Cost-Effectiveness of Reductions in Greenhouse Gas Emissions from California High-Speed Rail and Urban Transportation Projects

by

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SUMMARY

As California establishes its greenhouse gas 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. In a step toward closing this knowledge gap, we compare the cost-effectiveness of greenhouse gas reductions forecast to come to California High-Speed Rail with those estimated from recent urban transportation projects (specifically light rail, bus rapid transit, and bicycling) in California. The goal of the study is to link life-cycle greenhouse gas emissions estimates with full cost accounting to better understand the benefits of cap-and-trade investments.

We assess the California High-Speed Rail Phase 1 - Full Build case from the 2012 Business Plan (California High-Speed Rail Authority, 2012a). Our data for high-speed rail is based on the Authority's forecasts of ridership, economic costs, and construction program, which are uncertain.

We compare our results for California High-Speed Rail with three recent urban transportation projects in Los Angeles County:

- Phase I of the Metro Orange Line Busway, a $339M project in the San Fernando Valley that opened in 2005;
- The Metro Orange Line 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, a $859M project that connects Los Angeles Union Station with Pasadena, and which opened in 2003.

Table 1 summarizes 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 greenhouse gas reductions that come from these projects is quite high unless we consider the net cost savings to users of the transportation projects. When including users' cost savings, the urban transportation projects produce greenhouse gas reductions at a net savings, while the reductions from California High-Speed Rail's reductions are more costly. We discuss the results and the questions each economic cost allocation technique answers in the sections that follow.

Table 1: Cost-Effectiveness of Greenhouse Gas Reductions from Evaluated Projects ($/metric tonne CO_2-e)

	Public Capital Cost	Public Operating Subsidy (marginal case)	Full Public Cost (Operations + Capital)	Full Public Cost Less Net User Costs
California High-Speed Rail (Business Plan)	$461	$0	$461	$361
California High-Speed Rail (Independent Study - High)	$549	$203	$775	$588
Orange Line Busway	$501	$252	$1,074	-$676
Gold Line Light Rail Transit	$1,416	$724	$3,458	-$1,233
Orange Line Bicycle Path	$1,061	$0	$1,061	-$3,670

The results indicate that the cost-effectiveness of greenhouse gas reductions from passenger transportation projects can vary significantly depending on framing the assessment 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 urban transportation costs per metric tonne of CO_2-e reduced than high-speed rail, when Full Public Costs (Less Net User Costs) are assessed urban transportation projects produce greenhouse gas savings with economic savings.

MOTIVATION

As the California Legislature considers options to use proceeds from the auction of greenhouse gas allowances generated under the state's cap-and-trade system, information on the relative cost-effectiveness of greenhouse gas reductions can help prioritize investments.

Under California's cap-and-trade system, major emitters of greenhouse gasses 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 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_2-e) in California, and 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 greenhouse gas emissions in California, but grants the Legislature leeway in choosing between opportunities that reduce greenhouse gas emissions.

The cost-effectiveness of a greenhouse gas 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_2-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 greenhouse gas emissions at a per-tonne cost that is lower than the allowance price allows California to move toward its greenhouse gas goals at a lower public and private cost. Allocating cap-and-trade revenues to reduction opportunities that reduce greenhouse gas emissions at a per-tonne cost greater than the allowance price likely means that some of the 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 greenhouse gas emissions at a greater cost to California. As of February, 2014 prices for California allowances were $11.48 per metric tonne of CO_2-e (California Air Resources Board, 2014).

The cost at which a project can reduce a metric tonne of greenhouse gas 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 greenhouse gas emissions reductions. Transportation projects create new mobility and land use opportunities that can be beneficial independent of any reductions in greenhouse gas emissions. However, because Greenhouse Gas Reduction Fund revenues are generated from a market-based mechanism (cap-and-trade), the cost-effectiveness of reductions should be a key consideration in allocating expenditures.

While the cost of emissions reductions forecast to come from California High-Speed Rail is much higher than the current allowance price, there are many other reasons why policymakers might support the statewide project. These include the potential for statewide smart growth, economic development in the Central Valley, the potential for air quality improvements, a reduction in intra-state travel's contribution to the demand for airport expansion, diversification in transportation energy consumption, and resilience in transportation services.

RESULTS

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 & Orange, in decade 3 for HSR)
- the full public subsidy required to construct and operate the project
- 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

Greenhouse gas reductions are evaluated using life-cycle assessment. In general, we subtract the net savings from users who switch from other modes from the life-cycle emissions needed to construct the project and operate the transportation facility. In all but the marginal case (operations subsidy in decade 2 or 3), we evaluate net greenhouse gas emissions reductions over a 100-year period.

Public Subsidies for Capital Costs

All projects have a capital cost that greatly exceeds the current California allowance price. This cost allocation includes the price tag for the project, but ignores any operations cost or net savings (or costs) to users of the transportation project. The greenhouse gas 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.

These figures provide insight into the cost-effectiveness of reductions when only considering upfront costs. Results for this cost-allocation address how cost-effective near-term expenditures can produce greenhouse gas reductions over the long term. This is an incomplete analysis, especially for projects that will require a subsidy to operate after construction.

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 analysis. Included in the analysis are annual operating subsidies and net greenhouse gas 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 Business Plan (California High-Speed Rail Authority, 2012a), California High-Speed Rail will require no operating subsidy. This means that, under this cost allocation technique, greenhouse gas reductions are achieved without cost. The Reason Foundation's high-case estimate shows that California High-Speed Rail 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 Line and $6.815 million per year, or $724 per metric tonne, for the Gold Line.

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 greenhouse gas 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"?

Full Private and Public 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.

Avoided automobile trips

$$= \# \, User \, Trips * \frac{Users \, Shifting \, From \, Automobiles}{Total \, Users} * Competing \, Automobile \, Trip \, (miles) * IRS \, Mileage \, rate$$

Avoided air trips (for High Speed Rail)

$$= \# \, HSR \, Trips * \frac{Users \, Shifting \, From \, Air}{Total \, Users} * Avoided \, Air \, Ticket \, Cost$$

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 Line Busway, this means that we include 100% of the public subsidy needed to operate the Orange Line but only adjust for the net private costs (fares less savings from avoided automobile use) for the 25% of Orange Line users who would have traveled in an automobile if not for the Orange Line facility (52% predicted after decade 3) (Chester, et al., 2013). We do not consider transit fares for those who shifted to the Orange Line from transit nor fares from the new (induced) trips that passengers make because of the Orange Line's existence.

All projects evaluated bring net private cost savings to users. In the California High-Speed Rail business plan case, accounting for the $4.46 in average savings per High-Speed Rail user brings a $100 reduction in allocated costs per metric tonne reduced. The result is $361, around 30 times more expensive than California's current allowance value.

However, the urban transportation projects show a 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 savings to Californians. This is primarily the result of the avoided greenhouse gas emissions from travelers shifting from automobiles to transit coupled with their fuel savings. For the Orange Line Busway, costs are -$676 per metric tonne reduced. For the Gold Line Light Rail facility, costs are -$1,223 per metric tonne reduced. For the Orange Line Pathway, costs are -$3,670 per metric tonne reduced. Because these results represent average savings per tonne reduced, projects that achieve greater absolute greenhouse gas reductions at greater absolute economic savings after adjusting for user costs can seem less cost-effective. Because of this, we do not recommend using relative per tonne savings as a sole criteria for comparing projects that achieve greenhouse gas reductions at a negative cost per tonne.

Many greenhouse gas abatement projects produce negative costs, which represent a net savings independent of the greenhouse gas emissions reductions. For example, switching to LED lighting from residential can save over $200 per metric tonne of CO_2-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 mean the switch comes at a negative cost. When this negative cost is allocated over net reductions in greenhouse gas emissions, the result is a negative greenhouse gas abatement cost per tonne. Because of the initial capital outlay, greenhouse gas abatement projects available at negative per tonne costs sometimes require an added subsidy to incentivize the investment. In the case of greenhouse gas reduction opportunities in California, the three urban transportation projects evaluated require an initial capital investment in order to achieve future greenhouse gas reductions at a net negative cost per metric tonne.

DATA SOURCES and ASSESSMENT DETAILS

We join an economic assessment with life-cycle greenhouse gas assessments using several existing seminal studies. Where possible, bounding analyses are performed to capture the range of potential greenhouse gas reduction costs outcomes. In this section, we detail sources of data and assumptions used in the assessment.

Financial Assessment

We use various estimates to calculate the public subsidy needed for capital and operating costs for each project. For high-speed rail, we used economic cost and ridership estimates from the 2012 Revised High-Speed Rail Business Plan (California High-Speed Rail Authority (2012a) and its source reports. Given the uncertainty with high-speed rail forecasts, we also introduce an alternate forecast from the Reason Foundation (2008 & 2013), an organization which has been critical of the California project. For projects in Los Angeles County, we use capital cost data from the Los Angeles Metropolitan Transportation Authority (2003 & 2005). Few mass transportation systems (public or private) are profitable as travel is generally 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 Orange and Gold lines were calculated using data from the Federal Transit Administration's (2012) National Transit Database.

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. For the Metro projects in Los Angeles County, we consider avoided automobile costs at the IRS Standard Mileage Rate of $0.555/mile (Internal Revenue Service, 2012), less Metro's current fare of $1.50 (Los Angeles Metropolitan Transportation Authority, 2014). For High-Speed Rail, we subtract the average fare of $81 (California High-Speed Rail, 2012a) from avoided air travel at $97/trip (California High-Speed Rail, 2012a) and avoided automobile trips at $0.555/mile (Internal

Revenue Service, 2012). This is in contrast with the California High-Speed Rail Authority (2012b), which used an estimate for avoided automobile costs of $0.24 per mile. The American Automobile Association produces alternative per-mile automobile cost estimates that range from $0.449 per mile for a small sedan to $0.757 per mile for a sports utility vehicle (American Automobile Association, 2012).

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 (Michalek 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 High-Speed Rail (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.

Greenhouse Gas Emissions Assessment

For a life-cycle assessment of greenhouse gas emissions reductions associated with each transportation project, we used previously conducted studies on California High-speed Rail (Chester and Horvath, 2012), and the Metro Gold and Orange 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 greenhouse gas emissions. For each study, the sensitivity of greenhouse gas 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.

We develop a life-cycle assessment of bicycle travel on the Orange Line Bicycle path that includes bicycle manufacturing and maintenance as well as infrastructure. The manufacturing and maintenance of an aluminum frame 17 kg bicycle is modeled in SimaPro 8.0.1 assuming that manufacturing of materials occurs in China and retail in California (PRé Consultants, 2013). The resulting manufacturing greenhouse gas emissions are 110 kg CO_2-e and maintenance 18 kg CO_2-e over the bicycle's lifetime of 2,500 miles. The Orange Line bicycle infrastructure consists of approximately 14 miles of a predominantly asphalt surface, roughly 14 feet wide. A pavement life-cycle assessment 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 inches of asphalt wearing layers and 3 inches of subbase, the provision of the infrastructure amounts to 1,125 metric tonnes of CO_2-e. A 20-year lifetime is assumed and based on minimal wear from use consisting primarily of walkers, joggers, and cyclists.

Because the Orange Line Pathway serves recreational purposes that go beyond functional mobility needs, we consider only a portion of the economic costs and emissions from initial construction. We choose 4.49%, as this is the proportion of total bikeway users who previously used automobiles for the trip. In considering net savings to these users for the full public cost, less private savings scenario, we assume an average bicycle cost of $400. No financial costs are considered for reconstruction, but 4.49% of reconstruction emissions are assigned to the bikeway project. If we were to assign 100% of the costs from bikeway construction and emissions from bikeway construction and reconstruction, reductions would be achieved at an average cost of -$5,747 per tonne. This result may seem counterintuitive, but occurs because the bikeway achieves about one-half of the greenhouse gas reductions but roughly three-quarters of the initial savings to users, there are actually greater average savings per tonne. This result highlights the reason we do not recommend using relative per-tonne savings as a sole criteria for comparing projects that achieve greenhouse gas reductions at a negative cost per tonne.

Data on use of the Orange Line Pathway come from a study conducted by the Los Angeles County Metropolitan Transportation Authority (2011).

SENSITIVITY ANALYSIS

In this section, we discuss changes in assumptions and inputs that drive our results.

Differing estimates of avoided automobile costs for High-Speed Rail

In the 2012 Business Plan, the California High-Speed Rail 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. If we were to use the Business Plan figure for high-speed rail, the full private and public cost per-tonne cost increases from $361 to $1,212.

Sensitivity to mode-shift

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 not generalizable to all transportation projects in the state. Diverting automobile users to transit is the primary driver of the cost-effectiveness of greenhouse gas emissions reductions for urban transportation projects.

Table 2 shows our assumptions for mode-shift for the Los Angeles County transportation projects. Data on mode-shift and use for the Orange Line Busway and Pathway come from a study conducted by the Los Angeles County Metropolitan Transportation Authority (2011). Data on mode-shift for the Gold Line Light Rail come from Los Angeles County Metropolitan Transportation Authority (2004).

Table 2: Los Angeles County Projects - Assumed Mode Shift from Automobiles

	2009	2035
Orange Line Busway	25%	52%
Orange Line Bicycle Pathway	4.49%	4.49%
Gold Line Light Rail	67%	80%

Using figures from the California High Speed Rail Authority's Cost-Benefit Analysis (2012b), we calculate that 17.23% of passengers would come from air, 80.67% would come from automobiles, and 2.1% of trips would be induced because of the existence of California High-Speed Rail. Under these assumptions, we find a full private and public cost of $361 per metric tonne reduced.

Sensitivity to Avoided Automobile Trip for High-Speed Rail

Using data from the California High-Speed Rail Authority (2012b) we calculated an average trip distance of 149.76 miles for the 80.67% of high-speed rail users shifting from automobiles.

The full cost results that account for both public and private costs are extremely 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.

Table 3: High-Speed Rail Result Sensitivity to Avoided Automobile Trip Distance

Average Distance for Avoided Automobile Trip	Result (Business Plan Mode-Shift)
140 miles	$459
149.76 miles (Business Plan distance)	**$361**
160 miles	$258
175 miles	$108
185.71 miles	$11.48 (parity with allowance price)

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 greenhouse gas emissions reductions and savings to transportation facility users. Our results in Table 4 show that only the Orange Line Pathway performs well under this analysis, as constructions costs are relatively small compared to the cost savings to users and emissions reductions.

Net present value analysis is extremely sensitive to net financial costs and net emissions in early years.

Table 4: Net Present Value of Greenhouse Gas Emissions Reductions (Full Social Costs)

	0.5%	1%	2%	3%
HSR (Business Plan)	$490	$648	$1,062	$1,642
Orange Line BRT	-$481	-$266	$217	$763
Gold Line	-$146	$418	$2,794	$16,851
Orange Line Pathway	-$1,999	-$1,662	-$837	$186

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