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Summary of Research Findings: Assessing and Comparing Environmental Performance of Major Transit Investments

DETAILS

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SUMMARY OF RESEARCH FINDINGS: ASSESSING AND COMPARING ENVIRONMENTAL PERFORMANCE OF MAJOR TRANSIT INVESTMENTS

This digest presents the results of TCRP Project H-41, "Assessing and Comparing Environmental Performance of Major Transit Investments." The research was undertaken to offer decision makers optional criteria, metrics, and methods for assessing transit projects with regard to environmental performance. The research was led by Cambridge Systematics, Inc., Cambridge, Massachusetts. Chris Porter was the Principal Investigator.

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SUMMARY

TCRP Project H-41 addresses the need for new measures of the environmental benefits of transit investments. The objective of this research is to present, evaluate, and demonstrate criteria, metrics, and methods for assessing and comparing the environmental performance of major transit investments. For purposes of this research, the following definitions are used:

- Criteria: the characteristics that will be considered when performance is judged.
- Metric: a measure for something; generally a quantitative measurement or estimate, or an ordinal metric in the case of qualitative evaluation.
- Method: a way of doing something, especially a systematic technique or process used to develop a metric.

The research was undertaken in two phases. The first phase included

- a review of the literature to identify performance measures used for transit and other transportation projects, including a review of international practice in transportation environmental evaluation;
- interviews with 20 stakeholder agencies or groups;
- a review of four recent transit project alternatives analysis (AA) documents or environmental impact statements (EIS) to identify which environmental performance measures have been emphasized and how they have been treated;
- an enumeration of potential metrics of environmental performance, data sources and calculation methods, and preliminary screening of these metrics; and
- development of a more detailed approach to screening and selecting metrics, including selection of a short list of less than 20 metrics to evaluate in detail.

In the second phase, six pilot projects were recruited on which to test these metrics. Data were collected for each project and metrics were computed. Next, the ease of data collection and computation, reliability, and usefulness of each metric for purposes of distinguishing among transit projects were evaluated. Metrics were then placed in three tiers according to how promising they were for use in both local

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and national-level project evaluation. Finally, a set of "most promising" metrics was selected from the Tier 1 and Tier 2 metrics that represented each category of environmental performance without overlapping.

Table 1 summarizes the metrics that were considered most promising for use in comparison of projects or project alternatives. Any of these metrics could be used in the evaluation of different project alternatives. The table also identifies additional development activities that are needed before the metric is ready for use, particularly for comparing multiple projects in different regions. These metrics represent broad environmental performance issues of interest for comparing across projects (including benefits), rather than a detailed enumeration of all the environmental impacts considered in the environmental documentation process. The list includes only metrics that can be computed with existing data sources and modest resource requirements, and therefore is limited in its ability to fully represent some aspects of environmental performance.

Although these metrics were tested on only a few real-world projects, an initial review suggests that projects that perform well on some measures may perform poorly on others. This suggests that it is worth looking at a variety of metrics, because they illustrate different effects that may not be closely correlated. It also suggests that the choice of weights for each metric will affect how a project rates on overall environmental performance compared to other projects.

The remainder of this digest

- summarizes the research objectives, background research findings, and environmental performance categories and metrics considered;

Table 1 Summary of most promising metrics of environmental performance.

Performance Category	Metric	Scope	Further Development Activities
Energy and greenhouse gas (GHG) emissions	Operating energy or GHG emissions per passenger-mile	Calculated for new project Include energy and GHG from fuel production as well as direct vehicle operations	• Decide whether to use energy, GHG, or both • Develop standard energy and emission factors or guidance for developing project-specific factors
	Construction energy or GHG emissions	Calculated for new project	• Research required to develop models for nonmaterials construction energy and GHG • Consider normalizing (per passenger-mile or route-mile) if used for comparing projects
Air quality and public health	Change in total project emissions	Calculated for highway and transit	• Determine pollutants of interest • Develop standard emission factors • Consider combined weighted index of all pollutants • Determine whether and how to include emissions from electricity generation
	Project air pollutant emissions per passenger-mile[a]	Calculated for transit project only	
	Change in daily nonmotorized access trips	Calculated for new project versus no-project	• Validation of consistency of results among projects/models • Consider/test total nonmotorized trips accessing new project as alternative
Ecology, habitat, and water quality	Fraction of corridor land that already is developed	Project corridor (*x*-mile radius)	• Consider categorical rating system (e.g., high, medium, low) based on quantitative benchmarks

[a]This alternative air quality metric was considered too late in the process to fully test and compare it to other metrics. Although the project team feels that project emissions per passenger-mile may be preferable to change in total emissions for informing comparative project evaluation, the alternative metric will need to be more fully tested before a final judgment is made.

- describes and discusses the most promising metrics, including key assumptions, ease of computation, results for sample projects, pros, and cons; and
- identifies limitations of the metrics and current evaluation framework, as well as next steps and issues for further research.

RESEARCH OBJECTIVES

Relationship to the New Starts, NEPA, and Local Planning Processes

Environmental benefits, including air quality, energy, livability, land use, and other benefits, have long been important considerations in evaluating and justifying transit investments at a local level. Potential negative impacts have also been an important consideration in project evaluation, especially since the passage of the National Environmental Policy Act (NEPA) in 1969.

Within the past two decades, the importance of environmental considerations has also been reflected in federal programs for funding major capital investments. Specifically, FTA's New Starts program provides discretionary funds to meritorious transit projects across the country. These funds are awarded on a competitive basis following a number of justification criteria, including environmental benefit. Consideration of environmental benefits as part of the New Starts evaluation and rating process dates to 1991 and the ISTEA, which directs that a project must be "justified based on a comprehensive review of its mobility improvement, environmental benefit, cost-effectiveness, and operating efficiencies."[1] FTA policy adopted in 1996 defined a multiple-measure approach for justifying New Starts projects that included changes in criteria pollutant emissions, carbon dioxide (CO_2), and energy consumption as well as current EPA air quality attainment designation.[2] Over time, however, FTA ceased to use these measures in New Starts assessment, as they found that the measures provided little or no basis for meaningfully distinguishing among projects and that emissions and energy consumption were closely correlated with ridership forecasts and user benefits.

The national spotlight recently has been refocused on the environmental benefits of transportation investments. In June 2009, FTA reintroduced environmental benefits as part of its rating process, giving the current EPA air quality designation for a project's region 10 percent weight in the overall evaluation. In June 2010, FTA issued an Advance Notice of Proposed Rulemaking (ANPRM) soliciting input on a variety of questions related to the New Starts process, including how environmental benefits should be measured. In January 2012, FTA issued a Notice of Proposed Rulemaking (NPRM) proposing a new regulatory framework for the New Starts program.[3] This notice was accompanied by proposed guidance with new measures and suggested methods for calculating the project justification and local financial commitment criteria, including environmental criteria.[4] Energy and greenhouse gas (GHG) savings have been criteria in recent competitive transportation funding programs including FTA's Transit Investments in Greenhouse Gas and Energy Reduction (TIGGER) program.

The land use and economic development impacts of projects are often considered in local evaluations of alternatives, as well as by FTA as part of its New Starts criteria. While specific environmental outcomes related to land use change (such as water quality or habitat preservation) are not assessed, long-term changes to land use and development patterns can have a significant impact on environmental outcomes. For example, a transit project may support more compact development patterns, which can reduce impacts on open space, habitat, and water quality associated with land consumption. Conversely, a project that increases accessibility in outlying, undeveloped areas may lead to negative impacts on these environmental factors. Thus, land use and economic development impacts are related to the measurement of environmental benefits. FTA's January 2012 NPRM recognizes this issue and proposes to allow project sponsors at their discretion to estimate the vehicle-miles of travel (VMT) associated with changes in development patterns enabled by a New Start project, and then incorporate that VMT into proposed environmental benefits measures.

NEPA requires disclosure of environmental impacts to determine the potential impact of the

[1]National Transportation Library. Intermodal Surface Transportation Efficiency Act of 1991. Available at: http://ntl.bts.gov/DOCS/istea.html (accessed March 20, 2012).

[2]61 Fed. Reg. 67093 (December 19, 1996).

[3]77 Fed. Reg. 3848 (January 25, 2012).

[4]Federal Transit Administration. Proposed New Starts/Small Starts Policy Guidance, January 2012.

project on the natural, built, and human environments. The NEPA process has different objectives than may be set by project sponsors or by FTA for the evaluation of environmental benefits. NEPA focuses on ensuring that environmental impacts are disclosed and options for avoiding and minimizing adverse environmental impacts are identified, considering an expansive list of issues. In contrast, the purpose and need of a project may include a small number of goals to preserve or enhance aspects of these environments, and the New Starts process is focused on comparing projects nationally to guide investment decisions using a very limited set of measures.

The research performed in this project was not intended to duplicate the issues given the greatest scrutiny in the NEPA process, such as the direct, local air quality, water quality, and cultural resource impacts from project construction and operation. It is assumed that the outcomes of the NEPA process lead to acceptable avoidance or mitigation of these impacts such that they are not a major distinguishing factor from a national perspective. Instead, this research focuses on broad measures of environmental performance, including benefits as well as impacts, that may be of interest to decision makers.

RESEARCH PROCESS

The research was guided by a 20-member project panel that included representatives from transit agencies, state departments of transportation (DOTs), a regional planning commission, a department of urban planning from a major university, environmental and transportation planning consulting firms, an environmental action organization, the EPA, FTA, and several transportation industry associations including APTA, AASHTO, and the CTAA.

In the first phase of this research, a literature review and review of recent environmental documents were conducted to identify candidate metrics and to review current practices in environmental evaluation for transit projects. This process included a review of international practices in environmental evaluation. Opinions were also solicited from 20 stakeholders, including transit industry representatives and others, regarding how environmental performance measures should be developed and used. Finally, comments that were submitted by the August 9, 2010, deadline for public comment on the June 2010 FTA New Starts ANPRM were reviewed.

From this background research, more than 120 candidate performance metrics were identified. This list was screened according to a set of evaluation criteria. In consultation with the project panel, the researchers identified a set of 21 metrics in four environmental performance categories for further testing. The criteria used for screening the metrics included

- data availability and reliability;
- ease of forecasting; and
- environmental relevance.

A key objective of this research was to identify metrics that can be developed and assessed without placing undue burden on decision makers. At the same time, the metrics should be robust enough to reliably distinguish among projects in direct relation to their environmental performance.

In the second phase of the research, six pilot transit projects were recruited on which to test these metrics. These projects included light rail, diesel and electric commuter rail, and bus rapid transit projects located in a mix of urban and suburban areas. Available data were obtained from each project and used to calculate each of the metrics. The level of effort to provide and analyze the data was evaluated. In most cases, data availability and resource limitations permitted the metrics to be tested on only a subset of the pilot projects. However, the results were judged adequate to assess the usefulness, reliability, and ease of calculation of each metric. A second screening process was then applied to classify these metrics into three tiers: highly promising, somewhat promising, and not promising. The most appropriate uses of each metric also were identified.

BACKGROUND RESEARCH FINDINGS

Literature Review

Types of literature reviewed included reports enumerating and discussing how to measure benefits and impacts of transit, including environmental effects; reports examining transportation performance measures and evaluation frameworks both in the United States and abroad; and reports and detailed guidance on specific environmental measures, such as GHG reporting protocols. For example, the Strategic Highway Research Program 2 (SHRP 2) Project C02 produced a library of performance measures for highway capacity expansion investments, including environmental measures, many of which are applicable to transit as well as highway projects. An annotated bibliography is provided as Appendix I of the final research report, which is available online as *TCRP Web-Only Document 55: Assessing and Comparing Environmental Performance of Major Transit Investments.*

Environmental Performance Rating Systems. The literature review also identified environmental performance rating systems and tools. With growing interest in sustainability, a number of assessment tools have been developed to assist organizations in assessing and rating the sustainability or environmental performance of their operations. Most performance rating systems are not transit-specific, but many include metrics that may inform transit applications. Some of these systems are focused on buildings (e.g., Leadership in Energy and Environmental Design, or LEED), which could be applied to transit agency facilities. Others have been developed for infrastructure projects, primarily highways (e.g., Greenroads), but their principles could be extended to transit project construction. International Organization for Standardization (ISO) certification focuses on environmental impacts across a full range of an agency's operations. These systems generally evaluate the extent to which the direct impacts of project construction and operation are mitigated, rather than the overall environmental benefits of the project (including effects on travel).

International Practice. The literature review also included a review of the process and methods by which environmental criteria are assessed in other countries. The primary focus was on Strategic Environmental Assessment (SEA) or multicriteria analysis. SEA, which is required of European Union member states, seeks to evaluate the environmental effect of policies and plans during early stages of the planning process. One of the key features of SEA is that the multi-attribute analysis examines various environmental effects versus economic, equity, and other impacts of interest to policy makers. It typically covers all transport modes instead of being transit- or highway-specific. Identified benefits of SEA include early consultation and increased transparency of the planning process; actual changes in policies and plans in response to environmental problems; and reduction of the need for various mitigation procedures because of earlier consideration of environmental impacts. This approach to strategic policy-level environmental assessment contrasts with the U.S. and Canadian focus on project-based environmental impact analysis.

Performance Measurement in Environmental Analysis

To evaluate how transit's environmental performance is currently evaluated and considered in environmental documentation and project development in the United States, EIS and AA documents were reviewed in detail for four sample transit projects. The purpose of the review was to identify which environmental impact measures have been used and how they are calculated.

The specific measures evaluated and calculation methods used varied somewhat from project to project. Overall, however, the review confirmed that most (but not all) impacts are treated as negative impacts to be mitigated. Many impacts were considered to varying degrees in alternatives development and selection, although it was often difficult to quickly assess key differences among alternatives or tell from the documentation how much a particular impact weighed on the selection process. Specific findings included the following:

- Most impacts are treated as negative impacts to be mitigated (or documented as having no significant impact). In some cases, however, impacts such as air quality or GHG emissions are treated as positive impacts (e.g., helping to avoid traffic growth). Avoiding induced growth (or inducing growth consistent with local and regional plans) also was identified as a positive impact for some projects.
- Significant variability exists in how the information is reported. It was generally difficult to quickly compare the environmental impacts of different projects or alternatives.
- Most of the focus is on direct impacts from operating the system, although construction impacts (e.g., air quality, noise, and water quality) are evaluated, in some cases with varying degrees of rigor. If secondary or life-cycle impacts are addressed at all, the discussion is brief and qualitative, or too entangled with cumulative impacts to differentiate between what is a project impact versus an impact from other outside factors.
- When alternatives are compared, they are not always compared to one another in all categories. For example, a project may be compared to an alternative with respect to wetlands alteration, but no direct comparison is made with respect to environmental justice.

- The criteria by which alternatives are compared against one another are not weighted. For example, if a project has minor impacts on wetlands but significant impacts to historic resources, which factor "wins"?
- When comparing different projects from different parts of the country, a significant issue in one region may not even come into play in another region (e.g., earthquakes/landslides; maintaining groundwater levels in areas where buildings are supported by wooden piles).

Feedback from Stakeholders

Interviews were conducted with 20 stakeholder agencies or organizations in April through June 2010 to identify how transit agencies, state transportation agencies, advocacy groups, and academic researchers have evaluated the environmental performance of transit investments beyond the evaluation and reporting conducted for the NEPA process. In addition to specific measures and methodologies, the interviews sought to obtain feedback on how environmental performance should or might be evaluated in the future.

Environmental performance measures were found to have the following uses:

- **Prioritizing transit investments.** Although the use of environmental performance measures in selecting investments was not common among the survey respondents, respondents reported innovative ways to incorporate these metrics into project evaluation.
- **Applications for federal funding.** All transit agencies responded that in addition to improving the planning process, environmental metrics will prepare them for future funding application and reporting needs.
- **Participating in local requirements and environmental targets.** A few transit agencies participate in local environmental initiatives measuring the effects of public transportation on the regional environment.
- **Outreach and marketing.** Transit industry and advocacy groups are actively publicizing the environmental, social, and economic benefits of transit.

Stakeholders offered a variety of suggestions to consider in the development of environmental performance measures to compare and assess transit investments. Common themes and other notable points included the following:

- Reductions in VMT were widely viewed as a measure of interest related to environmental performance. Many projects, however, particularly those in densely developed areas with an existing high transit mode share, may not result in a significant reduction of VMT but instead will improve conditions for existing transit travelers. As a result, VMT reductions—or related measures such as vehicle emissions and energy use—should not be the sole measure used to determine the project's environmental efficacy. Another way of looking at this is that projects should be rewarded for improving travel conditions in highly developed settings, helping to attract and retain people in these settings where the environmental impacts of travel can be much lower.
- A number of respondents noted that the *indirect* environmental impacts of transit, related to changes in land development patterns, may be much more significant than the direct impacts and should be given important consideration.[5]
- Some respondents also noted that the *baseline of comparison*—transit versus no-build, or transit/development versus highways and sprawl—is significant in determining whether transit provides environmental benefits.
- Interest was expressed in measuring the *lifecycle* environmental impacts or benefits of transit, particularly with respect to energy use and GHG emissions, but further research and guidance is needed on this topic.
- Some transit agencies have developed metrics related to quality of life and view this as an important benefit, although these metrics differ from location to location.
- Some stakeholders noted that metrics and methods should be flexible to account for the unique operating environments for transit systems across the nation. At the same time, benchmarks and standards are needed for performance measures to provide guidance to transit agencies and consistency across projects.

[5] APTA has proposed a "land use multiplier" to capture additional benefits of more compact land use, although this concept needs additional research to identify its value and applicability across a wide range of project contexts. *See:* APTA Climate Change Standards Working Group, *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit,* APTA CC-RP-001-09.

ENVIRONMENTAL PERFORMANCE CATEGORIES AND METRICS CONSIDERED

Based on findings from the literature review and stakeholder outreach, the project team established the following categories for assessing and comparing the environmental performance of major transit investments:

- Energy use and GHG emissions
- Air quality and public health (including physical activity)
- Ecology, habitat, and water quality
- Community and quality of life (including livability)

This set of categories considers both the natural and human environment, consistent with practice under NEPA. However, this project was not intended to provide a detailed review of the full set of indicators of performance with respect to the human environment. In this project, the measures considered focused on the physical environment (natural or human), including factors such as noise, aesthetics, and historical resources. This project did not examine measures concerned with the human social environment, such as safety and security, access to affordable housing, and so forth.

At a meeting of the project panel in September 2010, it was determined not to include community and quality-of-life metrics in Phase 2 testing. These metrics were viewed as important, but not the focus of the current research project. Therefore, Phase 2 research focused on the first three environmental performance categories.

Various dimensions of environmental performance were also identified. These dimensions included impacts related to

- **direct effects of vehicle operations,** such as changes in transit and highway vehicle travel, including both the impacts of vehicles themselves and the production and transport of fuel to power the vehicles (full fuel cycle);
- **impacts from other system elements,** such as construction of infrastructure and vehicles (transit and highways, depending on the baseline for comparison), as well as maintenance, nonvehicle operations (e.g., station power), and disposal; and
- **indirect effects,** such as land conversion, changes in building stock, and travel impacts associated with changes in land use patterns.

The relationship between the performance categories and the dimensions is illustrated in Table 2.

This research primarily focused on vehicle operations (both highway and transit) as well as indirect environmental effects of land conversion. For energy and GHG metrics, both direct and fuel-cycle energy use and emissions were included. Energy and emissions associated with system construction were also considered to the extent that data were available, but

Table 2 Environmental performance categories and dimensions for evaluation of major transit projects.

	Vehicle Operations		System Construction, Maintenance, Operations, and Disposal		Indirect Effects		
Performance Category	Direct	Full Fuel Cycle	Facilities	Vehicles	Land Conversion	Buildings	Travel Impacts
Energy use and GHG emissions							
Air quality and public health							
Ecology, habitat, and water quality							
Community and quality of life	(Not assessed in this research)						

maintenance, operations, and disposal were not considered due to lack of data. Indirect effects from travel associated with land use changes resulting from the transit project are not currently considered in comparative analysis and therefore were not considered. Effects associated with changes in building stock were deemed too speculative to consider and also outside the range of typical transportation analysis.

The 120 candidate metrics identified through the background research were organized into the four performance categories. The full list of metrics initially considered is documented in Appendix H of the final research report, which is available online as *TCRP Web-Only Document 55: Assessing and Comparing Environmental Performance of Major Transit Investments.*

The metrics were screened to a shorter list of 21 metrics based on data availability and reliability, ease of forecasting, and environmental relevance as described above. Each metric was assigned a unique identifier, or key, beginning with a roman numeral that corresponds to one of the environmental performance categories. The metrics selected for more detailed testing in Phase 2 of the research are listed and described in Table 3. Table 3 also adds a category of "cross-cutting" metrics that address issues in all of the other categories.

The metrics shown in Table 3 were evaluated according to the following factors:

- Ease of data collection and computation
- Reliability of data
- Usefulness for purposes of distinguishing among transit projects and project alternatives based on environmental performance

The metrics were then placed in three tiers according to their performance:

- Tier 1: Strong candidate for use
- Tier 2: Possible candidate for use
- Tier 3: Not recommended for use at this time

Table 3 Metrics of transit's environmental performance evaluated in detail.

Key	Metric	Description	Tier
I. Energy and Greenhouse Gas Emissions			
IA	Operating GHG emissions per passenger-mile	Annual GHG emissions from new project divided by annual passenger-miles on project. Includes "upstream" emissions from transit vehicle operations and fuel production.	1
IB	Operating energy consumption per passenger-mile	Annual energy consumption from new project divided by annual passenger-miles on project. Includes energy use for transit vehicle operations and fuel production.	1
IC(i)	Change in operating GHG emissions	Change in annual GHG emissions for project versus no-project, considering transit and highway vehicles, including emissions from fuel production.	2
ID(i)	Change in operating energy consumption	Change in annual energy consumption for project versus no-project, considering transit and highway vehicles, including energy used in fuel production.	2
IC(ii)	Project cost per reduction in operating GHG emissions	Total annualized capital cost plus change in transit operating cost, divided by change in total annual GHG emissions.	3
ID(ii)	Project cost per reduction in operating energy consumption	Total annualized capital cost plus change in transit operating cost, divided by change in total annual energy use.	3
IE(i)	Construction GHG emissions	Total GHG emissions associated with project construction, including emissions embedded in materials.	2
IE(ii)	Construction energy consumption	Total energy use associated with project construction, including energy embedded in materials production.	2

Table 3 (*Continued*)

Key	Metric	Description	Tier
II. Air Quality and Public Health			
IIA(i)	Change in direct operating emissions	Change in annual pollutant emissions for project versus no-project, considering transit and highway vehicles, for the following pollutants: VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and seven mobile-source air toxics.	2
IIA(ii)	Dollar of project cost per change in direct operating emissions	Total annualized capital cost plus change in transit operating cost, divided by change in total annual emissions for each pollutant.	3
IIB	Exposure Index	An index of the change in pollution weighted by potential population exposure (based on emissions and population by area). Calculated for each pollutant.	3
IIC	Health Benefit Index	An overall index of the change in pollution weighted by potential population exposure (based on emissions and population by area) and health impacts of each pollutant.	3
IID	Air Quality Index	Indicator of the severity of the air quality problem in a metropolitan area, based on air quality monitoring data.	3
IIE	Forecast change in daily nonmotorized access trips	The change in daily nonmotorized access trips for the project versus no-project alternative.	2
	Level of Service and other measures of pedestrian and bicycle access to transit[a]	Measure of the extent to which the environment in proposed project station areas supports walk and bicycle access.	3
III. Ecology, Habitat, and Water Quality			
IIIA	Percent of corridor that is already developed	Percent of land in transit corridor (defined as a two-mile radius around the project alignment) that is in land use categories identified as developed.	2
IIIB	Potentially impacted acreage of undeveloped land	Amount of land in transit corridor that is in land use categories identified as developed.	3
IIIC	Potentially impacted acreage of sensitive habitat	Amount of land in transit corridor that is in land use categories identified as sensitive (in this case, agriculture and wetland).	3
IIID	Potentially impacted acreage weighted by ecosystem service value	Amount of land in transit corridor that is in land use categories identified as sensitive, weighted by ecological value.	N/A
IIIE	Adequacy of state, regional, and local habitat protection plans	Qualitative, benchmark-based assessment of the extent to which state, regional, and local plans provide protection against development for sensitive habitat.	3
IV. Cross-Cutting Metrics			
	Environmental performance ratings for transit projects[a]	Checklist approach to assessing the extent to which project planning, design, construction, and operation incorporates green or sustainable practices to minimize environmental impacts.	2

[a]The pedestrian and bicycle access and environmental performance ratings metrics were not tested on the pilot projects. However, the panel asked for information on them, which was provided in white papers that are included as Appendices E and F to the research report.

(The metrics summarized in Table 1 represent a subset of the metrics identified as Tier 1 and Tier 2 that are not redundant.)

Variations on some of the metrics shown in Table 3 were suggested later in the project, which precluded evaluating them in detail. Notably, these include *construction energy or GHG per dollar cost or project-mile* as a variant on IE: *transit air pollutant emissions per passenger-mile* as a variant on IIA; and *total nonmotorized trips accessing the new project* as a variant on IIE.

DESCRIPTION AND DISCUSSION OF MOST PROMISING METRICS

This section describes each of the most promising metrics, including how the metric is calculated, key assumptions, results from pilot-testing, pros, cons, and a summary of how it might be used. Each metric's potential is considered for use by decision makers to evaluate individual project alternatives and to compare multiple projects in different regions of the country. The metrics are discussed in an order that presents simpler or more basic metrics first.

Metric IB. Operating Energy Consumption: Btu per Passenger-Mile

Calculation. This metric is calculated as the total operating energy used by the proposed transit project (considering upstream energy associated with fuel production as well as direct vehicle energy use) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in energy use from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include

- ridership forecasts;
- transit VMT for the proposed project; and
- transit vehicle energy consumption rates.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects and from comparative analysis of multiple projects. Project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. Also, analysis of operating plans for the proposed project may be required to determine changes in transit VMT.

Results. Values for this metric from pilot-testing ranged from a low of 500 to 1,000 British thermal units (Btu) per passenger-mile for a bus rapid transit (BRT) project to a high of 3,200 Btu per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative of 1,800 Btu per passenger-mile. Estimates for two light rail projects were in the range of 1,400 to 1,800 Btu per passenger-mile.

Pros. Btu per passenger-mile has a number of advantages and seemed to be a useful metric. It is understandable and logical as a measure of the efficiency of travel. It clearly differentiates among projects, because it is not diluted across a system or broad area, and it shows a range of values across projects. It can be compared with the efficiency of other projects and other modes (for example, the average single-occupancy vehicle on the road today uses about 4,600 Btu per passenger-mile). It rewards both efficient vehicle technology and high ridership density. It eliminates some uncertainty factors present in other energy and GHG metrics that consider diverted automobile trips, including fuel efficiency of the future automobile fleet, forecast VMT and speed changes for highway vehicles, and choice of appropriate GHG factors. It addresses concerns from project sponsors who are improving travel conditions for a largely captive ridership base rather than shifting riders from automobiles to transit, given that the value of the metric does not depend upon mode-shifting. Compared with GHG emissions, energy consumption as a metric may appeal to a broader set of constituents, including those interested in energy security issues.

Cons. Btu per passenger-mile is not a complete measure of the energy impacts of a project, as it does not account for nonproject operational changes (transit or highway) or the benefits of riders who shift modes from automobile to transit. It only indirectly measures environmental impacts, because different fuel sources will have different environmental impacts (including GHG emissions and air quality) per Btu. It does not indicate the *relative* benefits or cost-effectiveness of the investment (i.e., how much energy use is being reduced as a result of federal and local spending). The use of national default vehicle energy consumption rates (Btu per vehicle-mile), while improving consistency, may not be appropriate given that individual transit projects have different levels of energy consumption depending upon vehicle technology as well as operating characteristics.

Summary. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric. If the metric is adopted for use in comparative project evaluation, consistent and appropriate energy consumption factors for different types of transit vehicles will be needed, reflecting current and anticipated future transit vehicle technology and/or close scrutiny of energy consumption estimates provided by the project sponsor.

Metric IA. Operating GHG Emissions per Passenger-Mile

Calculation. This metric is calculated as the total transit operating GHG emissions from the proposed project (considering upstream fuel emissions as well as direct vehicle emissions) divided by the number of passenger-miles on the proposed project. The metric does not consider increases or decreases in GHG emissions from other elements of the transit system (e.g., changes in feeder bus service) or from trips diverted from automobiles.

Key Assumptions. Key assumptions and areas of uncertainty include

- ridership forecasts;
- transit VMT for the proposed project;
- transit vehicle energy consumption rates; and
- upstream GHG emissions per unit of energy for alternative energy sources, including electricity.

Ease of Computation. The measure is fairly easy to compute from data sources typically developed for project ridership forecasting and environmental analysis of individual projects, and from comparative analysis of multiple projects. As is also the case for the Btu per passenger-mile measure, project-specific energy consumption rates are rarely known or reliably estimated, however, and national default averages by mode must generally be used. GHG emission rates must also be used from national or regional sources. Analysis of operating plans for the proposed project is required to determine changes in transit VMT.

Results. Values for this metric in pilot testing ranged from a low of 0.04 to 0.08 kilograms equivalent carbon dioxide (CO_2e) per passenger-mile for a BRT project to a high of 0.25 kilograms CO_2e per passenger-mile for a diesel commuter rail project. An electrified alternative of the commuter rail project showed a significantly lower value than the diesel alternative—0.13 kilograms per passenger-mile. Estimates for two light rail projects were in the range of 0.10 to 0.18 kilograms per passenger-mile.

Pros. The pros of this measure are largely similar to the pros of Btu per passenger-mile. This measure has an added benefit of relating directly to a particular environmental impact (GHG emissions) and considering the GHG intensity of different fuel types.

Cons. Cons are also largely similar to Btu per passenger-mile. The benefit of introducing GHG as a measure must be weighed against the challenges of fairly assessing differences in the GHG intensity of the same type of fuel among project sponsors (e.g., electricity generation by region of the country), as well as accounting for uncertainty in GHG intensity forecasts and current and future life-cycle GHGs associated with biofuels.

Summary. This metric should be considered as an alternative or supplement to Btu per passenger-mile. The transparency of this metric, limitations on uncertainty, and ability to distinguish among projects in a way that is clearly related to environmental impacts make this a promising metric. If the metric were adopted for comparing projects in different regions of the country, attention would need to be given to developing consistent and appropriate energy consumption factors for different types of transit vehicles as well as appropriate life-cycle GHG emission factors (current and future) for alternative fuels. A decision would also need to be made as to whether to use average national GHG intensity factors for electricity generation or regionally specific factors, which would reward projects in regions of the country with a "clean" electricity mix.

Metric IE(i). Construction GHG Emissions

Calculation. This metric includes emissions from materials and equipment used in construction of the transit project. Because of data limitations, it was not fully tested on the pilot projects. The metric could be reported in total or normalized per route-mile, per passenger-mile, or per dollar of project cost. It also could be annualized and combined with operating emissions for a life-cycle GHG metric.

Key Assumptions. Key assumptions and areas of uncertainty include

- all key assumptions for change in operating GHG emissions;
- GHG emissions embodied in materials used in construction, per unit of material;
- type and amount of materials used in construction (e.g., steel per track-mile);
- activity of equipment used in project construction, by type of equipment;
- GHG emission factors by type of equipment;
- other construction-related GHG emissions, including staging, lighting, and work zone traffic delays; and
- appropriate factors for annualizing construction GHG emissions over the project lifetime.

Ease of Computation. The research team for this project developed a model of GHG emissions embodied in materials used in transit projects, based on general estimates of materials use. This model allows for calculation of embodied GHG based on parameters generally available in transit project planning, such as new track-miles, miles of overhead catenary, number and type of stations, and so forth. However, data were not available to permit the estimation of emissions from construction equipment activity or other nonmaterial emissions, and therefore a complete estimate of construction GHG emissions could not be developed. A research project initiated in Fall 2011 by FHWA is intended to develop a model that includes all construction-related activities and can be used at a planning level for transit as well as highway projects.

Results. A sample calculation performed for one of the pilot projects resulted in an estimate of 268,000 tons CO_2e for a light rail project of roughly 10 miles in length.[6] This equates to approximately 5,000 tons per year when annualized over a 50-year period, which is a common expected lifetime for many project components. This can be compared to increases in transit operating GHG emissions in the range of 5,000 to 25,000 tons per year, and decreases in highway vehicle operating emissions in the range of 5,000 to 40,000 tons per year, for the pilot rail projects. This calculation suggests that construction emissions are a nontrivial contributor to the life-cycle GHG emissions of a transit project, and will to some extent offset savings in combined highway and transit operating emissions.

Pros. Including construction emissions has the advantage of more fully presenting the impacts of a project, and also helping to differentiate projects that have more or less GHG-intensive construction practices. Furthermore, it is likely that within the next 2 years a model will be publicly available that is suitable for making estimates of transit construction emissions based on data that are readily available once a project, mode, alignment, and station locations have been selected. This model is likely to allow testing of the impacts of alternative, GHG-reducing construction methods in addition to standard methods.

Cons. The use of average factors (e.g., GHG per track-mile of surface alignment) makes data collection practical at a planning level but also means that details of project construction that may have significant effects on construction GHG emissions (e.g., amount of cut-and-fill required, extent to which highway traffic is affected) are ignored. Including construction GHG emissions in a life-cycle metric may paint a misleading picture of the project if the results are used in comparisons with other projects (e.g., highway projects) that do not include full life-cycle emissions.

Summary. This metric is promising, but it needs further supporting research and development. Different ways of normalizing the metric (such as per dollar cost, per route-mile, or per passenger-mile)

[6] All tons are metric.

should be explored to allow comparison among projects of different sizes. At this point, the primary value of this metric is to compare different transit projects against each other to evaluate the GHG efficiency of their construction methods, or for evaluation of different project alternatives that include different amounts of underground versus above-ground construction, station configurations, and so forth. It is not recommended that construction emissions be combined with operating emissions for an overall life-cycle GHG metric because such life-cycle evaluation is not a standard practice in transportation project analysis.

Metric IIA(i). Change in Direct Operating Emissions

Calculation. This metric was originally defined as the total change in direct operating emissions from highway and transit vehicles, measured in kilograms of pollutant per year. Toward the end of the research, the research team suggested an alternative approach of taking only emissions for the new transit project and dividing by passenger-miles to get a metric similar to the proposed energy and GHG per passenger-mile metrics.

Emissions can be calculated for individual criteria pollutants or precursors, including oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), and coarse and fine particulate matter (PM_{10} and $PM_{2.5}$). Emissions also can be computed for a number of significant air toxics which are not currently regulated but nonetheless known to be a health concern. The EPA has identified six mobile-source air toxics (MSATs) that contribute significantly to health risk estimates and are released to the air mostly by transportation: acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel engine exhaust, and formaldehyde. The metric as originally calculated did not include air pollution from electricity-generation facilities, primarily because of lack of data, but also because these pollutants are also likely to be generated in non-urban areas where exposure to population and consequent health effects are less than for direct emissions from vehicles. However, to make emissions per passenger-mile a meaningful metric for comparing electric rail projects (for which direct emissions are zero), electricity-generation emissions should be included.

Key Assumptions. Key assumptions and areas of uncertainty for calculating total emissions changes include

- Changes in highway and transit VMT;
- vehicle emission rates, including current and future emissions for both highway and transit vehicles reflecting local conditions (traffic flow, fuel, vehicle fleet mix, climate, etc.), and emission rates for alternative fuel vehicles not included in current emissions models; speed changes on the roadway network due to impacts on congestion, and subsequent effects on emissions; and
- emissions of air pollutants from electricity-generating power plants (if included).

Highway vehicle data are not required if only emissions per passenger-mile for the new project are calculated.

Ease of Computation. The ease of computing changes in pollutants depends on the region's air quality modeling requirements and capabilities. Regions in nonattainment or maintenance status are likely to have developed emission factors for the pollutants of local concern, and may have already computed changes in these pollutants for environmental documentation purposes. If emission factors and/or pollutant changes have not been calculated, they can still be calculated by an analyst skilled in the use of an emission factor model, such as EPA's Motor Vehicle Emission Simulator (MOVES) model or the California Air Resources Board's EMission FACtors (EMFAC) model, using default assumptions in conjunction with travel demand forecasts developed for the project. Air toxics emissions factors are unlikely to have been calculated already and would need to be developed. Existing emission factor models only include diesel and compressed natural gas options for buses, and the project sponsor, in consultation with the transit vehicle manufacturer or using literature sources, must develop appropriate emission factors for any alternative technologies or fuels. As with the energy and GHG calculations, transit operating plans must also be identified to calculate VMT changes for all transit services affected by the project. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Once total emissions for the project are calculated, emissions per passenger-mile can be easily calculated based on the same ridership data as used in the energy and GHG metrics.

Results. Only four projects (of which two were variations on the same project) were evaluated for total emissions because of difficulties in collecting and processing data from some projects. All four projects showed reductions in all pollutants. The maximum changes observed were a reduction of 14 tons per year of NO_x, a reduction of 18 tons per year of VOC, and a reduction of 1.9 tons per year of PM_{10}. To provide scale, pollutant changes as a percentage of regional or subregional (modeled area) emissions from highway vehicles were computed for all four projects and found to be in the range of –0.05 percent to –0.2 percent for most pollutants. Emissions for one project were found to be somewhat more significant when measured as a percentage of corridor emissions (transportation analysis zones [TAZs] within a 2-mile buffer of the project alignment), where a project resulted in a 22 percent decrease in transit emissions in the corridor due to replacing bus service with electric rail. However, transit emissions were dwarfed by highway vehicle emissions in the corridor and the net effect was a reduction of less than 0.2 percent in combined highway and transit emissions. Subregional percent changes of NO_x for the BRT project differed from its percent changes for other pollutants because an increase in NO_x from the BRT service offset about half the savings from highway vehicles.

Emissions per passenger-mile were calculated for two projects, a light rail transit (LRT) project and an electric commuter rail project, using forecast national average pollutant emissions rates identified in a private-sector study. Only forecasts of VOC, NO_x, and PM_{10} were available. (The metric was introduced for consideration after most of the research was completed, which is why it was not tested on all projects.) Coincidentally, both projects showed approximately the same emission rates per passenger-mile. For the electric commuter rail project, the transit project emissions per passenger-mile were about one-third of highway vehicle emissions (per vehicle-mile) for NO_x and one-quarter for PM_{10}. For the LRT project, emission rates were about one-half of highway vehicles for NO_x and similar for PM_{10}. VOC emissions from electricity generation were very small relative to highway vehicle emissions and were not calculated.

Pros. Total emissions changes are a direct measure of air quality benefits. Changes in VOC, CO, NO_x, and PM emissions are familiar to air quality planners who often use them for evaluating projects for air quality program funding. Evaluating individual pollutants and examining transit and highway emissions separately can demonstrate the effects of differences in transit vehicle technology (e.g., diesel versus electric rail). This metric does not require the spatial allocation of emissions, as do the Exposure Index and Health Benefit Index metrics.

Measuring emissions per passenger-mile has the benefit of showing potentially meaningful differences among projects, considering both passenger loading and vehicle technology. It rewards clean and highly productive projects whether they attract new riders, or improve service for existing riders. It is a normalized metric whose value does not depend upon the scale of the project.

Cons. Changes in kilograms or tons of pollutant emissions is not a metric that most laypeople can readily grasp the significance of, and in fact, a ton of one pollutant may be much more or less important than a ton of another pollutant depending on the relative health effects of each pollutant. As has proven to be a problem in the past, the change in pollutant emissions for a single project tends to be small when compared with total regional emissions. Furthermore, multiple pollutants are of interest (particularly when air toxics are considered), and they cannot easily be combined into a single metric, leading to a proliferation of different metrics that are often (but not always) correlated. Although an individual region may be able to focus on two or three pollutants of particular concern to them, pollutants of local concern will vary from region to region, which poses a challenge for evaluating multiple projects consistently. The exclusion of emissions from electricity generation may be viewed as a bias in favor of electrically powered projects; these emissions could in theory be calculated, but more work would be required to identify local power plants and corresponding emissions rates.

As a metric, emissions per passenger-mile does not consider benefits from reduced highway vehicle travel, and does not indicate the aggregate air quality benefits of the project.

Summary. This metric is proposed as a second-tier metric. Change in total emissions has been used this way in the past (and therefore has been proven feasible), and is often used by regional planners to evaluate projects being considered for air quality improvement purposes. However, this metric was not found helpful for distinguishing among projects in the context of comparative evaluation. If it is used, consideration might be given to developing a single pollutant index based on relative toxicity weightings for current criteria pollutants and precursors (VOC, NO_x, CO, PM_{10}, and $PM_{2.5}$). A determination would also need to be made whether to include air toxics. Although air toxics are of increasing concern, they are currently not regulated from transportation sources and in general will be closely correlated with VOC and PM emissions, meaning that introducing MSATs into the evaluation is unlikely to further affect decision making.

A variation of this metric, project emissions per passenger-mile, should be considered as an alternative air quality indicator, as it will help show meaningful differences among projects, considering both transit vehicle technology/control and the efficiency of loading.

Metric IIE. Forecast Change in Daily Nonmotorized Access Trips

Calculation. This metric is calculated as the difference in nonmotorized transit access trips (usually walk trips) for the project versus no-project alternative, as determined from the travel demand forecasting model used for the project. This metric is proposed as the most direct measure of physical activity actually generated by the transit project. A variation of this metric, *total nonmotorized trips accessing the new project,* might be considered to alleviate concerns about projects that primarily improve conditions for existing riders.

Key Assumptions. Key assumptions and areas of uncertainty include

- accuracy and resolution of the access mode choice model included in the travel demand model (e.g., trip purposes differentiated, calibrated based on local versus transferred data, bicycle versus pedestrian included);
- lack of detailed data on the pedestrian environment and walkability, or other factors (e.g., parking availability) that may affect access mode choice; and
- models that do not account for spatial distribution of trip generators below a TAZ level (e.g., concentration within walking distance of the transit station versus dispersed throughout the TAZ).

Ease of Computation. This metric can usually be easily calculated from the data produced by the travel demand forecasts developed for ridership forecasting and traffic impact assessment.

Results. The forecast change in daily nonmotorized trips across six pilot projects ranged from 2,600 for a commuter rail project to 15,000 for an urban/suburban light rail project. An assessment of the model structures suggested that all the models should produce reasonable forecasts; nonetheless, some models had clear limitations compared to others. It was therefore impossible to say with confidence that a ranking of projects based on modeled walk trips would be proportional to the actual benefits of the projects, versus differences in the quality of the model or its underlying data.

Pros. As a proxy for physical activity and related health benefits, this metric is preferable to measures of the built environment, which indicate how much *potential* there may be for "active" modes of transport, but not the actual use of such modes. For most projects, this metric can be calculated from available travel forecast data.

Cons. This metric is an absolute measure and is not scaled by size of the project. (Scaled metrics such as walk trips per project-mile or per dollar invested could be developed, but would be less intuitive.) Differences in mode choice forecasting models mean that it may be difficult to reliably attribute differences in forecast nonmotorized trips to the actual benefits of the project rather than model limitations or sensitivities, when comparing across projects sponsored by different agencies. Projects that improve conditions for existing riders, rather than generating new transit trips, will not perform well on this metric.

Summary. This metric is clearly appropriate for decision makers to use to evaluate project alternatives. If used for comparative evaluation of multiple projects in different regions, it might benefit from sensitivity testing to assess how values will vary depending upon modeling methods (as opposed to project conditions). Development of standards for access mode choice models would provide more confidence that results across projects can be compared.

Metric IIIA. Percent of Corridor Land that Is Already Developed

Calculation. This metric indicates the extent to which the project serves existing communities or developed areas versus undeveloped areas. It is computed as the ratio of land in the corridor that is already developed to total land in the corridor. For purposes of pilot-testing, the *corridor* was defined as a 2-mile radius around the project alignment. A higher value for this metric is hypothesized to relate to lower environmental impact, because any project-related development pressures are more likely to occur in already-developed areas rather than greenfields areas.

Key Assumptions. Key assumptions and areas of uncertainty include

- spatial resolution of land use data to identify developed versus undeveloped land, and ambiguity over whether or not certain areas or land use classifications are considered developed (e.g., parks, rural residential parcels that could be subdivided);
- presence of undeveloped land as a proxy for potential environmental impacts (depending on the environmental quality of the undeveloped land, existence of land protections, and influence of the project on development); and
- whether land use data are up-to-date.

Ease of Computation. Land use databases in geographic information systems (GIS) format are available covering most metropolitan areas, including most of the pilot project regions, at zero or minimal cost from regional or state agencies. However, the land use or land cover categories in these databases must be manually classified to identify "developed" versus "undeveloped" categories. Once that is done, the metric can be calculated relatively easily using standard GIS software.

Results. For most of the pilot projects, this metric had a value of 90 percent or higher, meaning the corridors are already highly developed. However, one suburban commuter rail project had a value of 36 percent. This appeared to be due in part to a state land use database that was based on polygons derived from satellite imagery of land cover, rather than on parcel-level use data. For example, a wooded 2-acre residential parcel might be identified as 1 acre of forest and 1 acre of residential, whereas in another region it would be identified as 2 acres of residential. Also, in one region, existing land use data could not be obtained, and existing zoning was used as a proxy. Using existing zoning probably inflated the value of the metric, because land might be zoned for development but not actually developed.

Pros. The values reported for this metric do not depend on making (highly uncertain) inferences about the potential impact of the project on development. Even if its relationship to direct environmental impact is questionable, it can serve as a measure consistent with livability goals by objectively describing the extent to which the project serves existing communities.

Cons. This metric is only a rough proxy for environmental impacts rather than a direct measure. It is unclear that the additional effort involved in computing this measure is worthwhile compared to a simple qualitative assessment of the extent to which existing communities are served (as can be done using information already reviewed in the land use assessment). Not all decision makers are likely to agree that serving existing communities is environmentally preferable to serving new, growing communities, where transit might help shape patterns of sprawl into patterns of more compact growth. Different projects are likely to have different land use-related environmental impacts depending on growth pressures, land use policies, and other factors not captured, even if corridor land use conditions are similar.

Summary. This metric is recommended largely because of its potential utility as a quantitative measure related to livability, and because it is a relatively simple (if crude) indicator of the project's potential positive versus negative impacts on new development and associated environmental effects. Although it might be used for local evaluation, it may be best suited for comparing multiple projects in different corridors or regions, given that it is not likely to vary much between project alternatives in the same corridor. If it were used, guidance would be needed on which land use categories to classify as developed versus undeveloped. A categorical rating system (e.g., high, medium, low) should be considered based on quantitative benchmarks (e.g., less than 50 percent, 50 to 75 percent, greater than 75 percent). As an alternative to obtaining and quantitatively analyzing land use data, a qualitative assessment could be performed based on review of land use data and aerial imagery.

EVALUATION OF ALL PHASE 2 METRICS

Table 4 presents the factors used to evaluate the metrics, on a low-moderate-high scale, with high being a favorable rating. Table 5 summarizes the ratings for all of the metrics evaluated, including each metric's "tier" as well as an assessment of ease of calculation, reliability, and usefulness according to the factors listed in Table 4. Table 5 also identifies the advantages of each metric as well as any key drawbacks or concerns.

LIMITATIONS OF THE METRICS AND THE CURRENT EVALUATION FRAMEWORK

Two significant challenges were encountered in attempting to develop meaningful and reliable project-level metrics of environmental performance.

First, the impacts of any individual project generally look small when compared on a regional basis. For the projects evaluated in this research, energy, GHG, and emissions changes were typically less than 0.2 percent of regional or subregional totals. The relatively small impacts were also manifested

Table 4 Description of final evaluation factors.

Evaluation Factor	Description
Ease of Forecasting	
High	Can be calculated with relative ease from data and models typically available from the environmental analysis and/or New Starts process. • A few hours of project sponsor staff time. • Additional (one-time) work may be required to produce standard inputs and guidance, which will minimize work for project sponsors.
Moderate	Some new data collection and analysis required. • One to 2 days of decision maker staff time per project.[a]
Low	Significant new data collection and/or new analysis effort required. • More than 3 days of decision maker staff time per project.[a]
Reliability	
High	Modest uncertainty in key assumptions/inputs; level of uncertainty consistent with other existing factors such as ridership forecasts.
Moderate	Moderate uncertainty in key assumptions/inputs.
Low	High uncertainty in key assumptions/inputs.
Usefulness	
High	Capable of clearly distinguishing among projects or alternatives, and clear/interpretation of metric.
Moderate	Some limitations to ability to distinguish among projects or alternatives, or some lack of clarity/meaningfulness in interpretation of metric.
Low	Not capable of distinguishing among projects or alternatives, or interpretation of metric unclear/not meaningful.

[a]The level of effort required of decision makers would depend upon whether project sponsors are required to compute the metric directly or simply to provide datasets so that others can compute the metric.

Table 5 Summary evaluation of metrics.

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
I. Energy and Greenhouse Gas Emissions							
IA	Operating GHG emissions per passenger-mile	1	High	Moderate/ High	High	• Rewards both efficient vehicle technology and high ridership/ load factors	• Does not consider benefits from reduced automobile travel
IB	Operating energy consumption per passenger-mile	1	High	Moderate/ High	High		
IC(i)	Change in operating GHG emissions	2	Moderate/ High	Moderate	Low/ Moderate	• Considers benefits from all modes	• Small change relative to regional emissions • Sensitive to future uncertainties in relative modal energy and emission rates
ID(i)	Change in operating energy consumption	2	Moderate/ High	Moderate	Low/ Moderate		
IC(ii)	Project cost per reduction in operating GHG emissions	3	Moderate/ High	Low/ Moderate	Low/ Moderate	• Cost-effectiveness—reports GHG benefit per dollar spent	• Unstable/not meaningful for low or negative energy and GHG benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
ID(ii)	Project cost per reduction in operating energy	3	Moderate/ High	Low/ Moderate	Low		
IE(i)	Construction GHG emissions	2	Low	Unknown[a]	Moderate	• Expands scope of energy and GHG emissions considered • Rewards efficient construction practices	• Data/methods still under development
IE(ii)	Construction energy consumption	2	Low	Unknown[a]	Moderate		
II. Air Quality and Public Health							
IIA(i)	Change in direct operating emissions	2	Moderate	Moderate	Low/ Moderate	• Commonly used metric in air quality planning	• Small change relative to regional emissions • Previously not found useful in comparing multiple projects in different regions

IIA(ii)	Dollar of project cost per change in direct operating emissions	3	Moderate	Low/ Moderate	Low	• Cost-effectiveness—reports pollution reduction benefit per dollar spent	• Unstable/not meaningful for low or negative emissions benefits • May be misleading if project is compared with other air pollution reduction measures based only on cost-effectiveness
IIB	Exposure Index	3	Low	Unknown[a]	Low/ Moderate	• Weights emissions by exposure to population	• Difficult to calculate • Unclear interpretation/ significance
IIC	Health Benefit Index	3	Low	Unknown[a]	Low/ Moderate	• Additional weighting of emissions by toxicity	
IID	Air Quality Index	3	High	High	Low	• Indicates severity of regional air quality problem	• Not related to benefits of project
IIE	Forecast change in daily nonmotorized access trips	2	High	Moderate	Moderate/ High	• Reasonable proxy for physical activity generated by project	• Interproject consistency in modeling methods
	Level of service and other measures for assessing pedestrian and bicycle access to transit	3	Low/ Moderate	Moderate/ High	Unknown[a]	• Indicates extent to which station area environments are conducive to physical activity	• Already considered qualitatively under land use/economic development • Does not indicate actual physical activity levels
III. Ecology, Habitat, and Water Quality							
IIIA	Percent of corridor that is already developed	2	Moderate/ High	Moderate	Moderate	• Relates to livability principle, supporting existing communities • Proxy for potential to support infill versus greenfields development	• May not relate to actual environmental impacts
IIIB	Potentially impacted acreage of undeveloped land	3	Moderate/ High[b]	Moderate	Low/ Moderate	• Proxy for potential to induce greenfields development	• May not relate to actual environmental impacts
IIIC	Potentially impacted acreage of sensitive habitat	3	Moderate[c]	Low	Moderate	• Proxy for potential to induce development in areas of sensitive habitat	• No good, easy ways exist to obtain proxies for sensitive habitat

(*continued on next page*)

Table 5 (*Continued*)

Key	Metric Description	Tier	Ease of Calculation	Reliability	Usefulness	Benefits/Advantages	Key Drawbacks/Concerns
III. Ecology, Habitat, and Water Quality (continued)							
IIID	Potentially impacted acreage weighted by ecosystem service value		N/A—not calculated			• Weights potentially impacted land use by ecological importance	• Land use data not consistent enough to evaluate ecosystem service value
IIIE	Adequacy of state, regional, and local habitat protection plans	3	Low	Low/ Moderate	Moderate	• Assesses extent to which sensitive habitat is protected, without attempting to judge specific development impacts of project	• Interproject consistency in assessment • Level of effort required for assessment • Very indirect connection to potential impacts of project
IV. Cross-Cutting Metrics							
	Environmental performance ratings for transit projects	2	Low	Unknown[a]	Unknown[a]	• Indicates extent to which project sponsors are taking measures to mitigate, avoid, or offset negative impacts • Primarily useful for self-assessment and possible extra credit	• Does not indicate benefits of project, just reduction of negative impacts from construction and operation • Level of effort to assess and interproject consistency in assessment

[a]Unknown because not fully tested in this research or not enough projects tested to gauge reliability.
[b]Assuming this is calculated simply as undeveloped land in the corridor. If weighted by accessibility or another indicator of potential impact, “low” ease of calculation.
[c]Assuming this is calculated simply as agricultural and wetland land area in corridor. If weighted by indicator of development potential or using a better indicator of ecological sensitivity, “low” ease of calculation.

in cost-effectiveness metrics that are not favorable when compared to other air quality and GHG improvement projects on a stand-alone basis. This can lead to the potentially erroneous conclusion that the project is not worth doing. The small size of benefits reflects multiple factors:

- To some extent, this is the reality of the situation. Most individual projects make a relatively small dent in regional travel patterns and associated environmental benefits.
- However, it also reflects a potentially incomplete accounting of the project's benefits due to the current evaluation framework. This framework assumes that land use patterns are the same with or without the project. Secondary, longer-term benefits associated with land use changes that the project may induce or support, and further changes to travel patterns because of these land use changes, are not considered.
- The individual project versus no-project approach also does not consider potential synergistic benefits of multiple coordinated transit projects, combined with supportive land use policies.
- The poor cost-effectiveness of the projects when measured just on air quality or GHG effects does not account for the multiple other benefits of the project, including mobility. Environmental benefits are just one of multiple reasons to undertake a transit project.

The second major challenge is that it is not possible to reliably predict the secondary benefits or impacts of a transit project for ecology, habitat, and water quality. The factors affecting the secondary, growth-inducing impacts of transit projects (or highway projects for that matter) are complicated and include economic as well as policy factors and physical constraints. Models to predict the effects of transportation investments on land use patterns exist, but they are resource-intensive to apply, and a recent evaluation for FTA found that they were not yet suitable for evaluating individual projects, including transit projects.[7] Two TCRP projects currently underway continue to investigate methods for predicting land use and economic development impacts, using very different approaches.[8] Even if general growth patterns can be predicted, the level of detail required to assess specific environmental impacts (e.g., impacts to sensitive habitat or water quality) generally is unavailable. A qualitative assessment of supportive land use policies, such as FTA already performs in its assessment of the land use and economic development criteria, may be the best that can be done with respect to this factor at the current time.

Closely related to this challenge is the difficulty of quantifying benefits from projects that serve heavily built-up areas and primarily improve conditions for existing riders rather than diverting travelers from automobiles. The environmental benefit in this situation can be characterized as a long-term strengthening of the urban core through improved travel conditions, helping attract and retain people in settings where the environmental impacts of travel and development can be much lower. However, most current models are not well suited to forecasting the impacts of transportation improvements on metropolitan development patterns, including retaining or increasing population and jobs in urban core areas.

These two challenges suggest that a different evaluation framework may be required to provide a meaningful evaluation of transit's full environmental benefits. Specifically, this framework might assess and compare the *life-cycle impacts* (construction and operation) of *all modes* (including highways and transit) on a *network or systems* level. Such an assessment would consider differences in land use patterns that support, or would be influenced by, alternative transportation networks.

Multimodal, systems-level assessments have already been performed in many areas of the country as part of regional scenario planning exercises. Regional scenario planning studies have found long-term air quality and energy benefits ranging from 5 percent to 25 percent or more for regional scenarios

[7] *Deriving Economic Development Benefits of Transit Projects from Integrated Land Use Transportation Models: Review of Models Currently Used in the U.S. and Recommendations.* Prepared by Cambridge Systematics, Inc., and Dr. John Gliebe for Federal Transit Administration, April 2009.

[8] Current information about TCRP Project H-39, "Methodology for Determining the Economic Development Impacts of Transit Investments," is available at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2364; and information about TCRP Project H-46, "Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component," is available at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3092.

of compact growth and transit investment, compared to business-as-usual scenarios with highway investment.[9] These regional scenario evaluations could be further enhanced by incorporating life-cycle emissions and energy use (including construction, maintenance, fuel production, etc.) as better information on these factors becomes available. At a project level, evaluation could be performed by considering the consistency of the project with a regional plan that achieves substantial environmental benefits.

There are admittedly many challenges to moving toward this type of evaluation. For example, the ability to do regional scenario planning that includes land use as well as transportation will vary from region to region. Land use decisions are typically made at the local (municipal) level, whereas transit planning is part of a regional process. Even if a preferred transportation and land use scenario can be developed and adopted on a regional scale, there may be no way to ensure that it is implemented, and therefore that the full benefits of the transit project are realized. Also, to ensure consistency in methods across projects, closer attention would need to be given to the travel demand forecasting and land use assumptions across the region, rather than just the project corridor.

A regional scale approach, however, may be the only way to achieve a complete accounting of transit's environmental benefits. This type of evaluation framework would also be consistent with best international practice for transportation project evaluation, as identified in the literature review for this research. In its January 2012 NPRM and proposed policy guidance, FTA is proposing to allow project sponsors the option of submitting alternative land use forecasts and associated estimates of environmental impacts, which would begin to move the process in this direction.

[9]A recent review of scenario planning studies using travel forecasting models found that land use changes, combined with supportive transit investments, were estimated to reduce metropolitan VMT by a median of 8 percent below forecast levels over a 20-year time horizon and 16 percent over a 40-year horizon. Forty-year reductions ranged from 3 percent to 28 percent across studies. *See:* Rodier, C. Review of International Modeling Literature: Transit, Land Use, and Automobile Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions. *Transportation Research Record: Journal of the Transportation Research Board, No. 2132.* Transportation Research Board of the National Academies, Washington, D.C., 2009.

It would still be necessary for decision makers to evaluate individual projects on their merits. However, this evaluation might be done considering benefits that occur when the project is implemented in conjunction with other supportive projects and policies. The relative contribution of the project to the benefits of the overall regional plan might be assessed based on some factor such as ridership or passenger-miles.

If this approach were taken, transit agencies might have concerns about the fact that their project is being evaluated based on factors beyond their control (i.e., regional transportation and land use decisions made by the metropolitan planning organizations and local governments). On the other hand, this is already true within the current national land use and economic development evaluation criteria. Regional and local decisions also influence other benefits of the project, such as ridership, even within the current evaluation framework. A question that would need to be addressed is whether just the project would be evaluated, or whether the evaluation would also consider the broader regional planning context and the extent to which it supports the project.

NEXT STEPS AND ISSUES FOR FURTHER RESEARCH

This research has provided an overview of the use of different metrics of environmental performance, but it has left a number of issues unaddressed. These issues can be grouped into next steps for implementation, and issues for further research.

Next Steps

The following issues will need to be addressed by decision makers and others who choose to apply these metrics.[10]

- Which metrics, if any, will an individual agency use for its own project evaluation purposes? How will they be used to inform project

[10]FTA's January 25, 2012, Notice of Proposed Rulemaking and accompanying Proposed New Starts/Small Starts Policy Guidance address some of these issues. For example, the policy guidance proposes the specific environmental metrics to be examined, how they will be combined and weighted, general methods for calculating these metrics, and the use of national rather than regional emissions, energy, and GHG factors. Details of data sources and calculation methods remain to be developed.

decision making, including weighting them in relation to other measures of performance?

- Which metrics, if any, will be used for comparative evaluation of projects, and how will they be incorporated into the evaluation and reporting framework? What weights will be set for each metric within the environmental performance category, and how will this overall category be weighted in comparison to other categories?
- If a GHG metric is selected, will GHG be calculated based on regional emission factors or national average factors? ICLEI's protocol for development of GHG inventories by local governments specifies the use of local factors,[11] although decision makers would not necessarily need to be consistent with this practice.
- If an air quality metric is selected, which pollutants are included? Are emissions from electricity-generating power plants included? Again, if the metric is applied comparing projects in different regions of the country, are national or regional emission factors used?

Issues for Further Research

Technical issues that warrant further research include the following:

- What are the most appropriate energy and GHG emission factors (including electricity generation), particularly for future energy use and emissions from all types of transit vehicles?
- What is the full range of energy use and GHG emissions from transit construction? (This may be addressed by research underway for FHWA).
- Can the Exposure Index and/or Health Benefits Index be further developed so that they are useful for transportation project or plan evaluation, considering health effects?
- How do different models of nonmotorized access mode choice affect the reliability of access mode choice forecasts? To what extent do transit projects induce nonmotorized trips in addition to those accessing the transit project (e.g., by allowing households living in transit station areas to have fewer vehicles)?
- Can systems-level forecasting methods (considering regional transportation and land use systems) provide information on the environmental benefits of projects that differs significantly from that provided by project-level methods that simply compare the project versus no-project alternative in isolation from other changes?
- To what extent are the environmental benefits of transit increased by the "trip not taken" (or the "land use multiplier")? That is, to what extent are our current evaluation methods not capturing the benefits of more compact development and associated changes in travel patterns? Some research is underway through TCRP Project H-46, "Quantifying Transit's Impact on GHG Emissions and Energy Use: The Land Use Component," but further research will likely be required because of the complexity of the topic and the variability of the relationships in different situations.
- What are the advantages, drawbacks, and implications of evaluating the environmental benefits of a project as part of a regional plan (i.e., in comparison to a no-plan or alternative plan), rather than in isolation from other changes?

[11]ICLEI. International Local Government GHG Emissions Analysis Protocol (IEAP), Version 1.0. October 2009.

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