

# Cost-effectiveness of reductions in greenhouse gas emissions from High-Speed Rail and urban transportation projects in California



Juan M. Matute<sup>a,\*</sup>, Mikhail V. Chester<sup>b,1</sup>

<sup>a</sup> Institute of Transportation Studies, University of California, Los Angeles, 3320 Public Affairs Building, Mailcode #951656, Los Angeles, CA 90095-1656, USA

<sup>b</sup> Civil, Environmental, and Sustainable Engineering, Arizona State University, 660 S College Avenue, Tempe, AZ 85287-3005, USA

## ARTICLE INFO

### Article history:

Available online 7 September 2015

### Keywords:

California  
High-Speed Rail  
Greenhouse gas  
Cap-and-trade  
Bus rapid transit  
Light rail transit  
Life-cycle assessment  
Economic assessment

## ABSTRACT

A rising trend in state and federal transportation finance is to invest capital dollars into projects which reduce greenhouse gas (GHG) emissions. However, a key metric for comparing projects, the cost-effectiveness of GHG emissions reductions, is highly dependent on the cost-benefit methodology employed in the analysis. Our analysis comparing California High-Speed Rail and three urban transportation projects shows how four different accounting framings bring wide variations in cost per metric tonne of GHG emissions reduced. In our analysis, life-cycle GHG emissions are joined with full cost accounting to better understand the benefits of cap-and-trade investments. Considering only public subsidy for capital, none of the projects appear to be a cost-effective means to reduce GHG emissions (i.e., relative to the current price of GHG emissions in California's cap-and-trade program at \$12.21 per tonne). However, after adjusting for the change in private costs users incur when switching from the counterfactual mode (automobile or aircraft) to the mode enabled by the project, all investments appear to reduce GHG emissions at a net savings to the public. Policy and decision-makers who consider only the capital cost of new transportation projects can be expected to incorrectly assess alternatives and indirect benefits (i.e., how travelers adapt to the new mass transit alternative) should be included in decision-making processes.

© 2015 Elsevier Ltd. All rights reserved.

## Introduction

As California establishes its greenhouse gas (GHG) emissions cap-and-trade program and considers options for using the new revenues produced under the program, the public and decision-makers have access to tenuous information on the relative cost-effectiveness of passenger transportation investment options. Toward closing this knowledge gap, the cost-effectiveness of GHG reductions forecast from High-Speed Rail are compared with those estimated from recent urban transportation projects (specifically light rail, bus rapid transit, and a bicycling/pedestrian pathway) in California.

Under California's cap-and-trade system, major emitters of GHGs must purchase or otherwise acquire a quantity of allowances equivalent to their emissions. The California Air Resources Board, which administers California's cap-and-trade

\* Corresponding author. Tel.: +1 562 546 2831.

E-mail addresses: [jmatute@ucla.edu](mailto:jmatute@ucla.edu) (J.M. Matute), [mchester@asu.edu](mailto:mchester@asu.edu) (M.V. Chester).

URLs: <http://www.lewis.ucla.edu/people/staff/juan-matute/> (J.M. Matute), <http://chester.faculty.asu.edu/> (M.V. Chester).

<sup>1</sup> Tel.: +1 480 965 9779.

program, issues allowances via both regular auctions and free allocations. Each allowance unit grants the bearer the right to emit one metric tonne of carbon dioxide equivalent (CO<sub>2</sub>-e) in California, and the allowance must be surrendered to the Air Resources Board according to regulations. California's cap-and-trade system generates revenues for the state's Greenhouse Gas Reduction Fund. Existing law requires expenditures from this fund to reduce GHG emissions in California, but grants the Legislature leeway in choosing between opportunities that reduce GHG emissions.

The cost-effectiveness of a GHG reduction opportunity is one criterion which can be used to compare among expenditure alternatives. Cost-effectiveness is expressed as dollars expended (or saved) per metric tonne of CO<sub>2</sub>-e reduced. The current price of an allowance serves as a marker for evaluating a reduction opportunity's cost-effectiveness. Allocating auction revenues to opportunities that achieve reductions in GHG emissions at a per-tonne cost that is lower than the allowance price allows California to move toward its GHG goals at a lower public and private cost. Allocating cap-and-trade revenues to reduction opportunities that reduce GHG emissions at a per-tonne cost greater than the allowance price likely means that some of the regulated emitters could reduce emissions more cost-effectively. Thus, allocating Greenhouse Gas Reduction Funds to opportunities that are less cost-effective than the allowance price could lead to lesser reductions in GHG emissions at a greater cost to California. As of March, 2015 prices for California allowances were \$12.21 per metric tonne of CO<sub>2</sub>-e ([California Air Resources Board, 2014](#)).

The cost at which a project can reduce a metric tonne of GHG emissions should not be the sole criterion upon which a transportation project is evaluated. All projects produce ancillary effects and projects produce many co-benefits other than GHG emissions reductions. Transportation projects create new mobility and land use opportunities that can be beneficial independent of any reductions in GHG emissions. They also produce changes in other environmental impacts such as conventional air pollutants ([Chester et al., 2013](#)). However, because Greenhouse Gas Reduction Fund revenues are generated from a market-based mechanism (cap-and-trade), the cost-effectiveness of GHG reductions should be a key consideration in allocating California State expenditures.

But how should analysts evaluate the cost-effectiveness of GHG reductions from transportation projects? Choices to determine which monetary costs and which sources of emissions are included within the analysis can affect the results of the analysis. Whereas a public agency may only consider capital dollars invested, adding costs such as those associated with the building, owning, and operating of a transportation facility during its life-cycle and changes in private costs to use the transportation facility can greatly affect results. Our analysis highlights how the choice of accounting framing impacts the cost-effectiveness of GHG reductions.

Expansion of long-distance and local public transit systems are being promoted in California, a state where increasing air and automobile congestion has resulted in large fuel and time costs ([Resource Systems Group, 2010](#); [Texas A&M Transportation Institute, 2013](#)). In addition to High-Speed Rail (which is on track for construction to break ground but is facing many legal and financial barriers), new urban transit systems, particularly in the Los Angeles area, are being extensively deployed. Since the passage of an additional ½-cent sales tax in 2008, Los Angeles Metro has completed or started construction on 2 new bus rapid transit and 4 rail lines or extensions with plans to break ground on at least 4 additional rail lines or extensions by 2020. The healthy interest in public long-distance and local transit underscores the challenges the state faces with a growing population and aging infrastructure.

The California High-Speed Rail (CAHSR) project continues to evolve, as is evident in the substantial differences between the 2012 Final and 2014 Draft Business Plans. The CAHSR Authority expects substantial change in passengers diverted from air, down from 17.23% in 2012 ([California High-Speed Rail Authority, 2012a, 2012b](#)) to 5.85% in 2014 ([California High Speed Rail Authority, 2014a, 2014b](#)). This is a shift from 5.1 M diverted air trips in 2040 under the Authority's 2012 benefit-cost analysis ([California High-Speed Rail Authority, 2012a, 2012b](#)) to 2.0 M diverted air trips in 2040 under the Authority's Draft 2014 plan ([California High Speed Rail Authority, 2014a, 2014b](#)). Furthermore, the average length of an avoided automobile trip avoided due to CAHSR changed from 150 miles (240 km) under the Authority's 2012 benefit-cost analysis ([California High-Speed Rail Authority, 2012a, 2012b](#)) to 118 miles (188 km) in 2014 ([California High Speed Rail Authority, 2014a, 2014b](#)). According to the Authority, "[t]he new [ridership forecast] results reflect recent data that projects an increase in the total number of trips people will take, but also a reduction in the average length of their trips compared to the data used for the 2012 Business Plan forecasts" ([California High Speed Rail Authority, 2014a, 2014b](#)).

Because of the continued uncertainty surrounding the future CAHSR project versus the established urban transit projects, we perform sensitivity analyses on major factors that affect per-tonne GHG reduction costs. We compare our results for CAHSR with three recent urban transportation projects in Los Angeles County:

- Phase I of the Metro Orange Line Busway, a \$339M bus rapid transit (BRT) project in the San Fernando Valley that opened in 2005;
- The Metro Bicycle and Pedestrian Pathway, a \$10.6M bicycle and pedestrian facility that opened alongside the Orange Line Busway in 2005; and,
- Phase I of the Metro Gold Line Light Rail Transit (LRT), a \$859M project that connects Los Angeles Union Station with Pasadena, and which opened in 2003.

## Materials and methods

We join an economic assessment with life-cycle GHG assessments using several existing seminal studies and our own life-cycle assessment (LCA) of biking/walking infrastructure. Where possible, bounding analyses are performed to capture the range of potential GHG reduction costs outcomes.

## Calculations

### *Economic assessment*

We evaluate costs and benefits using four cost allocation techniques:

- public subsidies for capital costs;
- public subsidies for operations after the project has been constructed and ridership has stabilized (in decade 2 for Gold LRT & Orange BRT, in decade 3 for CAHSR);
- the full public subsidy required to construct and operate the project; and,
- the full public subsidy required to construct and operate the project, adjusted by the net economic savings from the transportation project's users who shift from automobiles or aircraft.

We use various estimates to calculate the public subsidy needed for capital and operating costs for each project. For CAHSR, we primarily used economic cost and ridership estimates from the 2012 Revised High-Speed Rail Business Plan ([California High-Speed Rail Authority, 2012a, 2012b](#)) and its source reports, but we do incorporate some results from the 2014 Draft Business Plan ([California High Speed Rail Authority, 2014a, 2014b](#)) in our sensitivity analysis. Given the uncertainty with High-Speed Rail forecasts, we also introduce an alternate forecast from the Reason Foundation ([Reason Foundation, 2008, 2013](#)), an organization which has been critical of the California project, and whose estimates often show higher costs for construction and operation of the project. For projects in Los Angeles County, we use capital cost data from the Los Angeles Metropolitan Transportation Authority ([Los Angeles County Metropolitan Transportation Authority, 2003, 2005](#)). Few mass transportation systems (public or private) are profitable as travel is most often considered to be a derived demand. Operating transit service in California typically requires a public subsidy in excess of fare payments from users. Our figures on operation subsidies for the Gold LRT and Orange BRT lines were calculated using data from the Federal Transit Administration's National Transit Database ([Federal Transit Administration, n.d.](#)).

To compare expenditures in different years, we adjust all costs to 2012 dollars. For past expenditures for urban transit projects, we use the U.S. Bureau of Labor Statistics CPI data ([U.S. Bureau of Labor Statistics, 2014](#)) to adjust 2003 (Gold LRT) and 2005 (Orange BRT) capital expenses to 2012 dollars. We incorporate these 2012-dollar-adjusted capital cost totals for the Gold LRT line (\$1071.85M) the Orange BRT line (\$398.53M) and a Bicycle/Pedestrian Pathway (\$12.461M), into our analysis.

Because the Bicycle/Pedestrian Pathway serves recreational purposes that go beyond functional mobility needs, in a proportional analysis we allocate a fraction of the economic costs and emissions from initial construction. We choose 4.49%, as this is the proportion of total pathway users who now make trips by bicycle without using the Orange BRT line ([Los Angeles County Metropolitan Transportation Authority, 2011](#)). In considering net savings to these users for the full public cost, less private savings scenario, we assume an average bicycle cost of \$500 and an average lifetime of 5 years. No financial costs are considered for reconstruction as significant asphalt impacts are not expected, but 4.49% of reconstruction emissions are assigned to the pathway project.

For the future expenditures of CAHSR, we use the Authority's assumed inflation rates of 1% in 2012, 2% in 2013–2015, and 3% after 2016 ([California High-Speed Rail Authority, 2012a, 2012b](#)). Using these figures, we find a total capital cost of \$53.338B. The Authority plans to finance the project with \$8.916B (in 2012 dollars) from private capital and \$175M (in 2012 dollars) in cash flow from operations, and subtracting these non-public contributions we find a required public capital subsidy of \$44.247B. According to the 2012 Business Plan ([California High-Speed Rail Authority, 2012a, 2012b](#)) CAHSR will require no public operating subsidy.

For users who shift to using a transportation project from another mode, we consider private user costs incurred and avoided in our "Full Public Cost, Less Net User Cost" allocation results. These methods are detailed in the following subsections.

### *Mode shift assessment*

Both the economic assessment and LCA rely on mode-shift estimates and forecasts. Mode-shift refers to the change in transportation mode used to make trips before the transportation facility was completed (or if the facility did not exist) versus the mode used after the transportation facility is completed. Because of sensitivity to project-specific conditions, especially mode-shift, our overall results are not generalizable to all transportation projects in the state. Diverting automobile users to transit is the primary driver of the cost-effectiveness of GHG emissions reductions for urban transportation projects.

Table 1 shows our assumptions for mode-shift for the Los Angeles County transportation projects. Data on mode-shift and use for the Orange BRT line and Bicycle/Pedestrian Pathway come from a study conducted by the Los Angeles County Metropolitan Transportation Authority (Los Angeles County Metropolitan Transportation Authority, 2011). Data on 2009 mode-shift for the Gold LRT line come from Los Angeles County Metropolitan Transportation Authority (Los Angeles County Metropolitan Transportation Authority, 2004) and 2035 projections are from Chester et al. (2013) who use 2035 ridership forecasts from Los Angeles Metro.

Using figures from the CAHSR's 2012 Cost-Benefit Analysis (2012b), we calculate that 17% of passengers would come from air, 81% would come from automobiles, and 2.1% of trips would be induced to the new system. Using data from the CAHSR Authority (California High Speed Rail Authority, 2014a, 2014b) we calculated an average trip distance of 150 miles (242 km) for the 81% of High-Speed Rail users shifting from automobiles.

Data on use of the Bicycle/Pedestrian Pathway come from a study conducted by the Los Angeles County Metropolitan Transportation Authority (Los Angeles County Metropolitan Transportation Authority, 2011). Approximately 4.49% of Orange Bicycle/Pedestrian Pathway users are cyclists who do not use the bus and previously used an automobile for their trip (Los Angeles County Metropolitan Transportation Authority, 2011). This is a small fraction of the 41.5% of pathway cyclists who use their bicycles to access the Orange BRT line (Los Angeles County Metropolitan Transportation Authority, 2011).

For the Metro projects in Los Angeles County, we consider avoided automobile costs at the IRS Standard Mileage Rate of \$0.555/mile (\$0.34/km) (U.S. Internal Revenue Service, 2012), less Metro's current fare of \$1.50 (Los Angeles County Metropolitan Transportation Authority, 2014). For CAHSR, we subtract the calculated average fare of \$52.75 (California High-Speed Rail Authority, 2012a, 2012b) from avoided air travel at \$97/trip (California High-Speed Rail Authority, 2012a, 2012b) and avoided automobile trips at \$0.555/mile (U.S. Internal Revenue Service, 2012). This is in contrast with the CAHSR Authority (2012b), which used an estimate for avoided automobile costs of \$0.24 per mile (\$0.15/km). The American Automobile Association produces alternative per-mile automobile cost estimates that range from \$0.449 per mile (\$0.28/km) for a small sedan to \$0.757 per mile (\$0.47/km) for a sports utility vehicle (American Automobile Association, 2012). For the Gold LRT and Orange BRT lines, passengers did switch from existing local service to these higher capacity and faster new lines, however, Los Angeles Metro did not reduce local service so costs and emissions are assumed to have stayed the same (Chester et al., 2013).

While we consider the public's operating subsidy for all passengers, we offset private costs only for users who previously used another mode for the trip. In the case of the Orange BRT line, this means that we include 100% of the public subsidy needed to operate the line but only adjust for the net private costs (fares less savings from avoided automobile use) for the 25% of users who would have traveled in an automobile if the line were not in operation (52% predicted after decade 3) (Chester et al., 2013). We do not consider transit fares for those who shifted to the Orange BRT line from transit nor fares from the new (induced) trips that passengers make because of the new line.

Indirect economic costs are not included in the analysis due to a dearth of high quality data and the challenges of accurately modeling vehicle travel across the state and future power grid operation. Costs including changes in health damages due to, e.g., air emissions exposure, and oil displacement costs (including the risk of losses due to oil supply disruptions, monopsony premium, and oil security policies) cannot be easily or accurately quantified and are therefore excluded. While challenging to quantify based on the complexity of behavior and energy systems, these costs are indeed real and can be significant (Mashayekh et al., 2011). The air quality morbidity and mortality benefits of avoided automobile travel in California cities due to transit can be expected to be larger than those avoided in less dense areas due to CAHSR (Muller, 2011). These costs would potentially be countered by increases in electricity generation for train propulsion (which may occur outside of the state because California is a net importer of electricity) and the combustion of fuels for bus travel. There is a wide range on oil displacement benefits estimates for US fuel market changes (Michalek et al., 2011) and accurately and meaningfully quantifying these effects for California's niche fuel market is beyond the scope of this analysis. As such, we do not include these indirect cost categories.

We use Eqs. (1) and (2) to estimate net user costs resulting from mode shift.

Economic assessment of avoided automobile trips

$$C_{\text{AUTO}} = U_{\text{SHIFT}} * D * R \quad (1)$$

where

$C_{\text{AUTO}}$  = cost of avoided automobile trips.

$U_{\text{SHIFT}}$  = number of users shifting from automobiles.

$D$  = distance of competing automobile trip (miles).

$R$  = IRS mileage rate (\$/mile).

**Table 1**  
Los Angeles County projects – estimated mode shift from automobiles.

	2009	2035
Orange BRT line	25%	52%
Bicycle/Pedestrian Pathway	4.49%	4.49%
Gold LRT line	67%	80%

### Economic assessment of avoided air trips (for High-Speed Rail)

$$C_{\text{AIR}} = U_{\text{SHIFT}} * Y \quad (2)$$

where

$C_{\text{AIR}}$  = cost of avoided air travel.

$U_{\text{SHIFT}}$  = number of users shifting from air.

$Y$  = air travel ticket cost.

### Greenhouse gas emissions assessment

GHG reductions are evaluated using LCA and include vehicle (manufacturing and maintenance), infrastructure (construction, operation, and maintenance), and energy production processes in addition to propulsion. The analyses were developed by the authors in a series of studies that have assessed the life cycle impacts of new long-distance and local mass transit service in California. In general, we start by estimating the emissions to construct the project and operate the transportation facility and then subtract the net savings from users who switch from other modes. In all but the marginal case (operations subsidy in decade 2 or 3), we evaluate net GHG emissions over a 100-year period. For the LCA of GHG emissions reductions associated with each transportation project, we used previously conducted studies on CAHSR (Chester and Horvath, 2012) and the LA Metro Gold LRT and Orange BRT lines (Chester et al., 2013). We use the infrastructure construction, operation, and maintenance results for the three transit lines from the two studies in combination with the average transit ridership adoption scenario. For each study, the sensitivity of GHG emissions to transit adoption was evaluated including the emissions from the propulsion of new transit modes (and how many vehicle trips would occur under varying levels of adoption), the avoided use of automobiles, and the avoided life-cycle effects of less automobile travel. Given that the systems are new, the avoided automobile trip is assumed to occur in a vehicle with a fuel economy that reaches 54.5 mi/gal (23.17 km/l) by 2035, consistent with emerging federal standards (U.S. Environmental Protection Agency, 2012).

We develop an LCA of bicycle travel on the Bicycle/Pedestrian Pathway that includes bicycle manufacturing and maintenance as well as infrastructure construction and reconstruction. A representative bicycle LCA was not identified so the life cycle effects for Los Angeles travel are estimated. The manufacturing and maintenance of an aluminum frame 37 lb (17 kg) bicycle is modeled in SimaPro 8.0.3 assuming that manufacturing of materials occurs in China and retail in California (PRé Consultants, 2013). The resulting manufacturing GHG emissions are 110 kg CO<sub>2</sub>-e and maintenance 18 kg CO<sub>2</sub>-e over the bicycle's lifetime of 2500 miles (4023 km). The Bicycle/Pedestrian Pathway consists of approximately 14 miles (22.5 km) of a predominantly asphalt surface, approximately 14 feet (4.26 m) wide. A pavement LCA of the construction and maintenance of this surface is developed using the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (Horvath, 2003). Assuming 3 in. (7.6 cm) of asphalt wearing layers and 3 in. (7.6 cm) of subbase, the provision of the infrastructure amounts to 1125 metric tonnes of CO<sub>2</sub>-e. A 20-year lifetime is assumed based on minimal wear from use consisting primarily of walkers, joggers, and cyclists.

## Results

Table 2 and Fig. 1 summarize our results, which we detail by different cost allocation techniques that each answer different questions about the cost of reductions that come from the projects. We found that the cost of GHG reductions that come from these projects is quite high until we consider the net cost savings to users.

The results indicate that the cost-effectiveness of GHG reductions from passenger transportation projects can vary significantly depending on cost allocation framing and the inclusion of indirect (specifically avoided automobile travel) effects. While public capital cost, public operating subsidy, and full public cost framing can result in greater costs per metric tonne of CO<sub>2</sub>-e reduced versus the California GHG allowance price, when full public costs (less net user costs) are assessed, the projects produce GHG reductions with net economic savings.

### Public subsidies for capital costs

All projects have a capital cost that greatly exceeds the current California allowance price ranging from \$56 to over \$2600 per metric tonne CO<sub>2</sub>-e reduced. This cost allocation includes the upfront price tag for the project, but ignores any operations cost or net savings (or costs) to users of the transportation project. The GHG allocation includes life-cycle emissions from the project's construction, operations, and maintenance, less any reductions from those using the project instead of another mode. Results for this cost-allocation address how cost-effective near-term expenditures can produce GHG reductions over the long term. This is an incomplete analysis, especially for projects that will require an operating subsidy.

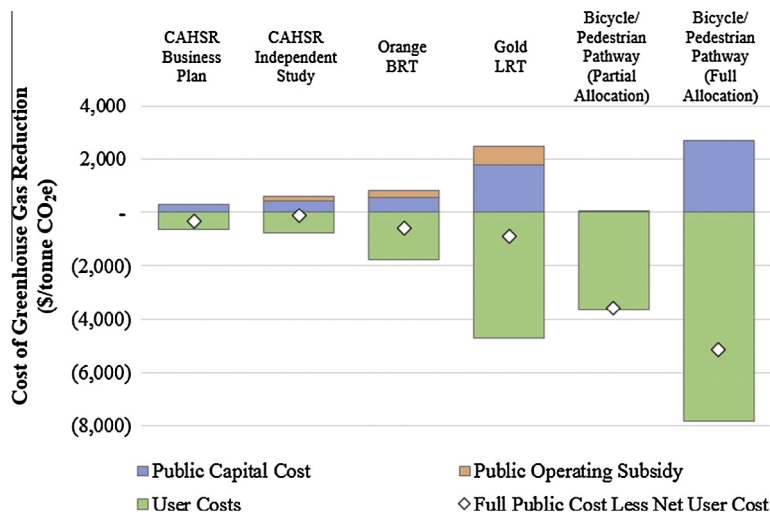
### Marginal public subsidy for operations

The marginal case arises from the decision to operate the project after construction. At this point in the facility's life, capital subsidies and initial infrastructure construction emissions are considered sunk costs and are thus excluded from the



**Table 2**Cost-effectiveness of greenhouse gas reductions from evaluated projects (2012 \$/metric tonne CO<sub>2</sub>-e).

	Public capital cost	Public operating subsidy (marginal case)	Full public cost (operations + capital)	Full public cost less net user costs
CAHSR (2012 Business Plan)	\$298	–	\$298	–\$335
CAHSR (independent study – high)	\$428	\$203	\$654	–\$109
Orange BRT line	\$589	\$252	\$1162	–\$588
Gold LRT line	\$1767	\$724	\$3809	–\$882
Bicycle/Pedestrian Pathway (proportional – 4.49%)	\$56	–	\$56	–\$3561
Bicycle/Pedestrian Pathway (full – 100%)	\$2697	–	\$2697	–\$5125

**Fig. 1.** Cost-effectiveness of greenhouse gas reductions from evaluated projects.

analysis. Included in the analysis are annual operating subsidies and net GHG emissions from operations. Thus, these figures provide insight into the decision to provide public funding to subsidize operations for a project after it has been constructed.

According to the 2012 Business Plan (California High-Speed Rail Authority, 2012a, 2012b) CAHSR will require no public operating subsidy. The Authority also plans to grant most of the potential operating profit to a private operator in exchange for capital contributions to construct the project (California High-Speed Rail Authority, 2012a, 2012b; California High Speed Rail Authority, 2014a, 2014b). Thus, the project will neither produce a public surplus nor require a public operating subsidy. Under the marginal cost allocation technique, GHG reductions are achieved without cost. The Reason Foundation's high-case estimate shows that CAHSR will require an operating subsidy of \$373 million per year, or \$203 per metric tonne (Reason Foundation, 2008, 2013).

Public transit projects operated by the Los Angeles County Metropolitan Transportation Authority require an operating subsidy of \$2.385 million per year, or \$252 per metric tonne for the Orange BRT line and \$6.815 million per year, or \$724 per metric tonne, for the Gold LRT line. The GHG operational abatement costs for the urban transit systems are higher than those of CAHSR revealing potential economies of scale for the cost-effectiveness of GHG reductions for long-distance transportation service.

#### Full public subsidy

In this case, we consider the full public contributions of capital costs and operating subsidies to the project. This is the total public cost and reductions in GHG emissions over 100 years. For projects that require an operating subsidy, evaluating this cost allocation technique provides a more complete picture of the public's decision to construct and subsequently operate a transportation project. This cost-allocation technique answers the question "If we consider only government expenditures and ignore costs and benefits to users of the transportation, how cost-effectively can reductions be achieved?"

Under this framing, the Bicycle/Pedestrian Pathway allocated to uni-modal bike/walk trips has the lowest GHG abatement cost at \$56 per metric tonne CO<sub>2</sub>e while the urban transit LRT and BRT reveal some of the highest costs (between \$1162 and \$3809). CAHSR's abatement cost is low compared to the other systems, between \$298 and \$654 per metric tonne CO<sub>2</sub>e. Here, urban transit projects experience greater abatement costs associated with capital outlay (likely due to increased costs of construction in a developed urban area) and this increases their full public subsidy to be on the high end of the systems. How-

ever, the greatest abatement costs are associated with the Bicycle/Pedestrian Pathway when 100% of construction impacts are allocated, combining the pathway's recreational benefit with its value as a mobility alternative.

#### *Full public costs less net user costs*

For this cost allocation, we offset the government-provided subsidies with net private costs for use of the transportation facility. Net private costs are user fees (HSR ticket, transit fare) less any avoided costs (air ticket, automobile travel). This cost allocation more completely accounts for each project's effects on the cost of mobility in California, and we recommend it for comparison among projects which have yet to be built.

All projects evaluated bring net private cost savings to users. In the CAHSR Business Plan case, accounting for the \$32.41 in average user savings brings a \$633 reduction in allocated costs per metric tonne reduced. The result is –\$335 per metric tonne reduced. The urban transportation projects show a greater net savings after adjusting for net user costs. Under this cost allocation, a net savings means that California can invest cap-and-trade revenues into these reduction opportunities at a net economic savings. This is primarily the result of the avoided GHG emissions from fuel savings from travelers shifting from automobiles to transit. For the Gold LRT line, costs are –\$822 per metric tonne reduced. For the Orange BRT line, costs are –\$588 per metric tonne reduced. For the Bicycle/Pedestrian Pathway, costs are –\$3561 per metric tonne reduced.

## Discussion

The abatement costs are sensitive to a number of estimates of future conditions for the transportation systems and the variation in costs is explored to estimate how results can change. Because of the continued uncertainty surrounding the future CAHSR project versus the established urban transit projects, most of our sensitivity analyses focuses on High-Speed Rail. Fig. 2 summarizes the calculations in this section, which utilize the undiscounted full public costs less net user costs framing.

#### *Sensitivity avoided automobile costs for High-Speed Rail*

In the 2012 Business Plan (California High-Speed Rail Authority, 2012a, 2012b), the CAHSR Authority chose to use an avoided automobile cost of \$0.24 per mile (average case). To be consistent in our evaluation among the transportation projects, we use the 2012 IRS standard mileage rate of \$0.555 per mile (\$0.34/km). If we were to use the Business Plan figure for High-Speed Rail, the full public cost less net user costs per-tonne cost increases from –\$335 to \$413.

#### *Sensitivity to avoided automobile travel for High-Speed Rail*

Using 2012 data from the CAHSR Authority (California High Speed Rail Authority, 2014a, 2014b) we calculated an average trip distance of 150 miles (242 km) for the 80.67% of High-Speed Rail users shifting from automobiles. Data from the Draft 2014 Benefit-Cost Analysis (California High Speed Rail Authority, 2014a, 2014b) indicates an average trip distance of 118 miles (189 km) for those shifting from automobiles. The full cost results that account for both public and private costs are highly sensitive to this average trip distance, which drives the economic savings of avoided automobile travel. Table 3 illustrates the sensitivity from our preliminary model, which we designed to assess the Business Plan case. Future research could further explore sensitivity to a range of scenarios not included in the Business Plan document. All results, including our calculated average avoided automobile trip distance from the 2014 Business Plan (California High Speed Rail Authority,

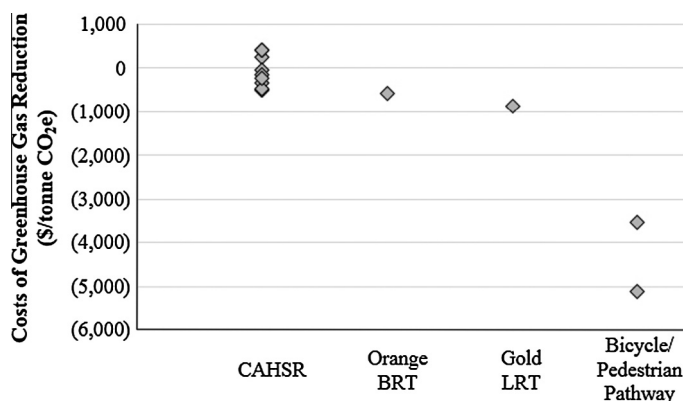


Fig. 2. Range of greenhouse gas avoidance costs.

2014a, 2014b), are derived from our analysis of finances, operations, and mode shift from the 2012 Business Plan (California High-Speed Rail Authority, 2012a, 2012b).

#### *Sensitivity to average High-Speed Rail ticket price*

Using 2012 data from the CAHSR Authority (California High-Speed Rail Authority, 2012a, 2012b) we calculated an average trip fare of \$52.75 in 2012 dollars. Table 4 shows our results' sensitivity to the average price of a High-Speed Rail ticket. All results, including the calculated average ticket price from the 2014 Business Plan (California High Speed Rail Authority, 2014a, 2014b), are derived from our analysis of finances, operations, and mode shift from the 2012 Business Plan (California High-Speed Rail Authority, 2012a, 2012b).

#### *Sensitivity to Bicycle/Pedestrian Pathway allocation*

Because the Bicycle/Pedestrian Pathway serves recreational purposes that go beyond functional mobility needs, in the proportional analysis we consider only a portion of the economic costs and emissions from initial construction. We choose 4.49%, as this is the proportion of pathway users who previously used automobiles for the trip but now ride a bicycle without using the bus (Los Angeles County Metropolitan Transportation Authority, 2011). If we were to assign 100% of the costs from pathway construction and emissions from pathway construction and reconstruction, reductions would be achieved at an average cost of –\$5125 per tonne, versus our result of –\$3561. This result may seem counterintuitive, but occurs because the pathway achieves about one-half of the GHG reductions but roughly three-quarters of the initial savings to users, the ratio of cost savings to GHG reductions is actually greater although absolute cost savings and GHG reductions are both lower. As such, we do not recommend using relative per tonne savings as a sole criterion for comparing projects that achieve GHG reductions at a negative cost per tonne.

#### *Discounting future costs and benefits*

Use of traditional cost-benefit analysis with discounted future expenditures and benefits is problematic in evaluating climate change policy (Lind, 1995). In the case of our analysis, capital costs and construction emissions are incurred initially, with benefits coming over time in the form of GHG emissions reductions and savings to transportation facility users. Net

**Table 3**

High-Speed Rail result sensitivity to avoided automobile trip distance.

Average distance for avoided automobile trip	Full public cost, less net user costs result (2012 Business Plan)
118 miles (189 km) (2014 Draft Business Plan distance)	–\$48
130 miles (209 km)	–\$157
140 miles (225 km)	–\$244
150 miles (242 km) (2012 plan)	–\$335
160 miles (258 km)	–\$419
170 miles (274 km)	–\$507

**Table 4**

High-Speed Rail result sensitivity to average ticket price.

Average High-Speed Rail ticket price (2012 dollars)	Full public cost, less net user costs result (infrastructure and ridership based on 2012 Business Plan)
\$46.10 (2014 Draft Business Plan)	–\$463
\$52.75 (2012 Business Plan)	–\$335
\$70	–\$5
\$83 (average ticket for LA-SF trip)	\$243
\$100 (high estimate)	\$569

**Table 5**

Net present value of greenhouse gas emissions reductions (full public less net user costs).

	1%	2%	3%
HSR (Business Plan)	–\$190	\$24	\$328
Orange line BRT	–\$130	\$415	\$1035
Gold line	\$425	\$3578	\$21,901
Orange line pathway	–\$3175	–\$3142	–\$3101



present value analysis is extremely sensitive to net financial costs and net emissions in early years. Our results in Table 5 show that only the Orange Line Pathway performs well under this analysis, as constructions costs are relatively small compared to user cost savings and emissions reductions.

## Conclusions

Many GHG abatement projects produce negative costs, which represent a net savings independent of the GHG emissions reductions. This is consistent with energy efficiency findings, for example, switching to LED lighting from incandescent lighting can save over \$200 per metric tonne of CO<sub>2</sub>-e reduced (McKinsey & Company, 2010). While the LED light bulb requires a higher initial cost than the incandescent bulb, the savings on electricity payments over time produce life cycle cost savings. When this negative cost is allocated over net reductions in GHG emissions, the result is a negative per-tonne GHG abatement cost. The same effect is true with California transportation projects and is the result of avoided automobile travel, a more expensive and GHG intense mobility option. Because of the initial capital outlay, GHG abatement projects available at negative per tonne costs sometimes require an added subsidy to incentivize the investment (in particular, urban transit). However, ensuring that large numbers of passengers shift to the new systems results in the lowering of user costs such that savings can easily outpace the initial cost investments. The High-Speed Rail, transit, and Bicycle/Pedestrian Pathway projects will all become more cost-effective if the cost of driving increases.

While the price of a GHG allowance indicates a break-even value for a GHG reduction project, the results are not sensitive to slight variations in the California allowance price (currently \$12.21 per tonne). The results show wide variations in project cost-effectiveness depending on the accounting framing and project sensitivities. None of the projects presented in this paper are marginal cases for investment that would be funded or shelved based on expected California allowance price. Rather, our results depend almost entirely on mode shift and the cost of automobile transportation.

As transportation is typically a derived demand, public and private transportation systems are not profitable when direct costs are considered, however, the results show how the inclusion of some indirect costs shows how new mass transit can save money while reducing GHG emissions. Public transit systems typically offer lower GHG emissions per passenger kilometer traveled than a competing automobile trip (Chester et al., 2013) but initial cost and GHG investments are needed to create opportunities for mode shifting. The results show that the investment in public transit over time will shift enough automobile travel to the new system thereby resulting in economic and GHG savings. Without the initial investment in public transit, a business-as-usual future with higher automobile-focused travel costs can be expected.

Our results depend on the accounting framing employed in the analysis. Even within an accounting framework, results are highly sensitive to the uncertainty in future forecasts. This uncertainty may be greater for CAHSR than for urban transit projects given the system's novelty and ability to connect to and create new infrastructure (e.g.: infill projects or transit nodes). We also caution the reader that our results may change significantly with future updates to the Authority's Business Plan. While the urban transit projects assessed have already been in operation for some time, the uncertainty in forecasting GHG cost effectiveness of new transit lines is likely to be lower than for High-Speed Rail given the rich historical data that exist for transit systems. For CAHSR to achieve a negative cost for GHG reductions a combination of: high automobile cost of ownership, long-distance counterfactual automobile trips, and high counterfactual airfares is needed.

California has emerged as a national leader in creating a market for the right to emit GHGs, and planning and partially funding new High-Speed Rail. Los Angeles County, California, is in the midst of the nation's largest rail transit expansion program. As other jurisdictions seek to reduce transportation GHGs, they can learn from California as the state's legislature works to determine the appropriate mix of investments to meet GHG goals while balancing ancillary outcomes. While the notoriously congested environmental leader is the first in the United States to create a new funding mechanism for transportation investments that reduce GHGs, it's unlikely to be the last.

## References

- American Automobile Association, 2012. Cost of owning and operating vehicle in U.S. increased 1.9 percent according to AAA's 2012 'Your Driving Costs' study. <<http://newsroom.aaa.com/2012/04/cost-of-owning-and-operating-vehicle-in-u-s-increased-1-9-percent-according-to-aaa%E2%80%99s-2012-%E2%80%98your-driving-costs%E2%80%99-study/>> (accessed January 2014).
- California Air Resources Board, 2014. California air resources board quarterly auction 8 August 2014: summary results report. <<http://www.arb.ca.gov/cc/capandtrade/auction/august-2014/results.pdf>> (accessed 15.10.14).
- California High Speed Rail Authority, 2014a. 2014 California High-Speed Rail Benefit-Cost Analysis. <[http://www.hsr.ca.gov/docs/about/business\\_plans/BPlan\\_2014\\_CA\\_HSR\\_Benefit\\_Cost\\_Analysis.pdf](http://www.hsr.ca.gov/docs/about/business_plans/BPlan_2014_CA_HSR_Benefit_Cost_Analysis.pdf)>.
- California High Speed Rail Authority, 2014b. Connecting California: Draft 2014 Business Plan. <[http://www.hsr.ca.gov/docs/about/business\\_plans/FINAL\\_Draft\\_2014\\_Business\\_Plan.pdf](http://www.hsr.ca.gov/docs/about/business_plans/FINAL_Draft_2014_Business_Plan.pdf)>.
- California High-Speed Rail Authority, 2012. California High-Speed Rail Benefit-Cost Analysis. <[http://www.hsr.ca.gov/docs/about/business\\_plans/BPlan\\_2012BCP.pdf](http://www.hsr.ca.gov/docs/about/business_plans/BPlan_2012BCP.pdf)>.
- California High-Speed Rail Authority, 2012. Revised 2012 Business Plan. <<http://californiastaterailplan.dot.ca.gov/docs/1a6251d7-36ab-4fec-ba8c-00e266dadec7.pdf>>.
- Chester, M. et al, 2013. Infrastructure and automobile shifts: positioning transit to reduce life-cycle environmental impacts for urban sustainability goals. *Environ. Res. Lett.* 8 (1). <http://dx.doi.org/10.1088/1748-9326/8/1/015041>.
- Chester, M.V., Horvath, A., 2012. High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California's future. *Environ. Res. Lett.* 7 (3). <http://dx.doi.org/10.1088/1748-9326/7/3/034012>.
- Federal Transit Administration, n.d. 2012 Profile report for the Los Angeles County metropolitan transportation authority. <[http://www.ntdprogram.gov/ntdprogram/pubs/profiles/2012/agency\\_profiles/9154.pdf](http://www.ntdprogram.gov/ntdprogram/pubs/profiles/2012/agency_profiles/9154.pdf)> (accessed 19.01.14).

- Horvath, A., 2003. Pavement life-cycle assessment tool for environmental and economic effects. <<http://www.uctc.net/papers/683.pdf>>.
- Lind, R.C., 1995. Intergenerational equity, discounting, and the role of cost-benefit analysis in evaluating global climate policy. *Energy Policy* 23 (4–5), 379–389. [http://dx.doi.org/10.1016/0301-4215\(95\)90162-Z](http://dx.doi.org/10.1016/0301-4215(95)90162-Z).
- Los Angeles County Metropolitan Transportation Authority, 2011. Metro orange line mode shift study and greenhouse gas emissions analysis. <[http://media.metro.net/projects\\_studies/bikeway\\_planning/images/Metro\\_Orange\\_Line\\_Study\\_March\\_2011.pdf](http://media.metro.net/projects_studies/bikeway_planning/images/Metro_Orange_Line_Study_March_2011.pdf)> (accessed 07.01.14).
- Los Angeles County Metropolitan Transportation Authority, 2003. MTA poised to open the Los Angeles to Pasadena metro gold line to the public on Saturday, July 26. <[http://www.metro.net/news/simple\\_pr/mta-poised-open-los-angeles-pasadena-metro-gold-li/](http://www.metro.net/news/simple_pr/mta-poised-open-los-angeles-pasadena-metro-gold-li/)> (accessed 07.01.14).
- Los Angeles County Metropolitan Transportation Authority, 2004. Gold line corridor before/after study combined report, s.l.: s.n.
- Los Angeles County Metropolitan Transportation Authority, 2005. Metro joins elected officials in dedication of new 14-mile Metro Orange Line. (Press Release). <[http://ebb.metro.net/press/2005/10\\_october/metro\\_159.htm](http://ebb.metro.net/press/2005/10_october/metro_159.htm)> (accessed 07.01.14).
- Los Angeles County Metropolitan Transportation Authority, 2014. Fares. <<http://www.metro.net/riding/fares/>> (accessed February 2014).
- Mashayekh, Y. et al, 2011. Costs of automobile air emissions in U.S. metropolitan areas. *Transport. Res. Rec.* (2233), 120–127.
- McKinsey & Company, 2010. Impact of the Financial Crisis on Carbon Economics: Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve. s.l.: s.n.
- Michalek, J. et al, 2011. Valuation of plug-in vehicle life-cycle air emissions and oil displacement benefits. *PNAS* 108 (40), 16554–16558. <http://dx.doi.org/10.1073/pnas.1104473108>.
- Muller, N.Z., 2011. Linking policy to statistical uncertainty in air pollution damages. *BE J. Econ. Anal. Policy* 11 (1). <http://dx.doi.org/10.2202/1935-1682.2925>.
- PRé Consultants, 2013. SimaPro 8.0.3 using ecoinvent v3 data. s.l.: s.n.
- Reason Foundation, 2008. California High-Speed Rail: A Due Diligence Report. <<http://reason.org/files/1b544eba6f1d5f9e8012a8c36676ea7e.pdf>>.
- Reason Foundation, 2013. California High-Speed Rail: An Updated Due Diligence Report. <[http://reason.org/files/california\\_high\\_speed\\_rail\\_report.pdf](http://reason.org/files/california_high_speed_rail_report.pdf)>.
- Resource Systems Group, 2010. Addressing Aviation Capacity Issues, Washington, D.C.: s.n.
- Texas A&M Transportation Institute, 2013. 2012 Annual Urban Mobility Report, College Station, TX: s.n.
- U.S. Environmental Protection Agency, 2012. EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2012–2025 Cars and Light Trucks. s.l.: s.n.
- U.S. Internal Revenue Service, 2012. 2012 Standard Mileage Rates. <<http://www.irs.gov/uac/IRS-Announces-2012-Standard-Mileage-Rates,-Most-Rates-Are-the-Same-as-in-July>>.
- U.S. Bureau of Labor Statistics, 2014. CPI Inflation Calculator. <<http://data.bls.gov/cgi-bin/cpicalc.pl>>.

## Glossary

*Allowance*: a permit to emit one metric ton CO<sub>2</sub>-equivalence of greenhouse gas emissions, issued by the California Air Resources Board

*Cap-and-trade*: a market mechanism used to assure a determined amount of greenhouse gas emissions. The price of tradable allowances varies to meet the pre-determined cap

*CPI*: the Consumer Price Index, a U.S. Department of Labor indicator of change over time in the prices of common consumer goods

*LED*: light-emitting diode, a form of energy-efficient lighting