requires most households to purchase additional vehicles (for example, an extra small car for local trips) due to increased vehicle ownership and residential parking costs, or if it increases vehicle travel and associated congestion, roadway and accident costs by 10%. However an energy conservation strategy provides much more total benefits if, by improving alternative modes, it allows 10% of households to reduce their vehicle ownership.

Described differently, a liter of fuel conserved through vehicle travel reductions provides about four times the total benefits as the same fuel savings provided by cleaner vehicle strategies, due to additional benefits such as congestion reductions, road and parking facility cost savings, consumer savings, and traffic safety, as illustrated in Figure 2.

Figure 2 **Comparing Benefits** (Litman 2009; Maibach, et al. 2008)[7]



A liter of fuel conserved by clean vehicle strategies provides about $1.00 of reduced costs. A liter conserved by reducing vehicle travel provides nearly $5.00 worth of reduced costs.

Such analysis can be structured in various ways to reflect different assumptions about user impacts. For example, fuel cost savings could be excluded from the benefit category based on the assumption that, since consumers can already choose more efficient vehicles and alternative modes, any user savings must be offset by disbenefits such as reduced vehicle performance or travel speed. However, excluding user savings does not change the basic conclusion that mobility management provides more benefits than cleaner vehicle strategies.

[7] Assumes that clean vehicle strategies reduce vehicle operating costs by 50%, and mobility management reduces vehicle ownership cost 10% by allowing some households to own fewer vehicles.

Fuel Efficiency Mandate

Corporate Average Fuel Efficiency (CAFE) standards force vehicle manufacturers to sell more fuel efficient vehicles. The 2016 standard, which increases average vehicle fuel economy from 30.2 mpg to 38.0 mpg (9.35 to 7.43 liters per 100 km), is predicted to increase production costs $907 per vehicle (USEPA/USDOT/CARB 2010, footnote XX). Table 8 summarizes an evaluation of this policy, ignoring and considering rebound effects.

Table 8 **Fuel Efficiency Standards Evaluation**[8]

	2011 Standard	2016 Standard No Rebound	*Diff.*	2016 Standard With Rebound	*Diff.*
Fuel economy	30.2	38.0	26%	38.0	26%
Lifetime vehicle-kilometers	160,000	168,000	0	172,404	12,404 (8%)
Lifetime fuel consumption (liters)	14,960	11,888	-3,072	12,810	-2,150
Carbon emissions (tonnes)	34.9	27.7	-7.2	29.9	-5.0
Fuel-Related Costs					
Fuel resource costs	$11,857	$9,422	$2,435	$10,153	$1,704
Energy externalities	$3,590	$2,853	$737	$3,074	$516
Local air pollution	$3,291	$2,615	$676	$2,818	$473
GHG emission costs	$1,496	$1,189	$307	$1,281	$215
Water pollution costs	$1,346	$1,070	$276	$1,153	$194
Totals	*$21,581*	*$17,150*	*$4,432*	*$18,479*	*$3,102*
Travel-Related Costs (Veh-Km)					
Vehicle ownership	$27,360	$27,360	$0	$29,481	-$2,121
Crash damages	$17,440	$17,440	$0	$18,792	-$1,352
Mileage-based depreciation	$6,400	$6,400	$0	$6,896	-$496
Residential parking	$6,400	$6,400	$0	$6,896	-$496
Parking subsidies	$6,080	$6,080	$0	$6,551	-$471
Roadway costs	$5,600	$5,600	$0	$6,034	-$434
Congestion	$3,360	$3,360	$0	$3,620	-$260
Barrier effect	$1,440	$1,440	$0	$1,552	-$112
Noise	$1,120	$1,120	$0	$1,207	-$87
Totals	$75,200	$75,200	$0	$81,030	-$5,830
Consumer surplus gain			$0		$190
Net benefits[9]			$3,525		-$3,635
Cost per tonne CO^2 reduced[10]			$127		$181
Net cost per tonne CO^2 reduced[11]			-$492		$725

Considering rebound effects significantly reduces the estimated net benefits of fuel efficiency standards.

Ignoring rebound effects, this policy is estimated to save 3,072 total liters of fuel which reduces 7.2 tonnes of carbon emissions, and provides $4,432 fuel-related cost savings, or $3,525 net benefits (savings minus incremental production costs), indicating direct costs of $127 per tonne of emission reduction (incremental production costs divided by tonnes of CO^2 reduced), or considering all impacts, $492 net *benefits* per tonne of emission reduced. This suggests that CAFE standards are cost effective and benefit society overall.

[8] *Comprehensive Emission Reduction Evaluation Spreadsheet* (www.vtpi.org/CERE.xls).
[9] Fuel savings minus incremental vehicle travel and production costs.
[10] Incremental production costs divided by carbon reductions.
[11] Net benefits divided by carbon reduction.

Comprehensive analysis considers the following rebound effects:

- Assuming a -0.3 long-run elasticity of vehicle travel with respect to fuel price, the 26% fuel cost reduction increases average annual vehicle travel approximately 8%, so lifetime emission reductions decline from 7.2 to 5.0 tonnes.
- The 8% increase in vehicle travel imposes additional costs estimated at 47.0¢ per vehicle-kilometer in total or 14.7¢ considering just external costs.
- The additional vehicle travel provides consumer benefits estimated to be worth $190 based on the rule-of-half (per-kilometer savings times additional vehicle travel divided in half).

Incorporating these impacts significantly changes analysis results. Fuel saving decline to 2,150 total liters, emission reductions decline to 5.0 tonnes of CO^2, fuel-related savings decline to $3,102, net benefits become negative (fuel-related savings are more than offset by increased vehicle-travel-related externalities and additional production costs), indicating direct costs of $181 per tonne of CO^2 reduced, or considering all impacts, $725 net *costs* per tonne reduced. This suggests that this policy is inefficient and overall harmful to society.

This analysis illustrates how ignoring rebound effects exaggerates cleaner vehicle strategy benefits. Different assumptions would change the magnitude of these conclusions but not their direction. An analysis could make fuel efficiency standards appear more cost effective by using a lower elasticity of vehicle travel with respect to fuel prices, higher values for fuel-related savings, lower values from vehicle-travel-related costs, and exclude all mileage-related user costs.[12] On the other hand, this analysis excludes some vehicle-travel-related costs, such as increased sprawl costs, and so understates total rebound incremental costs.

[12] In general, if an emission reduction strategy *allows* consumers to choose a more efficient or alternative fueled vehicle but imposes no penalty to those who choose conventional vehicles, both user (such as fuel savings) and external benefits should be included in benefit calculations. If a strategy forces consumers to choose such vehicles through regulations or penalties, only external benefits should be included in benefit calculations, since consumers would evidently prefer whatever attribute they lost (performance, status, etc.) over fuel savings. Many strategies have both positive and negative consumer impacts, for example, by improving the quantity and affordability of efficient and alternative fuel vehicles while also increasing taxes on fuel intensive vehicles, so a portion of user savings should be included in benefit calculations.

Public Transport Service Improvements

This example applies comprehensive evaluation to public transit service improvements. Moore, Staley and Poole's (2010) conclude that public transit improvements are an inefficient emission reduction strategy, costing $833 per tonne of CO^2 reduced. However, their evaluation only considers relatively expensive transit service improvements and only considers emission reduction benefits. The following uses a more comprehensive evaluation framework.

Assume a public transit improvement (increased service frequency, speed or comfort, or reduced fares) that requires $1 million annual subsidy would shift 1,000 daily automobile commute trips to transit, resulting in 7.2 million urban-peak vehicle-kms reduced (assuming 30 kilometers 240 annual days). If those vehicles average 150 grams of CO^2 equivalent per kilometer the emission reductions average about 1.0 tonnes per commute-year, costing a relatively high $1,000 per tonne of CO^2 reduced, similar to Moore, Staley and Poole's estimate. This implies that transit improvements are inefficient emission reduction strategies.

However, transit improvements that attract traveler who would otherwise drive can provide additional savings and benefits (Litman 2011). Avoided urban-peak automobile commutes can typically $4.00-8.00 in parking costs, $2.00-4.00 in congestion or roadway expansion costs, $2.00-3.00 in fuel costs (net taxes, which are an economic transfer), $1.00-3.00 in crash risk costs, $1.00-2.00 in petroleum externalities, $1.00-2.00 in vehicle ownership costs (assuming 10% of new transit riders are able to reduce their household vehicle ownership), $0.50-1.50 in mileage-based vehicle depreciation, $0.50-1.50 in local air pollution costs, and 18¢ worth of carbon emissions (Litman 2009; Maibach, et al. 2008). In addition, transit service improvements directly benefit existing users, improve mobility options for non-drivers, help support strategic land use development objectives (smart growth), and improve public fitness and health (since transit travel tends to increase walking). This indicates that urban-peak commute trips shifted from automobile to public transit typically provide $18.68 worth of total monetized benefits, plus additional non-monetized benefits.

Using these estimates, shifting 1,000 urban-peak commuters from driving to public transit provides about $4.5 million in monetized benefits, plus additional non-monetized benefits, as illustrated in Table 9. Climate change emission reductions are among the smallest of these benefits. Since other benefits exceed the $1.0 million subsidy costs, the climate change emissions can be considered free, making this a win-win emission reduction strategy.

Even larger benefits can result if public transit improvements leverage additional vehicle travel reductions by helping create more compact, multi-modal communities where residents tend to reduce their vehicle travel and rely more on walking, cycling and public transit. Studies indicate that high quality transit tends to leverage 3-9 vehicle-miles reduced per additional transit-passenger-kilometer (ICF 2008; Litman 2011). Non-commute trips tend to be shorter and occur during off-peak periods, and so reducing them tends to provide smaller but still significant savings and benefits, estimated to average $4.80 per round trip reduced. In this example, if each additional transit commute trip leverages a reduction in three non-commute vehicle trips, net benefits approximately double.

Table 9 **Benefits Of Reduced Urban-Peak Automobile Trip**[13]

Benefits Per Automobile Trip Reduced	Commute Trips	Other Trips	Totals
Direct Benefits			
Parking cost savings	$6.00	$1.00	
Congestion reduction/Roadway savings	$3.00	$1.00	
Fuel savings (net taxes)	$2.50	$0.83	
Traffic safety	$2.00	$0.67	
Reduced resource externalities	$1.50	$0.50	
Vehicle ownership savings	$1.50	$0.00	
Local pollution reduction	$1.00	$0.33	
Reduced mileage-based depreciation	$1.00	$0.33	
Climate change emission reductions	$0.18	$0.06	
Improved user convenience and comfort	NA	NA	
Improved mobility options for non-drivers	NA	NA	
Land use objectives (supports smart growth)	NA	NA	
Improved public fitness and health	NA	NA	
Totals	*$18.68*	*$4.73*	
Leverage factor[14]		3.0	
Total reduced auto trips	1,000	3,000	
Average route-trip distance (kilometers)	30	10	
Average annual commute days	240		
Total automobile trips reduced	240,000	720,000	$960,000
Total vehicle-kilometers reduced	7,200,000	7,200,000	14,400,000
Value of reduced automobile travel	$4,483,200	$3,403,200	$7,886,400
Emissions reduced (tonnes CO2)	1,800	1,800	3,600
Cost Per Tonne	$556	$556	$278
Total Benefits	$4,483,200	$3,403,200	$7,886,400
Benefit/Cost Ratio	4.5	3.4	7.9
Annual Net Benefits	$3,483,200	$3,403,200	$6,886,400

Public transit service improvements tend to provide various benefits. High quality public transit that attracts large numbers of discretionary travelers and helps stimulate transit-oriented development tends to leverage additional vehicle travel reductions and benefits.

This analysis illustrates how more comprehensive evaluation can result in very different conclusions about the cost efficiency of improving transport options. Emission reductions are one of the smaller benefits of public transit improvements so analyses that only consider them will significantly underestimate the cost efficiency and total benefits of such policies.

[13] *Comprehensive Emission Reduction Evaluation Spreadsheet* (www.vtpi.org/CERE.xls).
[14] Non-commute trips reduced per additional transit commute trip.

Pricing Reforms

Mobility management pricing reforms include increased road and parking pricing, distance-based vehicle insurance and registration fees, and fuel tax increases. These strategies tend to increase economic efficiency by making prices more accurately reflect the full costs of providing roads, parking, insurance and fuel. They correct existing market distortions that result in economically excessive vehicle travel (Litman 2006). In the U.S., efficient pricing would require additional roadway user fees averaging 2-4¢ per vehicle-kilometer, additional parking fees averaging 6-12¢ per vehicle-kilometer, distance-based insurance and registration fees averaging 6-8¢ per vehicle-kilometer, plus higher fuel taxes to reflect production and pollution externalities (Litman 2009). In total these reforms would increase average operating costs more than 14-24¢ per vehicle-kilometer, more than doubling current vehicle operating costs (Litman 2010; Parry, Walls and Harrington 2007). Such price increases are likely to reduce vehicle travel by 20-40% (Goodwin, Dargay and Hanly 2004; Gillingham 2010; Litman 2012), and more if implemented with supportive policies such as transit service improvements.

Vehicle travel underpricing tends to impose additional indirect costs by reducing demand for alternative modes which have scale economies, and stimulating sprawl. For example, underpricing urban automobile travel reduces demand for walking, cycling and public transit, which reduces the economic and political justification for improving non-motorized facilities and transit service quality. It also leads to more dispersed land use development, resulting in more destinations that are difficult to access without a car. As a result, underpricing vehicle travel tends to reduce mobility options for non-drivers.

Conventional evaluation tends to recognize transport price distortions but considers them individually and so underestimates their total impacts, and total pricing reform benefits. For example, many economists consider traffic congestion a symptom of underpricing and so advocate congestion pricing, and pollution a symptom of emission underpricing and so advocate higher fuel taxes and emission fees. However, few economists have evaluated the cumulative and interactive effects of these distortions, such as how roadway underpricing also increases parking costs, accidents, and pollution problems, or conversely, how more efficient parking pricing can help reduce traffic congestion, accidents, and pollution emissions. More comprehensive evaluation recognizes the total effects of market distortions and therefore the total benefits of pricing reforms. Because they stimulate vehicle travel, these market distortions increase the justification for mobility management on second-best grounds. For example, road and parking underpricing increase the justification for public transit subsidies as a second-best solution to reducing the resulting traffic and parking problems.

Examples of Incomplete Evaluations

Studies that favor cleaner vehicle strategies often ignore some of the most highly rated mobility management strategies. For example, Moore, Staley and Poole (2010), and Cox and Moore (2011) ignore fuel tax increases, distance-based vehicle insurance and registration fees, efficient parking pricing, and public transit priority, which are considered particularly cost-effective energy conservation and emission reduction strategies (Litman 2007, USDOT 2009). Table 10 compares the mobility management strategies considered by Moore, Staley and Poole (2010), Cox and Moore (2011), and Cambridge Systematics (2009).

Table 10 **Mobility Management Strategies Considered**

Strategy	M, S & P	Cox & Moore	Cam. Sys
Car-free planning and vehicle restrictions	✓		
* Commute trip reduction programs		✓	✓
* Distance-based vehicle insurance and registration fees			✓
* Distance-based emission fees			✓
* Efficient parking management and pricing			✓
* Freight transport management			✓
* Fuel tax increases			✓
Mobility management marketing			✓
* Non-motorized transportation improvements	✓	✓	✓
* Ridesharing improvements and incentives	✓	✓	✓
* Road pricing	✓	✓	✓
* Smart growth development policies	✓	✓	✓
Telework encouragement	✓	✓	✓
* Transit improvements and incentives	✓	✓	✓

*Moore, Staley and Poole (M,S&P) and Cox and Moore overlook many of the mobility management strategies considered most effective at conserving energy and reducing emissions, identified with an *.*

Much of the difference between advocates of cleaner vehicle and mobility management emission reduction strategies reflects different assumptions about the nature of travel demands and consumer preferences. Mobility management critics assume that automobile travel is always preferred and most efficient, so reducing vehicle travel is difficult and requires either high disincentives or large subsidies for alternatives. Mobility management advocates argue that high levels of vehicle travel may reflect inadequate alternatives that in many situations, vehicle travel reductions benefits users and the economy.

For example, Moore, Staley and Poole (2010) state that, "Curtailing mobility reduces the tangible welfare of individuals and households by limiting housing and transportation choice, increasing travel times, reducing productivity, and subsequently household incomes." But many mobility management strategies directly benefit consumers by improving their transport options or providing financial rewards, as indicated in Table 11. Most negative incentives are price increases, the overall impacts of which depend on how revenues are used. For example, even motorists who reduce their vehicle travel due to higher user fees may benefit overall if the revenues reduce other taxes or provide new services, as well as reducing the congestion, accident risk and pollution imposed on motorists.

Table 11 **Mobility Management Direct User Impacts**

Positive	Mixed	Negative
Public transit improvements	Smart growth	Road tolls
Walking and cycling improvements	New urbanism	Parking pricing
Rideshare and carshare programs	Parking management	Fuel tax increases
Flextime and telework	Transit oriented development	Vehicle travel restrictions
Distance-based pricing	Car-free planning	
Parking cash out and unbundling	Traffic calming	

Most mobility management strategies have positive or mixed direct user impacts, and even negative incentives can benefit users overall if the revenues reduce other taxes or problems such as congestion, accident and pollution damages.

Pozdena (2009) claims that positive correlations between energy consumption, vehicle travel and economic productivity prove that policies that reduce vehicle travel reduce economic productivity. However, theoretical and empirical evidence indicate that appropriate mobility management strategies actually increase economic productivity by correcting market distortions (Litman 2006), achieving agglomeration efficiencies (Graham 2007), and reducing costs (Concas and Winters 2007). Per capita GDP tends to increase in urban regions with lower per capita vehicle travel, higher public transit mode share, higher development densities, and higher fuel prices, outcomes that mobility management tends to support but cleaner vehicle strategies tend to contradict if they induce vehicle use and sprawl (Kooshian and Winkelman 2011; Litman 2008).

Much of this criticism can actually justify more rather than less mobility management implementation. For example, the Puget Sound *Traffic Choices Study* (PSRC 2005) found commute travel price elasticities are four times higher than average for commuters with high quality public transit service, and both Gillingham (2010) and Guo, et al. (2011) found that households more accessible, transit-oriented communities are much more price sensitive than comparable households in sprawled, automobile-dependent communities, indicating that an integrated program of pricing reforms, improvements to alternative modes and smart growth development policies are most effective and beneficial overall.

Current demographic and economic trends (aging population, rising fuel prices, increasing urbanization, changing consumer preferences, increasing health and environmental concerns) are reducing demand for automobile travel and increasing demand for other modes. For example, as the share of seniors increases and people care more about being physically active, consumer demands for walking, cycling and public transit is likely to increase, provided that they are responsive to users with features that emphasize convenience, safety and affordability. Similarly, an increasing portion of commuters would value parking cash out and distance-based insurance if it provides financial savings for using alternative modes. As a result, the direct user benefits of these strategies are likely to increase in the future.

Conclusions

There are many possible ways to conserve energy and reduce pollution emissions. For this analysis they are divided into *cleaner vehicle* strategies that reduce emission rates per vehicle-kilometer, and *mobility management* strategies that reduce total vehicle travel. How such policies are evaluated can significantly affect their estimated value to users and society. Incomplete analysis can lead to selection of strategies that are not overall optimal, resulting in society bearing two dollars of costs to achieve one dollar's worth of benefits.

Comprehensive energy conservation and emission reduction evaluation should consider:

- *Diverse strategies.* These should include various mobility management strategies, especially those identified as particularly effective at conserving energy and reducing emissions, plus integrated packages that take advantage of some strategies' complementary effects.
- *All significant impacts.* Analysis should consider impacts on traffic congestion, road and parking facility costs, consumer costs and affordability, accidents, mobility options for non-drivers, land use development patterns, and public fitness and health, in addition to energy conservation and emission reductions.
- *Rebound effects.* Account for the tendency of increased vehicle fuel efficiency, cheaper alternative fuels and roadway expansion to induce additional vehicle travel, and the resulting increase in fuel consumption and emissions, additional external costs of the induced travel, and additional consumer benefits.
- *Lifecycle analysis.* Analysis should account for all energy consumption and emissions, including those embodied in vehicle and fuel production.
- *Additional energy savings.* Analysis should account for additional energy savings that result from congestion reductions (from pricing reforms and grade-separated high-occupant vehicles), and from leveraged travel effects (from high quality public transit).
- *Economic transfers.* Analysis should account for all economic transfers, including additional revenues from price increases, and user savings from increased transit subsidies.
- *User impacts.* Analysis should recognize the direct user benefits from strategies that improve transport and location options, or which provide positive incentives to reduce vehicle travel, such as parking cash-out and distance-based pricing.

Analyses that ignore these factors tend to exaggerate cleaner vehicle benefits and undervalue mobility management strategies. Examples in this article show how ignoring rebound and lifecycle impacts tends to exaggerate CAFE standard net benefits, and ignoring co-benefits tends to undervalue public transit improvements. Similarly, ignoring existing market distortions and economic transfers tends to undervalue pricing reforms.

Critics sometimes claim that mobility management strategies provide small and unreliable energy conservation and emission reduction benefits, but such claims do not reflect current knowledge. The ability to model travel and emission impacts is improving, augmented by numerous examples and case studies of mobility management policies and programs.

The analysis described in this paper uses a -0.3 long-run elasticity of vehicle travel with respect to operating costs. This is a normal value for most times and places, but some studies found lower values between 1970 and 2000 in the U.S., which cleaner vehicle advocates cite as evidence that rebound effects are insignificant, and that pricing reforms are ineffective and harm consumers. However, those low elasticity values can be explained by unique demographic and economic factors that stimulated vehicle travel demand and reduced fuel costs relative to incomes. Most of these factors have since reversed; more recent studies indicate that U.S. transport elasticities have returned to normal levels.

Studies that favor cleaner vehicle over mobility management strategies (Cox and Moore 2011; Hartgen, Fields and Moore 2011; Moore, Staley and Poole 2010) tend to:

- Consider a relatively limited set of mobility management strategies and ignore many methods considered most effective at conserving energy and reducing pollution emissions.
- Fail to use lifecycle analysis or consider rebound effects, and so exaggerate cleaner vehicle strategy net benefits.
- Ignore mobility management co-benefits, although they mention roadway expansion co-benefits.
- Treat pricing reforms as costs rather than economic transfers.
- Ignore direct user benefits from improved alternative modes and smart growth development.

Comprehensive analysis can help identify win-win emission reduction strategies, which provide multiple benefits and opportunities for cooperation among interest groups. For example, comprehensive analysis can identify the emission reduction strategies that should be supported by transport agencies that want to reduce congestion, public health organizations that want to improve public fitness, and consumers that want savings and affordability.

This does not mean that all mobility management strategies are cost effective and optimal, but it does suggest that they can provide much greater total benefits than generally recognized. Comprehensive evaluation, as recommended in this article, is the key to identifying truly optimal solutions to transport problems.

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