CMAQ EMISSIONS CALCULATOR TOOLKIT

The purpose of the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) is to provide users a standardized approach to estimating emission reductions from the implementation of a CMAQ-funded project. The CMAQ Toolkit uses emission rates for highway vehicles based on a series of project-scale and default-scale runs of the Motor Vehicle Emission Simulator (MOVES[1]) as well as other data sources. For each tool in the Toolkit, the inputs and methodology are described in user guides along with some example cases. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses. Information regarding the development of default emission rates and guidance on incorporating user-supplied emission rates can be found in the accompanying documentation of the emissions data.

Telework Tool

Commuting constitutes a significant portion – approximately 28 percent – of total annual household vehicle miles traveled.[2] Recent shifts in travel patterns and behaviors, driven by the impact of the COVID-19 pandemic, have created a unique opportunity to explore alternative work arrangements on a large scale. Data from the American Community Survey[3], an annual publication shared by the Census Bureau, show that the percentage of the United States workforce working from home during a typical week increased from 5% in 2019 to 17.86% in 2021.[4] By reducing the number of employees who commute to physical office buildings each day, telework programs can decrease the total number of vehicles miles traveled and reduce commuting-related emissions.[5]

This tool provides estimates of emission reductions only for CMAQ-funded projects that encourage employees to switch to a hybrid or fully remote work schedule.[6] Additional emission benefits may come from shifts in commuting patterns to other forms of travel, such as carpooling, transit, biking, or walking due to the increased flexibility introduced by telework programs. For additional information on targeted carpool projects, view the Carpooling and Vanpooling Tool; for targeted transit bus expansion projects

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[1] U.S. Environmental Protection Agency, https://www.epa.gov/moves.

[2] Federal Highway Administration (FHWA), Summary of Travel Trends, 2017 National Household Travel Survey. Available at: https://www.fhwa.dot.gov/policyinformation/documents/2017_nhts_summary_travel_trends.pdf.

[3] U.S. Census Bureau, 2021 Commuting Characteristics by Sex, American Community Survey, https://data.census.gov/table?q=S0801:+COMMUTING+CHARACTERISTICS+BY+SEX&hidePreview=true&tid=ACSST1Y2021.S0801.

[4] Bureau of Transportation Statistics (BTS), Commute Mode, https://www.bts.gov/browse-statistical-products-and-data/state-transportation-statistics/commute-mode.

[5] It is important to acknowledge that the adoption of telework is not uniformly distributed across all demographics. Various factors such as employer characteristics and income status, can influence an individual's ability to telecommute.

[6] For the purposes of this tool, a telework day is defined as one in which an employee does not commute to a primary worksite for the entire duration of the day. Note that this tool does not apply to projects that promote flexible or alternative work schedule in which employees are permitted flexible start and end times but are still required to commute to a worksite.

view the Transit Bus Service and Fleet Expansion Tool, and for targeted biking and walking projects view the Bicycle, Pedestrian, and Shared Micromobility Tool.

This document is organized into four sections – User Guide, Tool Methodology, Examples, and Resources – to aid the user in selecting inputs and interpreting results from the emissions calculator tool. The User Guide provides direction on how to properly input values into the tool and definitions of both user inputs and tool outputs. The Tool Methodology section outlines the steps taken by the tool to calculate emission reductions, as well as any associated assumptions. The Examples section provides instructive examples of how to use the tool for different types of project analysis. The Resources section provides information on references used to develop the Telework Tool and other tools that may be helpful to users. The Appendices (Commute Distance, Non-Work-Related Travel and Mode Shift) provide resources for calculating specific inputs.

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USER GUIDE

This section describes each user input and tool output, as well as error messages and key assumptions incorporated into the tool.

User Inputs

The module contains a series of questions to guide the user in inputting information for emission reduction calculations in a step-by-step process. Inputs for questions 3, 4, 5 and 7 must be entered for before and after project implementation. The user-defined inputs for this tool are described in Table 1, with additional guidance provided in the section below for specific inputs.

Table 1. User Inputs

Question	User Input	Units	Description
(1)	Project Evaluation Year	-	Use the drop-down menu to select a year between 2018 and 2040.
(2)	Number of Employees	-	Input the number of employees in the project area.
(3)	*Before* – Percent of Employees that Telework	%	Input the percent of employees that telework in some capacity (1 or more days) before the telework program is implemented. The entry may be 0.
	After – Percent of Employees that Telework	%	Input the percent of employees that telework in some capacity (1 or more days) after the telework program is implemented. The entry must be greater than 0.
(4)	*Before* – Average Number of Days Teleworked	Days per Week	Input the average number of days employees telework per week before the telework program is implemented. The entry may be 0 and must be less then or equal to 5.
	After – Average Number of Days Teleworked	Days per Week	Input the average number of days employees telework per week after the telework program is implemented. The entry must be greater than 0 and less then or equal to 5.
(5)	*Before* – Average Roundtrip Commute Distance	Miles	Input the average round trip commute distance before the telework program is implemented. See section below for guidance on this input.
	After – Average Roundtrip Commute Distance	Miles	Input the average round trip commute distance after the telework program is implemented. See section below for guidance on this input.
(6a)	Travel on Telework Days	-	Indicate whether there is expected to be passenger vehicle travel on telework days after the program is implemented. Checking the box “Yes” indicates that there will be additional home-based travel, while leaving the box unchecked indicates that there is not expected to be any additional travel. See section below for guidance on this input.

Question	User Input	Units	Description
(6b)	Average Miles Traveled per Employee on Telework Days	Miles per Person per Day	If the box in 6a is checked, input the additional expected average miles traveled per employee per telework day after the telework program is implemented. See section below for guidance on this input.
(7)	*Before* – Commuter Mode Breakdown	%	Input the percentage of employees that travel by Single Occupancy Vehicle (SOV), Carpool/Vanpool, Transit or Bike/Walk before the telework program is implemented. The total must add to 100%. Note that the tool displays the commuter mode breakdown for the 2021 5-year average from the American Community Survey as a default. See section below for guidance on this input.
	After – Commuter Mode Breakdown	%	Input the percentage of employees that travel by SOV, Carpool, Transit or Bike/Walk after the telework program is implemented. Note that the tool displays the commuter mode breakdown for the 2021 5-year average from the American Community Survey as a default. If the mode breakdown is expected to remain the same after the telework program is implemented, then enter the same breakdown as entered in the before column. See section below for guidance on this input.

Guidance on Specific Inputs

Question 3 – Percent of Employees that Telework: The user must enter the percent of employees that telework for before and after the implementation of the project. If survey data is not available for percent of employees that are expected to telework once a program is implemented, the user may reference regional or metropolitan area telework averages during 2021[7]. The increase in teleworking due to the COVID-19 pandemic can give insights into the range of employees whose jobs can be conducted remotely when supporting measures are in place. Averages are from the American Community Survey.

Question 5 - Average Roundtrip Commute Distance: The user must enter the average roundtrip commute distance per employee (in miles per day) for before and after the implementation of the telework project. Note that the user may enter the same value for commute distance before and after if such changes cannot be approximated for the project area or if there is no expected change in commute distance. This input accounts for the potential changes in worker proximity to the workplace resulting from the new or expanded ability to telework.

[7] U.S. Census Bureau, American Community Survey, 2021: 1 year Estimates, https://data.census.gov/table?tid=ACSDP1Y2021.DP03.

Users are encouraged to provide their own estimates where possible, rather than relying on national default values. However, users may consider the following data from the Brookings Institute as a useful reference point for typical (one-way) commute distances in 96 large metro areas.[8] For more detail on calculating this value, please refer to Appendix A of the documentation.

Question 6 - Travel on Telework Days: Some data suggest that teleworkers may travel on during work hours on telework days. If the data are available, the user should enter the estimated amount of additional non-work related travel as a result of teleworking. By capturing this information, the tool can provide a more precise assessment of the emission reductions resulting from telework programs. Additional non-work travel includes any trips that would ordinarily be linked with the employee's commute to work but which, due to the telework program, is now a stand-alone trip. Examples include errands such as grocery shopping, picking up or dropping off children from school, or going to the gym that may have previously occurred on the way to or from work and now occur as a separate trip on telework days.

Trips that take place outside of peak hours (e.g., commuting hours) may result in lower emissions than commute trips due to decreased idling and a smoother drive cycle. However, differences in drive cycles from trips taken at different times of day (peak versus non-peak) are not accounted for in the emission reduction calculations in this tool as the tool does not apply to projects that encourage flexible or alternative work schedules. For more information regarding emission benefits from shifting drive times, please reference the Highway Capacity Manuel.[9]

For a more detailed description of the underlying assumptions supporting the estimation of travel on telework days, please refer to Appendix B.

Question 7 - Commuter Mode Breakdown: The user must provide the percent distribution of commuters by different modes of transportation (SOV, carpool, transit, or biking/walking) before and after the implementation of the telework program. The distribution among these modes may change after the telework program is implemented; for example, commuters may change from driving to biking due to less frequent commuting. To obtain the most accurate data, it is recommended to conduct surveys or utilize existing transportation data specific to the project area. However, for baseline averages, please refer to the Bureau of Transportation Commute Mode data.[10] Data is available by year for a range of geographic levels including County, County Subdivision, Metropolitan Statistical Area, and Census Tract. Note that the total distribution must add to 100%. For a more detailed description of the default values and how the breakdown may change after the project, please refer to Appendix C of the documentation.

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[8] Elizabeth Kneebone and Natalie Holmes (2015), Brookings Institution, Appendix B. Typical Commute Distances, 96 Large Metro Areas in "The growing distance between people and jobs in metropolitan America." Available at: https://www.brookings.edu/wp-content/uploads/2016/07/Srvy_JobsProximity.pdf

[9] https://doi.org/10.17226/24798. Available at:

[10] BTS, https://www.bts.gov/browse-statistical-products-and-data/state-transportation-statistics/commute-mode

Tool Outputs

Emission benefits are derived from a reduction in daily emissions due to vehicle miles traveled (VMT) taken off the road and the elimination of vehicle starts. Increases in the percentage of employees that telework and the number of days employees telework per week result in decreases in total VMT. Note that shifts in commuting modes before and after the project is implemented may result in either decreases or increases in VMT. Additionally, a project may result in an increase in VMT depending on the commute distance before and after the telework program is implemented and the number of miles of home-based travel on telework days.

In the tool output, a positive change in emissions is equivalent to an emissions reduction (benefit), while a negative value can be interpreted as an emissions increase (disbenefit). Emission reductions (i.e., benefits) are calculated for five pollutants – CO, NO_X, $PM_{2.5}$, PM_{10}, and VOC – reported in kilograms per day (kg/day). Reductions in carbon dioxide (CO_2), carbon dioxide equivalents (CO_2e) (in kg/day) and total energy consumption (in million BTU/day) are also provided.

The tool also outputs network performance metrics for the single occupancy vehicle (SOV) miles traveled before and after project implementation as well as the net change in single occupancy VMT.

Robust Metropolitan Planning Organizations (MPOs) with less homogenous telework policies can enter telework scenarios for multiple workplaces to estimate an aggregated benefit.

Note that emission results will not automatically update. If any changes are made to the input parameters, the 'Calculate Output" button must be clicked again to calculate updated emission reductions. If you would like to return to default settings and clear inputs, click on the 'Reset to Default Values' button at the top right of the interface.

Error Messages

Error messages that the user may encounter in this tool, the reason for the error messages, and the solutions are listed in Table 2.

Table 2. Error Messages

Error Message	Solution
Invalid Input: The value you entered is not a valid project evaluation year. Please use the pull-down menu to select a year between 2018 and 2040.	Select a project evaluation year between 2018 and 2040 from the pull-down menu.
Invalid Input: Missing or unexpected value for number of employees in the project area.	Input a whole number between 1 and 100 million for the number of employees in the project area.
Invalid Input: Missing or unexpected value for percentage of employees that telework.	Input a whole number between 0 and 100 for the percent of employees that telework.
Invalid Input: Missing or unexpected average number of days teleworked.	Input a whole number between 0 and 5 for the average number of days teleworked per week.
ERROR: Please select a project evaluation year.	Input a project evaluation year.
ERROR: Please enter the number of employees in the project area.	Input a number for the number of employees in the project area.

Error Message	Solution
ERROR: Please enter the percent of employees who telework before the telework program is implemented.	Input a percentage for employees that telework before the project is implemented.
ERROR: Please enter the percent of employees who telework after the telework program is implemented.	Input a percentage for employees that telework after the project is implemented.
ERROR: Please enter the number of days that employees telework each week before the telework program is implemented.	Input the number of days that employees telework each week before the project is implemented.
ERROR: Please enter the number of days that employees telework each week after the telework program is implemented.	Input the number of days that employees telework each week after the project is implemented.
ERROR: Please enter the roundtrip commute distance before the telework program is implemented.	Input the roundtrip commute distance before the project is implemented.
ERROR: Please enter the roundtrip commute distance after the telework program is implemented.	Input the roundtrip commute distance after the project is implemented.
ERROR: Please enter the average miles traveled per employee per telework day. Note that this value must be greater than zero when the box to left is checked 'Yes'.	Input the average miles traveled per employee per telework day after the project is implemented.
ERROR: Please ensure that the percentages entered for commuter mode before project implementation add up to 100 percent.	Enter percentages for each mode that sum to 100.
ERROR: Please ensure that the percentages entered for commuter mode after project implementation add up to 100 percent.	Enter percentages for each mode that sum to 100.
ERROR: This tool does not accept negative values.	A negative number has been entered for one of the inputs. Please review the inputs and enter a positive number.

Click 'Calculate Output' to recalculate the results once errors are resolved.

TOOL METHODOLOGY

Emissions Reductions

Emissions reductions for the tool are derived from the reduction in vehicle miles traveled and vehicle starts as well as from shifting commutes to more efficient modes such as carpool, transit, or non-motorized modes such as biking and walking. Please refer to Appendix B for more information about mode shift estimates. Emission reductions, reported in kilograms per day of the telework program[11], are calculated for a given pollutant as follows:

$$daily\ emissions\ reduced = e_{running} * VMTreduced + e_{starts} * starts\ reduced \quad (1)$$

[11] The telework program is assumed to apply to a 5-day work week.

where:

$daily\ emissions\ reduced$ = total emissions reduced for each pollutant in kg/day

$e_{running}$ = running emission rate per pollutant in kg/mile

$VMTreduced$ = total single-occupancy vehicle VMT reduced in veh-miles/day

e_{starts} = vehicle start emission rate per pollutant in kg/start

$starts\ reduced$ = $starts$ = total number of starts from vehicles taken off the road due to the telework program in starts/day

$VMTreduced$ is calculated from the average number of employees that commute on a given day of the telework program, the average roundtrip commute distance, and the commute mode. Note that emission rates for biking and walking are assumed to be zero for all pollutants reported in this tool. Transit emission rates are also assumed to be zero since transit operations (light-rail, transit bus, etc.) will continue to run at the same rate regardless of the telework projects modeled in this tool. Therefore, an increase in employees commuting via public transportation does not result in an increase in transit-based emissions. For users interested in calculating emissions that result from an expansion of transit service, please use the CMAQ Toolkit's Transit Bus Service and Fleet Expansion Tool.[12] $VMTreduced$ is thus contingent only on the percentage of employees that commute alone in a private vehicle or in a carpool program, as well as any home-based travel on telework days as entered by the user:

$$VMTreduced = VMTreduced_{SOV} + VMTreduced_{carpool} - (teleworkers_{post} * HBT_{post}) \quad (2)$$

The $VMTreduced_{SOV}$ is then calculated as the difference between the SOV VMT before and after the telework program is implemented:

$$VMTreduced_{SOV} = (commuters_{pre} * commute\ distance_{pre} * \frac{SOV_{pre}}{100}) - (commuters_{post} * commute\ distance_{post} * \frac{SOV_{post}}{100}) \quad (3)$$

where:

$$teleworkers = total\ employees * \%\ telework * (\frac{days\ teleworked/week}{5\ days/week}) \quad (4)$$

$$commuters = total\ employees - teleworkers \quad (5)$$

The variables for Equations 2-5 are defined below:

[12] FHWA, CMAQ Emissions Calculator Toolkit Transit Bus Service and Fleet Expansion Tool, https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/#sect1e

HBT = user input for non-work-related home-based travel in miles during telework days (applies only to after project implementation)

$commuter$ = weighted average of the number of employees that commute on a given day

$commute\ distance$ = user input for the average round trip commute distance

SOV = user input for the percentage of employees that commute via SOV

$teleworkers$ = weighted average of the number of employees that telework on a given day

$total\ employees$ = user input for the total number of employees in the project area

$\%\ telework$ = user input for the percentage of employees that telework before or after project implementation

$days\ teleworked/week$ = user input for the number of days of telework per week for employees who telework in some compacity before or after project implementation

The $VMTreduced_{carpool}$ is calculated as the difference between the carpool VMT before and after the telework program is implemented, divided by the average vehicle occupancy per carpool:

$$VMTreduced_{carpool} = ((commuters_{pre} * commute\ distance_{pre} * \frac{carpool_{pre}}{100}) - (commuters_{post} * commute\ distance_{post} * \frac{carpool_{post}}{100})) * (\frac{1}{AVO}) \quad (6)$$

where:

AVO = average vehicle occupancy, assumed to be 2 (rounded from 2.35) passengers per vehicle, including the driver[13]

$carpool$ = user input for the percentage of employees that commute via carpool

Emission reductions from starts ($starts\ reduced$) are only included when there is no additional home-based travel as a result of the project (e.g., when the user does not check "Yes" in question 6a). Two starts are eliminated per vehicle removed from the road due to the telework program under the assumption that an individual employee when commuting to work starts their vehicle once to commute to the place of work and once to commute home. In the case of the user choosing to include additional home-based travel in the analysis, starts are assumed to cancel out before and after project implementation (starts due to commute are assumed to be equally replaced by starts due to home-based trips on telework days).

$$starts\ reduced = (displaced\ vehicles_{SOV} + displaced\ vehicles_{carpool}) * 2 \quad (7)$$

[13] U.S. Census Bureau, 2021, Sex of Workers by Means of Transportation to Work American Community Survey 1-year estimates, https://censusreporter.org/data/table/?table=C08006&geo_ids=01000US&primary_geo_id=01000US.

where:

$$displaced\ vehicles_{SOV} = (commuters_{pre} * \frac{SOV_{pre}}{100}) - (commuters_{post} * \frac{SOV_{post}}{100}) \quad (8)$$

$$displaced\ vehicles_{carpool} = ((commuters_{pre} * \frac{carpool_{pre}}{100}) - (commuters_{post} * \frac{carpool_{post}}{100})) * \frac{1}{AVO} \quad (9)$$

For the purposes of this telework tool, it is assumed that the pickup location for employees participating in a carpool is non-centralized (e.g., carpool participants are not driving to a central location for pickup). For more detailed calculations of emission reductions from carpool programs, please refer to the CMAQ Toolkit's Carpooling and Vanpooling Tool.[14]

A positive change in emissions is equivalent to an emissions reduction (benefit), while a negative change in emissions can be interpreted as an emissions increase (disbenefit). To annualize emission reductions, multiply the daily emissions reduced by the number of days per year that the carpool program is active. Note that emissions rates can be accessed within the tool by right-clicking the tab bar at the bottom of the spreadsheet tool and selecting 'Unhide' for the appropriate tab ('Emission Rates'). Additional information on the emission rates can be found in the Emissions Data documentation.

Network Performance

This tool also outputs network performance metrics, including the net change in single-occupancy VMT ($VMTreduced$), as well as the single-occupancy VMT before and after the telework program is implemented:

$$VMTreduced = VMT_{before} - VMT_{after} \quad (10)$$

$$VMT_{before} = (commuters_{pre} * commute\ distance_{pre} * \frac{SOV_{pre}}{100}) + ((commuters_{pre} * commute\ distance_{pre} * \frac{carpool}{100}) * (\frac{1}{AVO})) \quad (11)$$

$$VMT_{after} = ((commuters_{post} * commute\ distance_{post} * \frac{carpool}{100}) * (\frac{1}{AVO})) + (commuters_{post} * commute\ distance_{post} * \frac{SOV_{post}}{100}) + (teleworkers_{post} * HBT_{post}) \quad (12)$$

[14] FHWA, CMAQ Emissions Calculator Toolkit, Carpooling and Vanpooling Tool, https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/#sect1g.

EXAMPLES

The following examples demonstrate how the tool calculates emissions savings by applying user-provided input.

Example 1: Coordinating a New Telework Program

An MPO decides to fund a free telework consulting service for employers in the metro area. The program provides consultations, design, implementation, evaluation, and training session assistance for interested employers. Prior to the project, 25% of the 100,000 employees in the area teleworked for an average of two days per week. After the project, 45% of employees telework for an average of four days per week. The average one-way commute distance is 6 miles. The project will be implemented in 2024. The MPO uses ACS data for the year 2021 instead of the 5-year average provided as a tool default. The MPO also assumes that the percentages of commuters who commute via SOV and bike/walk will increase while the percentages who commute via carpool and transit will decrease.

	BEFORE	AFTER	
% of Employees	25	45	%
# of Days Teleworked	2	4	days/week
Average Roundtrip Commute Distance	12.0	12.0	miles/person/day

		AFTER	
☐ Yes			miles/person/day

	BEFORE	AFTER	
% Single Occupancy Vehicle	84.07	86.07	%
% Carpool	9.66	7.66	%
% Transit	3.05	1.05	%
% Bike/Walk	3.22	5.22	%

Once inputs are entered, click the 'Calculate Output' button to estimate net change in annual activity (in ton-miles) and emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

NETWORK PERFORMANCE — Last Updated: 6/7/2023 17:16

Single Occupancy Vehicle Miles Traveled	
Before	960,120
After	690,432
Net Change	269,688

EMISSION REDUCTIONS

Pollutant	Total (kg/day)
Carbon Monoxide (CO)	1,024.100
Particulate Matter <2.5 µm ($PM_{2.5}$)	2.803
Particulate Matter <10 µm (PM_{10})	10.324
Nitrogen Oxides (NOx)	57.031
Volatile Organic Compounds (VOC)	29.762

Carbon Dioxide, CO_2	97,045.349
Carbon Dioxide Equivalent, CO_2e	97,806.861
Total Energy Consumption (MMBTU/day)	1,310.742

Emissions Reductions

Total

CO = 1,024.100 kg/day

$PM_{2.5}$ = 2.803 kg/day

PM_{10}= 10.324 kg/day

NOx = 57.031 kg/day

VOC = 29.762 kg/day

CO_2 = 97,045.349 kg/day

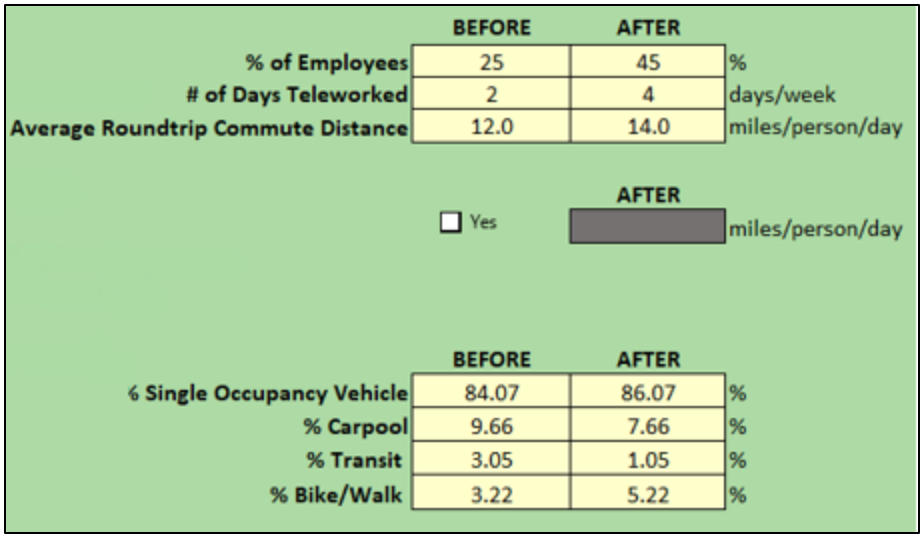
CO_2e = 97,806.861 kg/day

TEC = 1,310.742 MMBTU/day

Example 2: Accounting for Changes in Travel Behavior

The same MPO the following year is able to collect travel behavior data from an annual transportation survey. The data shows 20% of employees that switch to a fully remote schedule move further from the city center. It is estimated the new average one-way commute distance increases to 7 miles, for an average roundtrip commute distance of 14 miles after the project is implemented. The data also show a larger share of employees use SOV or bike/walk to work, with carpool and public transit shares decreasing. The new breakdown is 86.07% SOV; 7.66% carpool; 1.05% transit; 5.22 bike/walk.

In the tool, the user would select the following inputs as shown below:



	BEFORE	AFTER	
% of Employees	25	45	%
# of Days Teleworked	2	4	days/week
Average Roundtrip Commute Distance	12.0	14.0	miles/person/day

	AFTER	
☐ Yes		miles/person/day

	BEFORE	AFTER	
% Single Occupancy Vehicle	84.07	86.07	%
% Carpool	9.66	7.66	%
% Transit	3.05	1.05	%
% Bike/Walk	3.22	5.22	%

Once inputs are entered, click the 'Calculate Output' button to estimate net change in annual activity (in ton-miles) and emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

NETWORK PERFORMANCE — Last Updated: 6/7/2023 17:24

Single Occupancy Vehicle Miles Traveled	
Before	960,120
After	805,504
Net Change	154,616

EMISSION REDUCTIONS

Pollutant	Total (kg/day)
Carbon Monoxide (CO)	693.534
Particulate Matter <2.5 µm ($PM_{2.5}$)	1.965
Particulate Matter <10 µm (PM_{10})	6.323
Nitrogen Oxides (NOx)	39.993
Volatile Organic Compounds (VOC)	26.109

Carbon Dioxide, CO_2	57,689.282
Carbon Dioxide Equivalent, CO_2e	58,356.850
Total Energy Consumption (MMBTU/day)	780.088

Emissions Reductions

Total

CO = 693.534 kg/day
$PM_{2.5}$ = 1.965 kg/day
PM_{10} = 6.323 kg/day
NOx = 39.993 kg/day
VOC = 26.109 kg/day
CO_2 = 57,689.282 kg/day
CO_2e = 58,536.850 kg/day
TEC = 780.088 MMBTU/day

Example 3: Non-Work Related Travel

The same MPO would like to understand the rebound effects of their telework program. Data collected from their employees shows that when working remotely, telecommuting workers travel an average of 2.5 miles each day for non-work related trips.

In the tool, the user would select the following inputs as shown below:

	BEFORE	AFTER	
% of Employees	25	45	%
# of Days Teleworked	2	4	days/week
Average Roundtrip Commute Distance	12.0	14.0	miles/person/day

		AFTER	
☑ Yes		2.5	miles/person/day

	BEFORE	AFTER	
% Single Occupancy Vehicle	84.07	86.07	%
% Carpool	9.66	7.66	%
% Transit	3.05	1.05	%
% Bike/Walk	3.22	5.22	%

Once inputs are entered, click the 'Calculate Output' button to estimate net change in annual activity (in ton-miles) and emission reductions for the project. The estimated emissions reductions in kg/day (TEC is in MMBTU/day) are:

NETWORK PERFORMANCE — Last Updated: 6/7/2023 17:26

Single Occupancy Vehicle Miles Traveled	
Before	960,120
After	895,504
Net Change	64,616

EMISSION REDUCTIONS

Pollutant	Total (kg/day)
Carbon Monoxide (CO)	185.622
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.470
Particulate Matter <10 µm (PM_{10})	2.246
Nitrogen Oxides (NOx)	9.567
Volatile Organic Compounds (VOC)	2.051

Carbon Dioxide, CO_2	22,099.482
Carbon Dioxide Equivalent, CO_2e	22,152.234
Total Energy Consumption (MMBTU/day)	297.977

Emissions Reductions

Total

CO = 185.622 kg/day
$PM_{2.5}$ = 0.470 kg/day
PM_{10}= 2.246 kg/day
NOx = 9.567 kg/day
VOC = 2.051 kg/day
CO_2 = 22,099.482 kg/day
CO_2e = 22,152.234 kg/day
TEC = 297.977 MMBTU/day

RESOURCES

Data Dictionary

The CMAQ Data Dictionary, which can be found here, is a resource available to the public to help understand terms that may be used in this tool. On the Data Dictionary webpage, select "Travel Demand Management" and for strategy type select "Telecommuting". If you are searching for a particular term, you can use the "Find in results" button. After clicking submit you will be shown a list of results, an example is included below.

Home-Based Other Trips

Definition	The average number of home-based other trips by participants in the telecommuting or work schedule change program.
Units	Number of Trips
Input Category	Scoping
CMAQ Project and Program Type	Travel Demand Management
Strategy Type	Telecommuting
Values	None Given
Uncertainty	National average number of home-based other trips may differ from regional.
Common Errors	Employing incorrect estimation methodology.
Resources	National Household Travel Survey (NHTS)

MOVES

General information about the MOVES model can be found on the EPA's website. MOVES is free to download and allows users to model mobile source emissions at different scales ranging from project to national (called default). The website includes subpages to download the latest version, watch webinars and training sessions, and contact the developers for help.

Appendix A. Commute Distance

Users can estimate the average commute distance by using national averages weighted by the distribution of their workforce that commutes by that mode. Data from the 2017 National Household Travel Survey in the table below show commute distance averages by mode.

Table A1: Commute Distance by Mode[15]

Mode of Transport	Average one-way Distance (miles)
SOV	11.84
Carpool	10.8
Walk	1.19
Transit	12.09
Bike	2.8[16]
All	**11.46**

It is worth considering how the increased flexibility introduced by telework may influence employees' tolerance to longer commutes. A review of commute distances and durations for both one-worker and two-worker households collected from the 2001 and 2009 U.S. National Household Travel Surveys, showed that telecommuting tends to increase the household one-way commute.[17] A study by the Pew Research Center in 2022 found that 17% of U.S. employees reported relocating away from the workplace as the major reason for working from home all or most of the time.[18] De Vos et al. (2018) observe that people who work from home are willing to accept 5% longer commuting times on average due to increased telework ability.[19] If survey data isn't available regarding changes in commute distances, users are encouraged to use these baseline statistics to determine impacts on commute distances.

Appendix B. Non-Work-Related Travel

Understanding the impacts of telecommuting on travel behavior can be complex. Studies have shown both positive and negative changes in vehicle miles traveled (VMT) depending on specific circumstances.

[15] FHWA, Summary of Travel Trends, 2017 National Household Travel Survey, https://www.fhwa.dot.gov/policyinformation/documents/2017_nhts_summary_travel_trends.pdf

[16] Oregon Transportation Research and Education Consortium, Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice, https://nacto.org/wp-content/uploads/2012/06/Dill-and-Gliebe-2008.pdf.

[17] Zhu, P. Telecommuting, Household Commute and Location Choice. Urban Studies at 50, 50(12) 2441-2459 (2013), https://www.researchgate.net/publication/258199169_Telecommuting_Household_Commute_and_Location_Choice.

[18] Pew Research Center, COVID-19 Pandemic Continues To Reshape Work in America (2022), https://www.pewresearch.org/social-trends/2022/02/16/covid-19-pandemic-continues-to-reshape-work-in-america/#:~:text=There%E2%80%99s%20also%20been%20a%20significant%20increase%20since%202020,is%20a%20major%20reason%20why%20they%E2%80%99re%20currently%20teleworking.

[19] De Vos, D., Meijers, E. & van Ham, M. Working from home and the willingness to accept a longer commute. Ann Reg Sci 61, 375–398 (2018), https://doi.org/10.1007/s00168-018-0873-6.

To gain a comprehensive understanding of the impacts of teleworking on travel behavior, it is essential to consider various factors such as geographical context, transportation infrastructure, and the specific characteristics of the work arrangement.

Teleworking can lead to “rebound” effects when there is an increase in the frequency or distances of trips as a result of teleworking. In urban areas, where essential services are easily accessible near residences, these trips often involve non-motorized travel, such as walking or biking. However, in rural areas, car travel becomes more common as telecommuters no longer engage in "trip chaining", where multiple tasks are combined in a single trip as in dropping off children at school on the way to work[20].

Review of the 2009 U.S. National Household Travel Surveys found telecommuters’ average daily total non-work trips was 15.7 percent longer in distance, 14.3 percent longer in duration, and 10.7 percent more frequent than that of non-telecommuters[21], additional analysis found this complementary effect consistent across 3 different metropolitan statistical areas.[22] In 2020, data collected on a sample of teleworking employees in California indicated that working from home led to an increase of 26% in the amount of additional trips.[23] However it is important to collect data specific to the project area, as Zhu (2014) reveals hybrid work arrangements – a combination of remote and in-person work – are associated with a greater number of non-work trips compared to fully remote or fully in-person arrangements.[24]

Appendix C. Mode Shift

Increased flexibility provided by telework programs may influence how employees decide to travel to work. The handbook Transportation Cooperative Research Program (TCRP) Report Number 95 entitled *Traveler Response to Transportation System Changes* reports that telecommuting has marginally better vehicle trip reduction (VTR) performance, as computed on the basis of mode shifts alone, when implemented with high transit availability. However, when telework programs are implemented with only medium and low transit availability levels, the effects vary as to whether the work schedule program is associated with a positive or negative VTR. [25] A study of the Chicago Metropolitan Area in 2019, before the COVID-19 pandemic, found suburban part-time telecommuters were much more likely

[20] Mokhtarian, Patricia L., Telecommuting and Travel: State of the Practice, State of the Art. The University of California, Transportation Center. August 1991, https://escholarship.org/content/qt4zc486ph/qt4zc486ph_noSplash_808f7143692d89d8dd93a5e2a59efefa.pdf?t=mc2sth.

[21] Zhu, P. Are telecommuting and personal travel complements or substitutes?, Ann Reg Sci 48, 619–639 (2012), https://doi.org/10.1007/s00168-011-0460-6.

[22] Zhu, P., Wang, L., Jiang, Y., Zhou, J., Metropolitan Size and the Impacts of Telecommuting on Personal Travel, Transportation, 2018, https://hub.hku.hk/bitstream/10722/261164/1/Content.pdf?accept=1.

[23] Riggs, William, Telework and Sustainable Travel During the COVID-19 Era (June 29, 2020), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3638885.

[24] Caros, Guo, Zheng, Zhao, The Impacts of remote work on travel: insights from nearly three years of monthly surveys. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. 2023, arxiv.org/pdf/2303.06186.pdf.

[25] Traveler Response to Transportation System Changes Handbook, Third Edition: Chapter 19, Employer and Institutional TDM Strategies (2010), http://nap.edu/14393.

to rely on transit on days when they worked in the office than their fulltime, in-person counterpart. While urban part-time telecommuters were much more likely to walk to work when they worked in the office than their fulltime, in-person counterpart.[26]

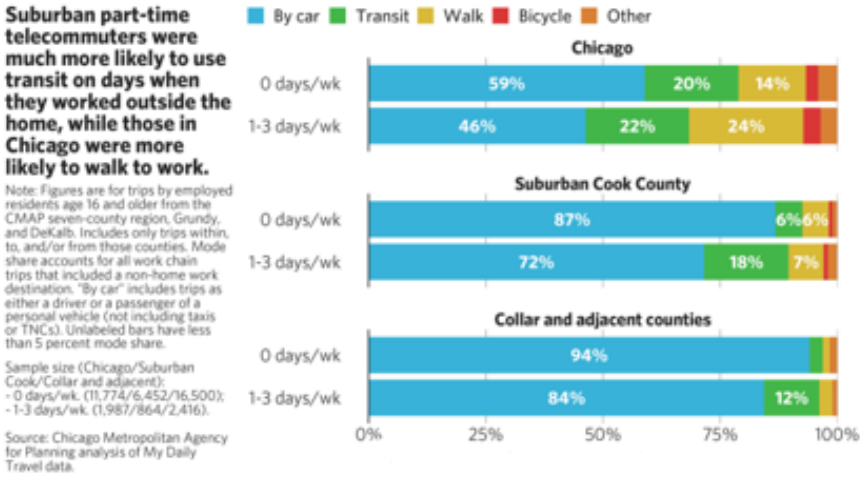


Figure A1: Mode share for work trips by home location and telecommute status (Chicago 2019)

In April 2023, many transit systems are still seeing less than 70% of pre-pandemic traffic.[27] Data from the Bureau of Transportation Statistics show a decrease in transit use between 2021 and 2019 from 4.96% to just 2.46%.

Default values in the tool for commuter mode breakdown are derived from the 2021 American Community Survey 5-year aggregate. If the user is interested in commuting behaviors directly before, during or after the COVID-19 pandemic, they should reference data from a specific year. The data summarizes the principal means of transportation to work, meaning the mode of travel used most frequently. If more than one means of transportation was used each day, those surveyed were asked to specify the one used for the longest distance during the trip. Because the dataset includes the percentage of remote workers, a weighted average was used to determine the percent distribution of the modes when just accounting for SOV, carpool, transit, and bike/walk. 'Other' percentages, which includes taxicab or rideshare, and motorcycle, are excluded for the purposes of this tool.

Table A2: Principal Means of Transportation to Work, 2021[28]

Mode of Transport	Percent of Commuters
Works at home	9.7%
SOV	73.2%

[26] Chicago Metropolitan Agency for Planning (CMAP), Pre-COVID telecommuting patterns reveal possible future impacts of remote work, cmap.illinois.gov/documents/10180/684566/My+Daily+Travel+-+telecommuting.pdf/408a6de5-6754-608e-5d32-606a169a45e4?t=1634763564429.

[27] Danieele Muoio Dunn and Ry Rivard (2023), Politico, "Remote work is straining public transit." https://www.politico.com/news/2023/05/03/public-transit-office-workers-00094999.

[28] U.S. Census Bureau, American Community Survey 2021, Table S0801: Commuting Characteristics by Sex, 5-Year Estimates, https://data.census.gov/table?q=S0801&tid=ACSST5Y2021.S0801.

Carpool	8.6%
Public Transportation	4.2%
Bicycle	0.5%
Walk	2.5%
Other	1.4%

Table A2: Principal Means of Transportation to Work (Adjusted)

Mode of Transport	**Percent of Commuters**
SOV	82.24%
Carpool	9.66%
Public Transportation	4.72%
Bicycle	0.56%
Walk	2.81%