CMAQ EMISSIONS CALCULATOR TOOLKIT

The purpose of the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) is to aid a user with limited modeling experience to estimate emission reductions from the implementation of a CMAQ funded project. The CMAQ Toolkit uses emission rates based on a national-scale run of the Motor Vehicle Emission Simulator (MOVES) for emission inventories and activity output. The use and methodology of this tool are explained in this document. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses. For further information regarding the specific setup and use of MOVES to generate the emission rates found within this tool, please refer to the Documentation of Emissions Data associated with this category of emission calculators.

Carpooling and Vanpooling Tool

Carpooling and vanpooling encourage participants to commute together between home and work. With fewer commuters driving alone[1], these programs reduce vehicle activities and subsequent emissions.

This tool contains two modules: 1) Carpooling, and 2) Vanpooling. The tool can model participants driving to a centralized location or being picked up at their residences. These modules estimate emission reductions from eligible CMAQ projects, which include starting new carpool and vanpool programs, increasing ridership in existing programs[2], and purchasing vehicles for vanpool programs.

The most current version is dated March 2018. To verify the version, check the date on the Introduction page of the tool. Release notes are included in the Change Log tab, which can be viewed by right-clicking on any tab in the tool, selecting “Unhide”, and revealing the tab.

Carpooling Module

Carpooling is the sharing of passenger vehicle trips, most often from home to work and vice versa. By having more than one person per vehicle, carpooling reduces vehicle miles traveled and any associated tailpipe emissions. Other carpooling potential benefits include less congestion by reducing the number of vehicles on the road, decreased vehicle operating costs, and the opportunity to take advantage of faster moving high occupancy vehicle (HOV) travel lanes.

This document is organized into three sections – User Guide, Tool Methodology, and Examples – to aid the user in understanding and interpreting results from the calculator. The User Guide gives direction for the user to properly input values into the tool and provides definitions of both user inputs and tool outputs. The Tool Methodology outlines the steps taken by the tool to calculate emission reductions, as well as any assumptions that are made by the tool. This Tool Methodology includes all equations used within the tool. The Examples section gives some examples of how to properly input information into the tool for different types of analysis.

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[1] For simplicity, this tool does not consider other types of mode-switching.

[2] See the examples section on how to calculate benefits of increased ridership.

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USER GUIDE

This section lists the units and description for each user input and tool output. A description of emission reductions reporting and error messages as well as other assumptions inherent in the tool are provided.

User Inputs

The interface of the Carpooling module functions as a wizarding tool, with questions intending to help the user input proper information for emission reductions calculations in a step-by-step process. The inputs for this tool should be specific to the vehicles that will participate in the carpool. The user-defined inputs for this type of project are described in Table 1.

Table 1 User Inputs

Item	User Input	Units	Description
(1)	Project evaluation year	-----	Use the drop-down menu to choose a year between 2016 and 2021.
(2)	Centralized pick-up/drop-off locations (check box)	-----	Click on the box if you know there will be a centralized location for the participants in the carpool to gather. This option is checked by default. Unchecking this check box will grey out the *Average Distance to Centralized Location* field. If the cell does not grey out, minimize and maximize the program.
(2a)	Average distance participants drive to the centralized locations (daily roundtrip)	miles	Input the average roundtrip commute distance that the participants will drive to the centralized location, assumed to shorten the commute distance.
(3a)	Population of commuting workers (radio button)	people	Select either *Population of Commuting Workers* or *Vehicles Participating in the Carpool Program*. Input the human population of all commuting workers within the desired study area.
(3b)	Number of vehicles participating in the carpool program (radio button)	vehicles	Select either *Population of Commuting Workers* or *Vehicles Participating in the Carpool Program*. Input the number of vehicles that will be participating in the carpool program. That is, the total number of cars that will stay on the road and drive in the carpool.
(4)	Share of commuters participating in pool	percentage	If *Population of Commuting Workers* is selected, then input the percentage of commuting workers that will participate in the carpool program.
(5)	Passengers per carpool vehicle (not including driver)	people	Input the average number of passengers per vehicle, not including the driver. This value can include decimals as it is an average of people.
(6)	Average commute distance (daily roundtrip)	miles	Input the average roundtrip commute distance that a carpool vehicle will drive from the pickup location to the end destination. For non-centralized pickups, the distance driven to each home should be incorporated into the total distance.

Default values: There are three fields that have default values that are based on national averages: the share of commuters (9.4 %)[3], passengers per vehicle (one passenger, driver not included)[4], and average roundtrip commute distance (25.2 miles)[5]. For specific localities, a Brookings study determined the typical one-way commute distance in 96 metropolitan areas across the country.[6] Users are encouraged to enter their own estimates where possible rather than relying on national default values. Share of commuters and occupancy rates (passengers per vehicle) can be obtained through local surveys.

Vehicle Type: The vehicle type that is used in the carpooling module is an aggregate of a MOVES run for passenger car (source type 21) and passenger truck (source type 31). For all evaluation years, the percentage of passenger cars is roughly 59.7% and the percentage of passenger trucks is 40.3%.[7] The sum of the emissions inventory for both source types was divided by the sum of the activity for both source types.

Other Assumptions: The passengers per vehicle field assumes that the driver of the carpool vehicle is not hired but rather volunteers to drive the carpool since they would be driving to the same location without the carpool program. The carpool module assumes that the carpool vehicle would be on the road regardless of the carpool program. Therefore, there is no extra VMT to add into the net benefit calculation. The tool also assumes that carpool vehicles will travel roughly at the same speeds and along the same routes as participants would have without the carpool.

Once the parameters are input, click on the 'Calculate Output' button to calculate results. Emission results will not automatically update, so anytime changes are made to the input parameters, this button must be pushed to calculate the updated emission reductions. If you would like to return to default settings, please click on the 'Reset to Default Values' button.

Tool Outputs

The carpooling module assumes that for each passenger in the program, one vehicle is being taken off the road. The benefits are derived from the amount of daily emissions reduced by vehicle miles travelled (VMT) taken off the road. Certain values entered for fields could show an increase rather than a decrease in VMT, yielding a net transportation disbenefit. For example, if the participants have to drive a long distance to get to the centralized pick-up location, this could yield a disbenefit as a whole.

Emission reductions are calculated for five pollutants – CO, $PM_{2.5}$, PM_{10}, NOx, and VOC – in kilograms/year, and then are divided by 250 for the CMAQ daily emission reductions reporting in kilograms/day. In the event that a different annualized reporting rate is desired, users are

[3] US Census Bureau, https://www.census.gov/content/dam/Census/library/publications/2015/acs/acs-32.pdf (share of commuters is an average of workers that live in and outside the metropolitan area from Figure 1 in *Who Drives to Work? Commuting by Automobile in the United States: 2013)*.
[4] Florida DOT, http://www.1800234ride.com/13-fun-facts-about-carpooling (Florida DOT estimates that more than three quarters of all carpooling is between two people)
[5] US DOT, FHWA, https://www.fhwa.dot.gov/policy/2010cpr/execsum.cfm#c1
[6] Elizabeth Kneebone and Natalie Holmes (2015), Brookings Institution, "The growing distance between people and jobs in metropolitan America," https://www.brookings.edu/wp-content/uploads/2016/07/Srvy_JobsProximity.pdf
[7] Refer to Emissions Data documentation for more information on the MOVES run specifications.

recommended to multiply their daily results by 250 and then divide by their chosen number of working days in a year.

Error Messages

The error message that the user may encounter in this tool, the reason for this error message and the solution is listed in Table 2 below:

Table 2 Error Messages

Error Message	Reason for Error	Solution
WARNING: The number of passengers entered exceeds the tool's recommended capacity for a passenger vehicle.	A passenger value either below 1 or above 7 has been entered.	Enter a number of passengers between 1 and 7.

Once you correct any errors, please follow the instructions and press 'Calculate Output' to clear any errors and recalculate the results.

TOOL METHODOLOGY

Emission reductions, reported in kilograms per day of the carpool program, are calculated for a given pollutant as follows:

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

where,

$$VMT\ reduced_{non\ central} = displaced\ vehicle\ pop \cdot commute\ distance \quad (2)$$

$$VMT\ reduced_{central} = displaced\ vehicle\ pop \cdot (commute\ distance - distance\ to\ central\ location) \quad (3)$$

$$starts\ reduced_{non\ central} = displaced\ vehicle\ pop \cdot starts \quad (4)$$

such that the centralized and non-centralized cases are calculated somewhat differently. For the non-centralized case, the reduced emissions will look just like Equation 1. For the centralized case, the reduced emissions would not include the starts reduced and the variable e_{starts} in Equation 1 should be zero due to there being no starts reduced. The variables for the equations are defined below:

$e_{running}$ = running emission rate[8] for a pollutant based on the given evaluation year,

[8] In this tool, the running emission process includes crankcase running emissions for all pollutants as well as brakewear and tirewear for both PM2.5 and PM10.

e_{starts} = starting emission rate[9] for a pollutant based on the given evaluation year,
$displaced\ vehicle\ pop$ = number of vehicles taken off the road, calculated as either Equation 5 or 6.

If entering number of vehicles directly (second radio button), then the displaced vehicle population equals the vehicles participating in the carpool program on the given day multiplied by the number of passengers per vehicle (the driver is not counted since his/her vehicle is being used in the carpool and not taken off the road); or

$$displaced\ vehicle\ pop = vehicles\ participating\ \cdot passengers\ per\ vehicle \quad (5)$$

If entering population of commuting workers and the share of those participating in the carpool program (first radio button), then the displaced vehicle population instead equals the product of the population of commuting workers and the share of carpooling participation divided by the total number of people per vehicle including the driver, and then multiplied by the number of passengers per vehicle.

$$displaced\ vehicle\ pop = \left(\frac{commuting\ workers \cdot share}{passenger\ per\ vehicle + 1}\right) \cdot passengers\ per\ vehicle \quad (6)$$

$commute\ distance$ = average roundtrip distance the active carpool vehicle will travel to and from the common workplace,
$distance\ to\ central\ location$ = average roundtrip distance to the centralized pick-up/drop-off location, which is assumed to shorten the commute distance,
$passengers\ per\ vehicle$ = the number of passengers in each carpool vehicle, not including the driver, and
$starts$ = number of starts from vehicles taken off the road due to the program, where two starts will be reduced for each vehicle in the non-centralized case and no starts will be reduced in the centralized case.

NOTE: To annualize emission reductions, multiply the daily emissions reduced by the number of days per year that the carpool program is active.

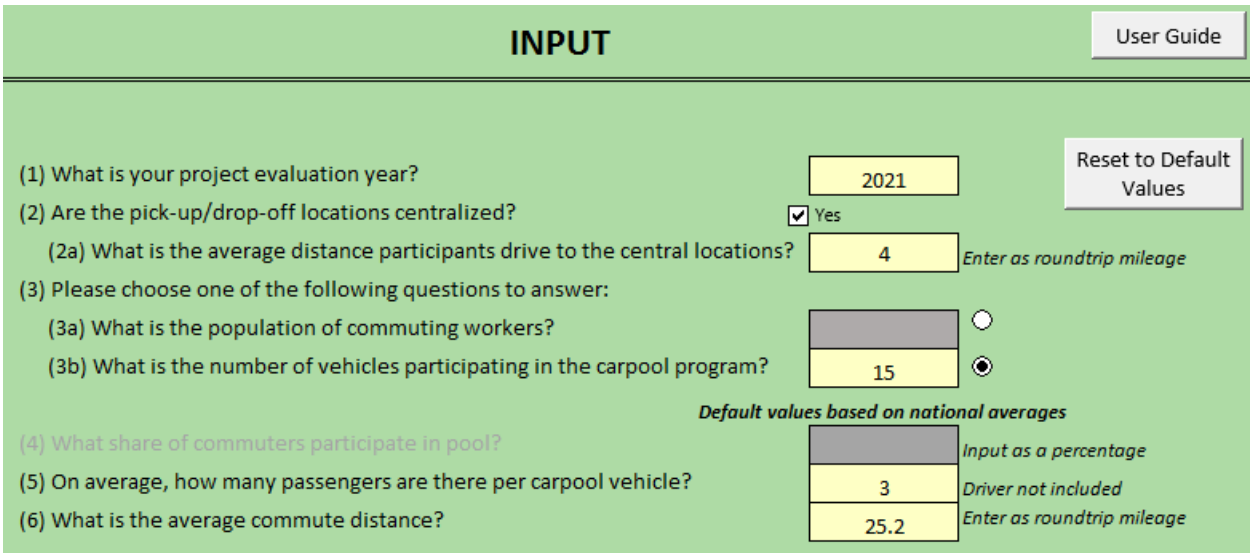
[9] The tool's start emission process includes crankcase start emissions.

EXAMPLES

Example 1: Calculating Benefits of a New Carpool Program

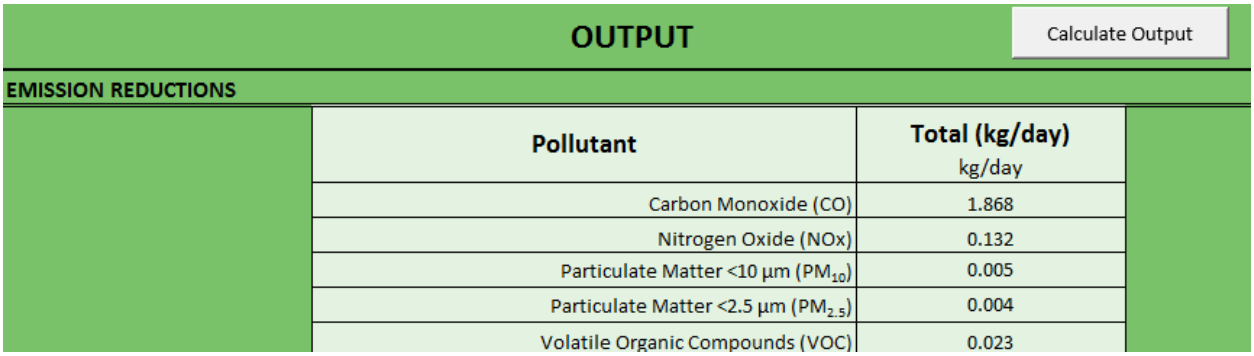
Scenario: County X in State AA would like to calculate the benefits of a new carpool program. The county has the number of vehicles that participate in the carpool, an average number of passengers per vehicle, and average distance to the centralized pick up location, and an average number of days per week the rideshare is active. The county does not have the average commute distance for the carpool, so they will rely on the national default. The proposed carpool program will use centralized drop-off/pick up locations and it is estimated that on average people will drive 2 miles from their residence to that location (4 miles roundtrip each day). County X estimated a total participation of 60 people, with an average of 3 passengers per car (4 people per car if you include the driver). This equates to 15 participating vehicles.

In the Carpooling module, the following inputs would be chosen, as shown in the image below:



Project Year: 2021
Centralized Location [check box]: Selected
Average Distance to Centralized Location: 4
Vehicles Participating in the Carpool Program: 15
Passengers per Vehicle: 3
Average Commute Distance: 25.2

Once the inputs are entered, select the 'Calculate Output' button to estimate emissions for the project:



The emission reductions in kg/day for all five pollutants are:

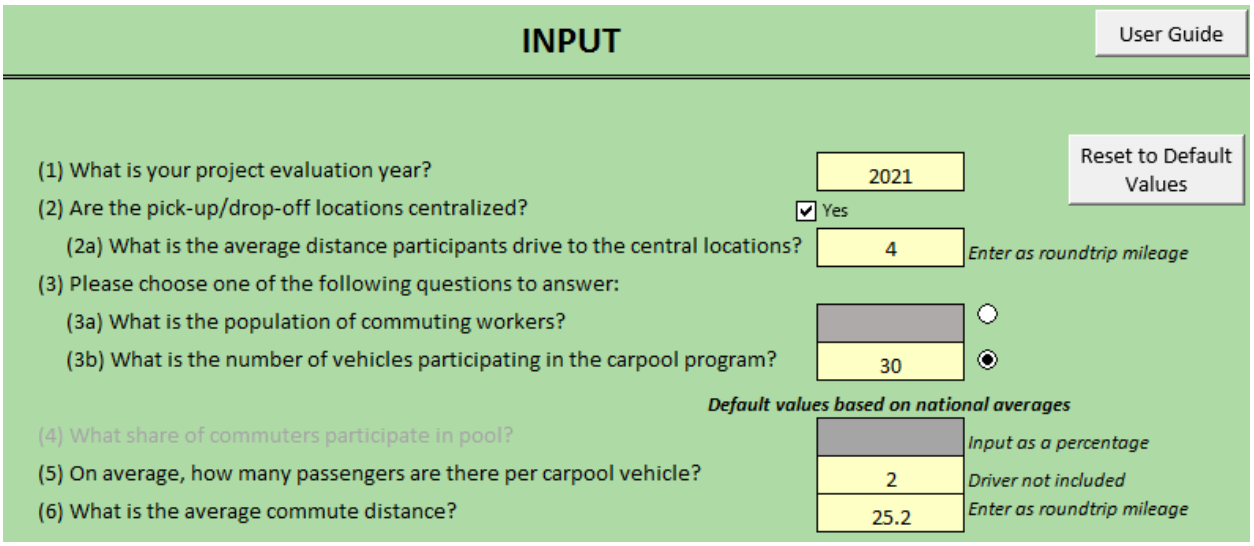
Carbon Monoxide (CO): 1.868
Nitrogen Oxide (NOx): 0.132
Particulate Matter (PM2.5): 0.005
Particulate Matter (PM10): 0.004
Volatile Organic Compounds (VOC): 0.023

Example 2: Calculating Benefits of Increased Ridership

There are a few different ways in which ridership may increase. Ridership increases when there are more vehicles in the carpool program, more passengers in each vehicle, and when the number of carpool days increases. For this example, the number of passengers in each vehicle will be increased to show increased ridership.

Step 1: Estimate the Baseline

Scenario: County X in State AA would like to see the benefits of increased ridership in a carpool program. The county has the number of vehicles that participate in the baseline carpool, an average number of passengers per vehicle, and average distance to the centralized pick up location. The county does not have the average commute distance for the carpool, so they will rely on the national default. In the Carpooling module, the following inputs would be chosen, as shown in the image below:



Project Year: 2021
Centralized Location [check box]: Selected
Average Distance to Centralized Location: 4
Vehicles Participating in the Carpool Program: 30
Passengers per Vehicle: 2
Average Commute Distance: 25.2

Once the inputs are entered, select the 'Calculate Output' button to estimate emissions for the project:

OUTPUT Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day) kg/day
Carbon Monoxide (CO)	2.491
Nitrogen Oxide (NOx)	0.177
Particulate Matter <10 µm (PM_{10})	0.006
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.005
Volatile Organic Compounds (VOC)	0.030

The emission reductions in kg/day for all five pollutants are:
Carbon Monoxide (CO): 2.491
Nitrogen Oxide (NOx): 0.177
Particulate Matter (PM2.5): 0.006
Particulate Matter (PM10): 0.005
Volatile Organic Compounds (VOC): 0.030

Step 2: Estimate the Emission Reductions with Increased Ridership

The county then estimates an increase in the ridership of the program, as shown in the image below:

INPUT User Guide

Reset to Default Values

(1) What is your project evaluation year? 2021
(2) Are the pick-up/drop-off locations centralized? ☑ Yes
(2a) What is the average distance participants drive to the central locations? 4 *Enter as roundtrip mileage*
(3) Please choose one of the following questions to answer:
(3a) What is the population of commuting workers? ○
(3b) What is the number of vehicles participating in the carpool program? 30 ◉

Default values based on national averages

(4) What share of commuters participate in pool? *Input as a percentage*
(5) On average, how many passengers are there per carpool vehicle? 4 *Driver not included*
(6) What is the average commute distance? 25.2 *Enter as roundtrip mileage*

Project Year: 2021
Centralized Location [check box]: Selected
Average Distance to Centralized Location: 4
Vehicles Participating in the Carpool Program: 30
Passengers per Vehicle: 4
Average Commute Distance: 25.2

Once the inputs are entered, select the 'Calculate Output' button to estimate emissions for the project:

OUTPUT Calculate Output

EMISSION REDUCTIONS

Pollutant	Total (kg/day) kg/day
Carbon Monoxide (CO)	4.982
Nitrogen Oxide (NOx)	0.353
Particulate Matter <10 µm (PM_{10})	0.012
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.011
Volatile Organic Compounds (VOC)	0.061

The emission reductions in kg/day for all five pollutants are:
Carbon Monoxide (CO): 4.982
Nitrogen Oxide (NOx): 0.353
Particulate Matter (PM2.5): 0.012
Particulate Matter (PM10): 0.011
Volatile Organic Compounds (VOC): 0.061

Step 3: Calculate the Net Benefits

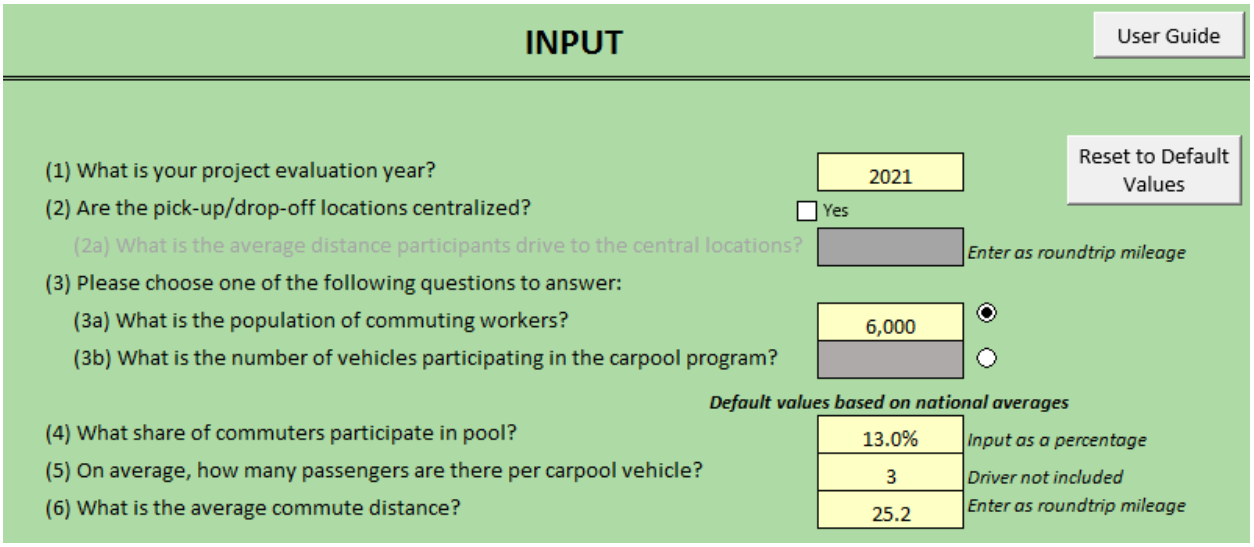
We can determine the benefits of increasing the ridership of the program by subtracting the benefits from the emission reductions of the high ridership case against the baseline reductions from the low ridership case. The net benefits are calculated in the table below.

Table 3 Net Benefits in kg/day

Pollutant	Low Ridership	High Ridership	Net Benefits
Carbon Monoxide (CO)	2.491	4.982	7.473
Nitrogen Oxide (NOx)	0.177	0.353	0.53
Particulate Matter (PM10)	0.006	0.012	0.018
Particulate Matter (PM2.5)	0.005	0.011	0.016
Volatile Organic Compounds (VOC)	0.030	0.061	0.091

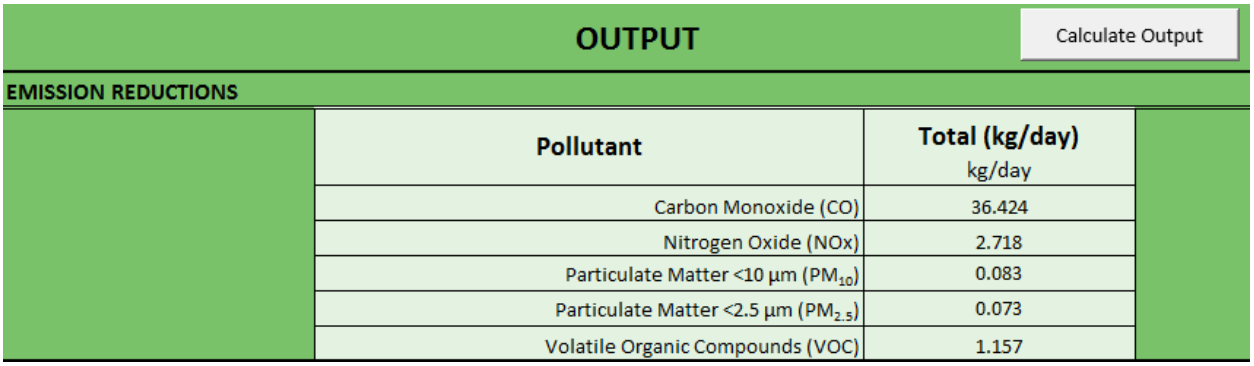
Example 3: Calculating Benefits of an Existing Carpool Program Using Population of Commuting Workers

Scenario: County X in State AA would like to calculate the benefits of an existing carpool program. The county has the population of commuting workers that drive to work, the share of that population that participate in the carpool program, and an average number of passengers per vehicle. The county does not have the average commute distance for the carpool, so they will rely on the national default. The carpool program does not use centralized drop-off/pick up locations. County X estimated a total population of 6,000 commuting workers of which 13% participate in the carpool program, with an average of 3 passengers per car. In the Carpooling module, the following inputs would be chosen, as shown in the image below:



Project Year: 2021
Centralized Location [check box]: Unselected
Population of Commuting Workers: 6,000
Share of Commuting Workers: 13.0%
Passengers per Vehicle: 3
Average Commute Distance: 25.2

Once the inputs are entered, select the 'Calculate Output' button to estimate emissions for the project:



Pollutant	Total (kg/day) kg/day
Carbon Monoxide (CO)	36.424
Nitrogen Oxide (NOx)	2.718
Particulate Matter <10 µm (PM_{10})	0.083
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.073
Volatile Organic Compounds (VOC)	1.157

The emission reductions in kg/day for all five pollutants are:

Carbon Monoxide (CO): 36.424
Nitrogen Oxide (NOx): 2.718
Particulate Matter (PM2.5): 0.083
Particulate Matter (PM10): 0.073
Volatile Organic Compounds (VOC): 1.157