CARBON ANALYSIS

I-880 High-Occupancy Toll Express Lanes

Urban Planning M258

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March 11, 2022

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Executive Summary

This memorandum provides a carbon analysis of the I-880 high-occupancy toll (HOT) express lanes in the Bay Area from 2015 to 2021. Using a report on the project by the Metropolitan Transportation Commission (MTC), data from the Caltrans Performance Measurement System (PeMS) database, and a polynomial model from a 2009 paper from Matthew Barth and Kanok Boriboonsomsin on the association between vehicle average speeds and CO_2 emissions, we were able to compare estimated CO_2 emissions under a “no-build” scenario with those under a “build” scenario. From this analysis, we estimate a reduction of 484,235 metric tons of carbon dioxide (CO_2) emissions and a cost of $287 per metric ton of CO_2 reduced throughout the construction period to a year after their opening.

To contextualize the estimated CO_2 reductions from this project, we compared the total CO_2 reduced and the cost per metric ton of CO_2 reduced for the year 2021 with the estimated values for a similar project: express lanes on the nearby I-580. We found that the I-880 express lanes may be more effective at reducing CO_2 emissions than the I-580 lanes, as it leads to average speeds that are more optimal for minimizing emissions, as indicated in the Barth and Boriboonsomsin model, and a significantly smaller cost per metric ton of CO_2 reduced. We also made recommendations for some additional policies based on a paper by Barth and Sperling (2019) that could complement the I-880 express lanes to further reduce CO_2 emissions on the freeway.

From our analysis, we feel confident that the I-880 express lanes have and will continue to positively contribute to reducing CO_2 emissions in the Bay Area in the future.

MEMORANDUM

TO: Exxon Foundation for the Climate
FROM: Jackson Zeng, Metropolitan Transportation Commission
Purva Kapshikar, Metropolitan Transportation Commission
DATE: March 11, 2022
SUBJECT: Carbon Analysis: I-880 High-Occupancy Toll Express Lanes

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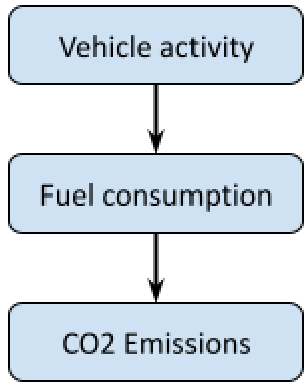
High-occupancy toll (HOT) lanes are freeway lanes that operate like high-occupancy vehicle (HOV) lanes, where vehicles carrying more than one person may use the lane to bypass congestion on the freeway. In addition, HOT lanes also provide single-occupancy vehicles with the opportunity to access the quicker lane in exchange for paying a toll. HOT lanes help alleviate traffic congestion by providing an incentive for carpooling (hence, reducing the number of vehicles on the freeway) and diverting some single-occupancy vehicle traffic from the general purpose lanes, freeing up capacity on the rest of the freeway. This reduction in traffic congestion also leads to lower CO_2 emissions by reducing the extent that vehicles idle and travel in fuel-inefficient stop-and-go traffic and by allowing vehicles to move at more fuel-efficient speeds than before (Poole & Orski, n.d.). The following diagram in Figure 1 indicates the relationship between factors that will allow us to calculate emissions for HOT lane projects.

Figure 1

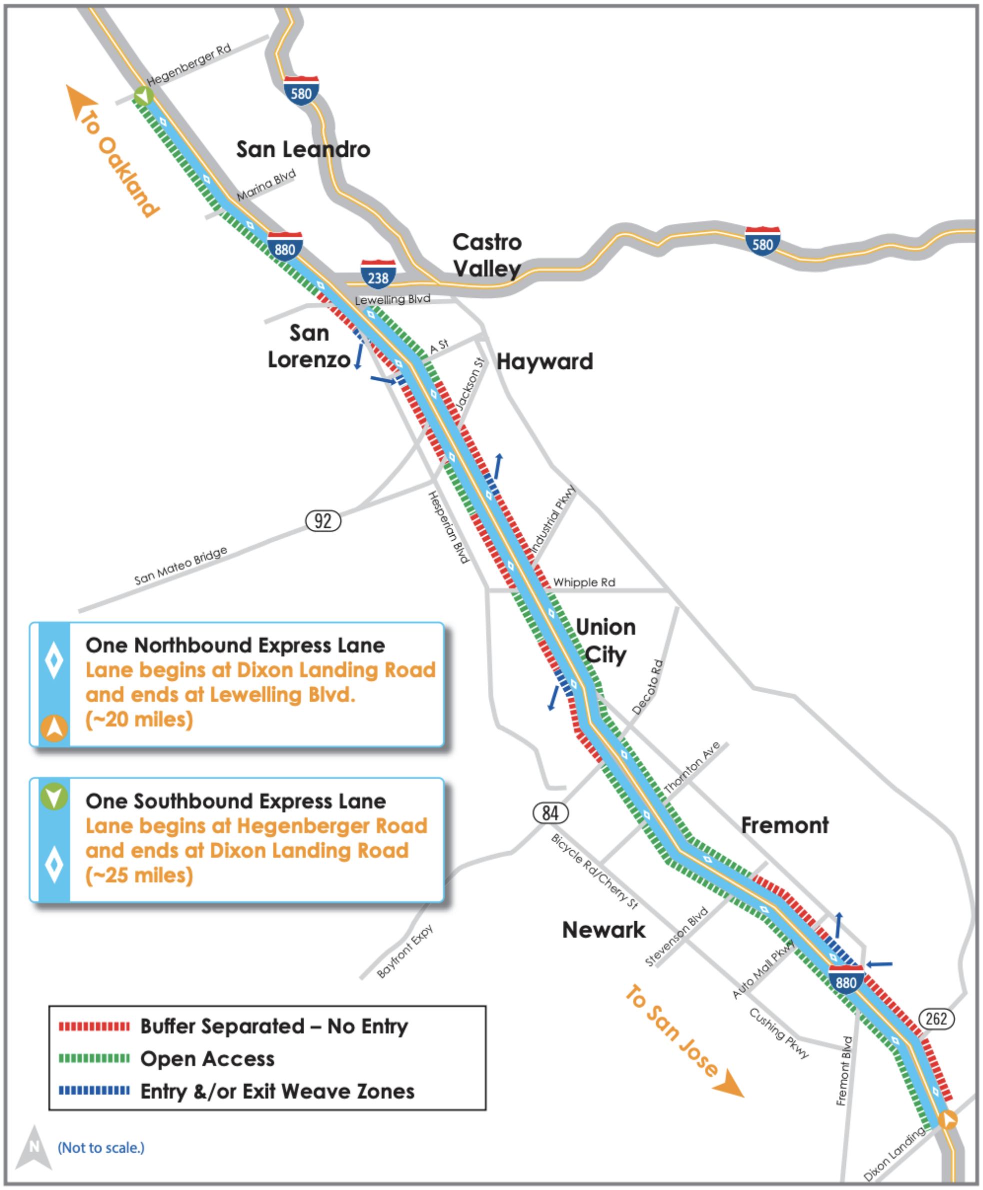
Diagram of the Causal Relationship Leading to CO_2 Emissions



In this memo, we will analyze CO_2 emissions from Interstate 880 (I-880), also called the Nimitz Freeway. This freeway is a north-south Interstate Highway in the San Francisco Bay (Bay) Area. It runs from Oakland to San Jose, along the eastern shore of the Bay. In 2015, construction of high-occupancy toll (HOT) lanes began along I-880, by converting the existing high-occupancy vehicle (HOV) lanes into HOT lanes. This toll lanes span around 30.1 miles in either direction, from the 66th Avenue interchange in Oakland to the Montague Expressway interchange in Milpitas, which can be seen in Figure 2 below ("Summary of I-880, SR-84 and SR-92 Express Lanes Project," 2016). The total estimated cost of the project was $139,000,000 based on an MTC report ("I-880 Express Lanes HOV Lane Conversion," 2019).

Figure 2

I-880 Project Detail Map



Note. Reprinted from "I-880 Express Lanes HOV Lane Conversion," 2019. Although the diagram suggests that the express lanes are 20-25 miles, measurement of the lanes via Google Maps is around 30.1 miles in either direction.

This memo, therefore, provides an estimate of the amount of carbon dioxide (CO_2) reduced from implementing this project as well as its cost per metric ton of CO_2 reduced, comparing both the "build" and "no-build" scenarios.

1. Sources

Our main guiding sources were reports put together by other staffers at Metropolitan Transportation Commission (MTC), which is the Bay Area's regional transportation planning agency and a metropolitan planning organization (MPO). These provide detailed summaries of the project, as well as quantitative estimates including vehicle miles traveled (VMT), average travel times and greenhouse gas (GHG) emissions associated with the build and no-build scenarios. We reached out to MTC staffers to understand how their specific estimates, such as values of VMT or average speed in the "no-build" scenario, were calculated, so that we could use a similar approach in our model and analysis to achieve greater accuracy. Unfortunately, they were unable to get back to us in time, so we have chosen to rely on various assumptions and models for some of these variables, which we have outlined in the following section. We relied on a 2009 paper from Matthew Barth and Kanok Boriboonsomsin on the impacts of traffic congestion on CO_2 emissions, and used their resulting model on the association between vehicle average speeds and CO_2 emissions. We also used data from Caltrans Performance Measurement System (PeMS) for VMT and speed (VMT/VHT) estimates, which provides data from individual detectors spanning California's freeway system; we collected this for the stretch of I-880 between the 66th Avenue and Montague Expressway interchanges (i.e., between postmiles 6.8 and 36.71).

2. Assumptions

Chosen Period of Analysis

Since the express lanes were opened on October 2, 2020, it is now impossible to perform an ex-ante prediction of the project's greenhouse gas emissions ("BAIFA Newsletter - 880 Opening," 2020). Additionally, the project has a horizon year of 2035, making an ex-post analysis for the entire horizon of the project infeasible as well. Instead, we chose to focus our analysis on the period immediately following the beginning of project construction in 2015 until the end of 2021. We believe that construction should be considered in our analysis as it will impact average speeds (and, by extension, CO_2 emissions) on I-880. However, we also wanted to consider travel behavior changes immediately following the installation of the express lanes, as existing freeway users learn about the new toll lanes and make decisions about whether to use them, and more drivers may choose to use the freeway due to the reduction in congestion. Unfortunately, as the lanes were only opened in late 2020, we were unsure whether our time frame sufficiently captured enough time after this initial period of adjustment immediately following the project implementation, which would have allowed travel behaviors to reach a new equilibrium and led to a more consistent pattern of annual VMT. As the pandemic is ongoing and travel patterns have changed since early 2020, we believe that accounting for these factors will be challenging, as they were entirely unimaginable when this project was proposed and started, but at play when the lanes were opened. Therefore, we hope to revisit this analysis once travel patterns have settled again and we have a better grasp on post-pandemic trends. As a result, our cost per ton estimates are considering the costs of a project that has a 20-year horizon, but for the emissions associated with only the first seven years of the project period.

Average Speed

For the average speed for the “build” scenario, we are relying on Caltrans PeMS data for monthly average speeds from January 2015 to December 2021. We have taken the weighted average of these speeds based on the VMT in each month for each year. For our values of average speed for the “no-build” scenario for 2015 and 2035, we are relying on estimates from an MTC report. As we do not have estimates for the years from 2016 to 2021, we are assuming that average speed will decrease linearly from 2015 to 2035, and are using these linearly interpolated values for these years. The opening (2015) and horizon (2035) year values from the MTC report are in Appendix A.

We noticed, however, that the average speeds in the PeMS data (i.e., the data used to calculate the average speed for the “build” scenario) were substantially greater in the years 2020 and 2021, likely due to changes in driving patterns during the pandemic. To better fit our estimates to this change, we assumed that the percent change in speeds in the “no-build” scenario would mirror those in the “build” scenario and adjusted the 2020 and 2021 speeds in the former scenario accordingly. The Methods section of this memo provides more detail on the process behind this modification.

Vehicle Miles Traveled (VMT)

For the “no-build” scenario, we also linearly interpolated VMT for 2016 through 2021 using estimates for 2015 and 2035 from the same MTC report. Additionally, similar to the adjustment made to 2020 and 2021 average speed estimates in the “no-build” scenario, we also adjusted VMT estimates in these two years for the “no-build” scenario to account for the change in driving patterns during the pandemic. Meanwhile, for the “build” scenario, we believe that Caltrans PeMS data provides an accurate estimate of VMT for each year. For these measures of VMT, as well as average speed in the above section, we cannot detect nor account for issues that are out of our control, such as sensors that were perhaps broken or incorrectly collecting data, that are a source of uncertainty in our analysis. However, we believe it is safe to trust these results as PeMS is one of the “most comprehensive and reliable data sources currently available in California” (Barth & Boriboonsomsin, 2009).

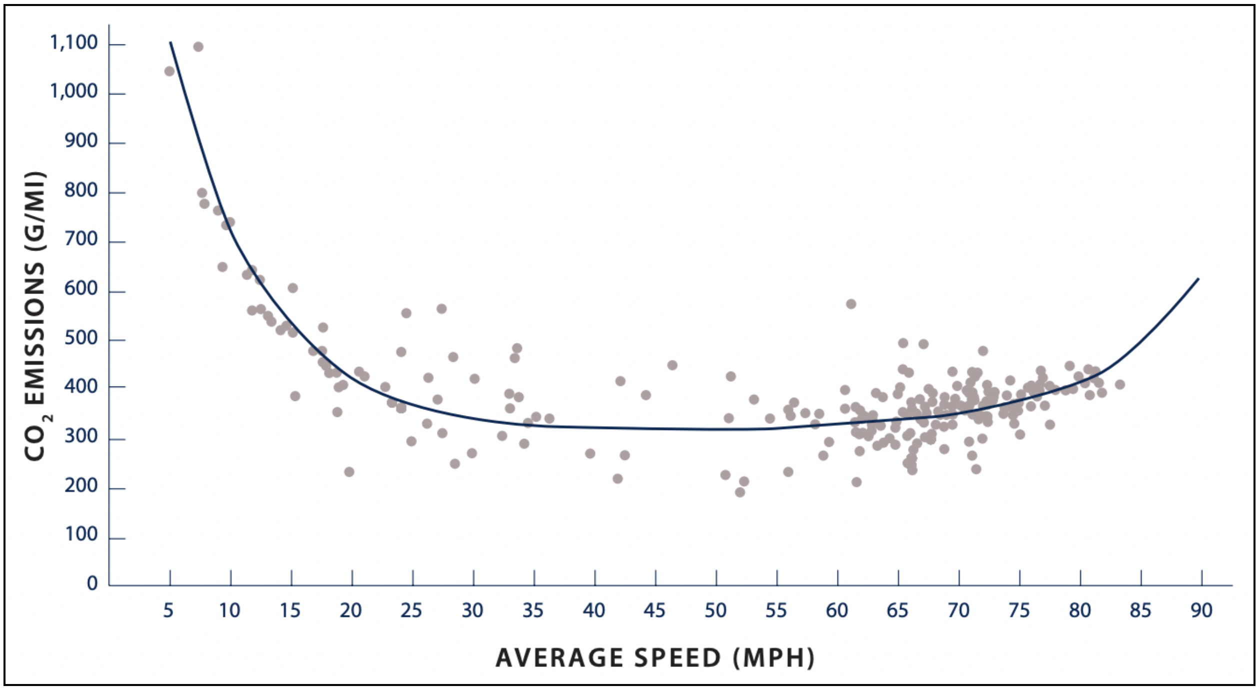
CO_2 Emissions

Barth and Boriboonsomsin’s model is based on a database of typical vehicle trips in Southern California. Their model is a fourth degree polynomial, and we believe that this best fits their data based on the information shared in their paper. We assume that this model is applicable to Bay Area traffic congestion patterns on I-880, despite being developed using data on a different freeway from another region. Relying on this model, we conclude that average vehicle speeds less than 45 miles per hour (mph) and greater than 65 mph have the most adverse impact on CO_2 emissions (Barth & Boriboonsomsin, 2009). Emissions are expected to increase for speeds below 45 mph as vehicles spend longer periods of time on the road (Barth & Sperling, 2019).

For speeds greater than 65 mph, emissions are expected to increase as energy efficiency is lower (Barth & Sperling, 2019). Their data and model can be seen in Figure 3 below.

Figure 3

Model for CO_2 Emissions Based on Average Speed



Note. Reprinted from Barth and Sperling, 2019.

Construction

Emissions from construction include those from material processing, onsite equipment, and traffic delays due to construction ("Summary of I-880, SR-84 and SR-92 Express Lanes Project," 2016). For this project, construction involved "lane striping and installing sign structures, signs tolling equipment, traffic monitoring video cameras, a data communications network, lighting, median barrier replacement and CHP observation areas" ("I-880 Express Lanes HOV Lane Conversion," 2019). I-880 was also widened in three places to accommodate lanes for merging in and out of the express lanes ("I-880 Express Lanes HOV Lane Conversion," 2019). However, Caltrans and the Bay Area Air Quality Management District have not implemented any significance thresholds for construction projects ("Summary of I-880, SR-84 and SR-92 Express Lanes Project," 2016). Additionally, the reports we are referencing do not quantify GHG emissions from construction "due to the limited construction scope proposed" ("Summary of I-880, SR-84 and SR-92 Express Lanes Project," 2016). As a result, we do not consider these emissions in our analysis. However, the emissions prior to October 2020 in our analysis are attributable to construction, in that ongoing construction reduced average vehicular speed and VMT on I-880, which affected CO_2 emissions.

Pricing Mechanism and Toll Revenue

The HOT lanes operate on Mondays through Fridays, from 5 a.m. to 8 p.m. ("I-880 Express Lanes HOV Lane Conversion," 2019). Carpools of three or more people, motorcycles, and buses are able to use the lanes without paying a toll ("I-880 Express Lanes HOV Lane Conversion," 2019). Carpools of two people or eligible Clean Air Vehicles can use the lanes if they pay a half-price toll ("I-880 Express Lanes HOV Lane Conversion," 2019). Individual drivers can use the lanes if they pay the full tolls ("I-880 Express Lanes HOV Lane Conversion," 2019). We were unable to find the toll revenue from these lanes, other than that the minimum toll price was $0.50 per toll zone and that toll price was set based on the traffic congestion conditions at the time, with no set maximum toll price ("I-880 Express Lanes HOV Lane Conversion," 2019). Due to our large uncertainty surrounding the toll pricing scheme, we have not considered toll revenues or the fact that different lanes have different pricing mechanisms in this analysis. However, if we did consider toll revenues, we might have a negative cost per ton of CO_2 reduced value, in the case that these revenues exceeded the cost of construction and implementation for the project.

3. Methods

To estimate the total amount of CO_2 reduced and the cost per metric ton of CO_2 reduced from the I-880 HOT lane project, we adapted the method used in a MTC report with several adjustments (“Summary of I-880, SR-84 and SR-92 Express Lanes Project,” 2016). As mentioned above, we used linear interpolation to estimate the average speed of vehicles traveling on the study segment of the I-880 freeway for the years from 2016 to 2021 for the “no-build” scenario based on the average speed values for 2015 and 2035 in the MTC report.

As previously mentioned, we used PeMS to extract VMT data as well as average speeds for the “build” scenario. This required several steps to retrieve only data relevant to our segment of analysis. First, we set the postmile range from postmile 6.8 to 36.71, constituting only the study segment between the 66th Avenue interchange and the Montague Expressway interchange. Then, we set the granularity of data to “Month” and ran the query for each year. Since the output data contained VMT values for each month, we summed these values for each year from 2015 to 2021 to obtain the total VMT in each year. This process was performed for both the northbound and southbound directions. For the average speeds, we retrieved data from PeMS for VMT divided by VHT for each of these months. To change these values to the average speed of each year, we used a weighted average, weighting by the VMT of each month.

As mentioned in the Assumptions section of this memo, we notice a substantial increase in the average speed values in 2020 and 2021 in the PeMS data (i.e., the data used for the average speeds in the “build” scenario), likely due to changes in travel behavior during the pandemic. To account for this change in the “no-build” scenario, we first calculated the average of the “build” speeds from 2015 to 2019 separately for both freeway directions and characterized these values as our assumed “normal” speeds, given that these were speeds before the pandemic in our period of analysis. Then, we determined the percent change of the “build” scenario speeds in 2020 and 2021 from these “normal” speeds, for both freeway directions. Finally, we adjusted the average speeds in the “no-build” scenario by increasing the linearly-interpolated 2020 and 2021 estimates in this scenario by the aforementioned percent change values. A similar process using VMT values was performed to also adjust the 2020 and 2021 VMT estimates in the “no-build” scenario.

To calculate the total CO_2 emissions each year, we input these average speed values for the northbound and southbound directions, and for the “build” and “no-build” scenarios, into the fourth degree polynomial model provided in the Barth and Boriboonsomsin paper (see Appendix B) to estimate CO_2 emissions in grams per mile. Then we multiplied the CO_2 emissions values in grams per mile by the VMT per year to arrive at grams of CO_2 emitted each year for both scenarios. We then converted these CO_2 emissions values from grams to metric tons (MT) and summed the results separately for the two scenarios to arrive at the total CO_2 emissions in metric tons for each alternative.

Finally, to calculate the total amount of CO_2 reduced due to the project's implementation, we subtracted the total CO_2 emissions from the "build" alternative from the total CO_2 emissions from the "no-build" alternative. To calculate the cost per metric ton of CO_2 reduced, we simply divided the estimated cost of the project from the MTC report ($139,000,000) by our calculated estimate of the total amount of CO_2 reduced ("I-880 Express Lanes HOV Lane Conversion," 2019).

4. Estimates

Table 1

Results from Carbon Analysis of I-880 Express Lanes

Total CO_2 Reduced (MT)	484,235
Cost per Metric Ton of CO_2 Reduced ($/MT)	$287

5. Analysis

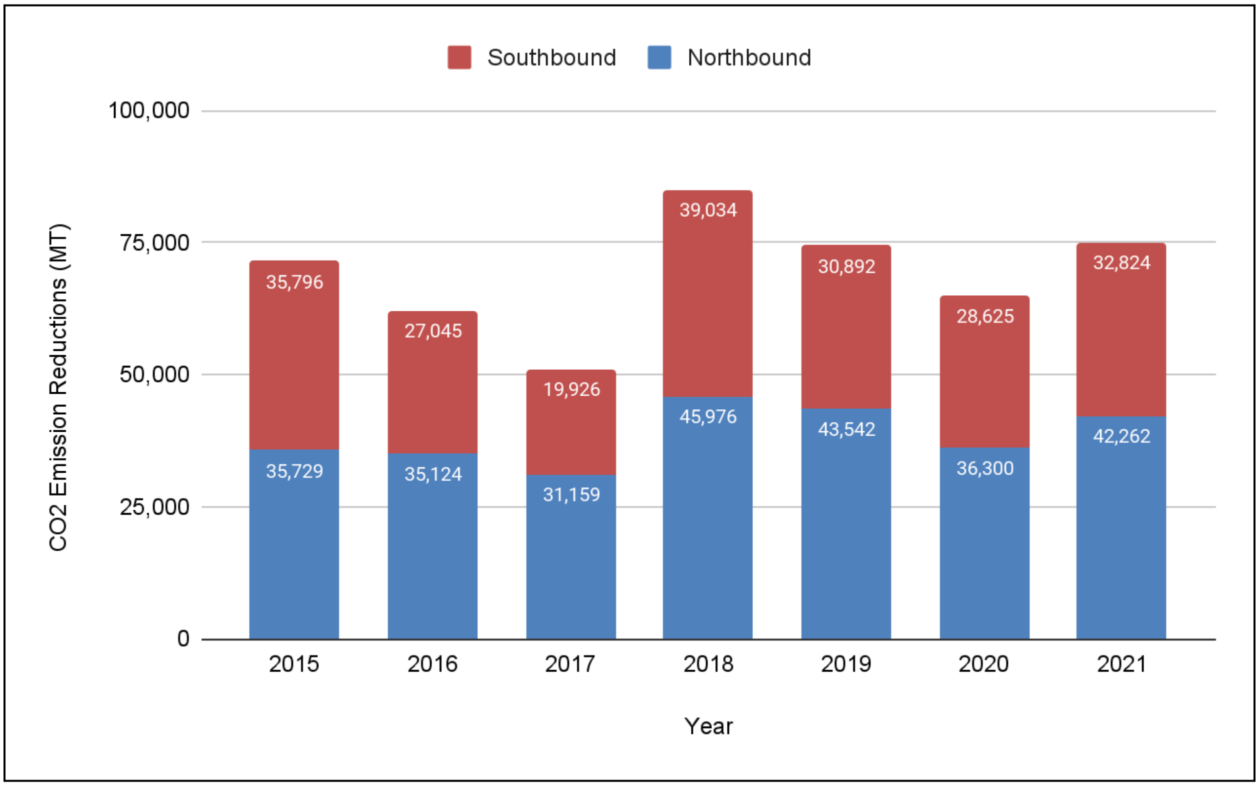
As shown in Table 1, the estimated total amount of CO_2 reduced due to the construction of the express lanes and the first year of operations is 484,235 metric tons. Also shown in Table 1 is the estimated cost per metric ton of CO_2 reduced, which is $287 per metric ton. Had we considered toll revenues, this value may have been negative, which would have indicated that the toll revenue actually exceeded the costs for implementing this project.

Our results for this initial seven year period indicate that the express lanes have reduced potential CO_2 emissions in these years. The data clearly show that lower annual VMT in the "build" compared to the "no-build" scenario is the primary driver for this reduction in emissions. During the construction of the lanes (2015 to 2020), it is likely that VMT may have been lower in the “build” scenario if drivers deliberately strayed away from traveling on the freeway to avoid the added congestion caused by construction. However, we see that VMT in the “build” scenario is still lower than in the "no-build" scenario after the construction period (2021), possibly because the toll lanes have incentivized freeway users to carpool to take advantage of the lane, reducing the number of vehicles on the freeway.

Figure 4 displays the combined amount of CO_2 emissions reduced in each year during the period of analysis from both the northbound and southbound directions. From this figure, we can see that the amount of CO_2 emissions reduced increased from 2020 to 2021, the first year that the lanes opened. Based on this initial trend, we are optimistic that the total amount of CO_2 emissions reduced will continue to increase as more single-passenger vehicles transition to carpooling to utilize the toll lane, which would mean that the project will prove effective in reducing emissions in future years as well, compared to the “no-build” scenario.
Additionally, although the magnitude of the cost per ton estimate may seem large, this is also because the estimated cost of $139,000,000 is only divided by the emissions reduced during the first seven years. Therefore, the project may have a lower cost per metric ton of reduced emissions when considering the full 20 years until the horizon year, indicating even greater effectiveness of these lanes.

Figure 4

Trend of CO_2 Emission Reductions Due to I-880 Express Lanes From 2015-2021



Note. These emission reductions were calculated by subtracting the emissions from the "build" scenario from the "no-build" scenario.

Comparison with I-580 Express Lanes

To put our results into context, we performed a similar analysis for the I-580 freeway express lane project for comparison, which is also in the Bay Area. This tolled segment of this freeway runs east-west from Dublin/Pleasanton to Livermore and similarly has a single HOT lane in either direction, which spans 10 miles in the eastbound direction and 12 miles in the westbound direction (*I-580 Express Lanes*, n.d.). The construction of the electronic tolling system began in 2015, and the toll lanes opened in February 2016 (*I-580 Express Lanes*, n.d.). The estimated total cost of the project was $345,000,000 (Gary Richards, 2016).

For the I-580 analysis, we used a method that was similar to our I-880 analysis with a few changes, as we primarily relied on PeMS data for this analysis due to the lack of a publicly available environmental report on the project (for a full description of the method used, see Appendix C). To maintain consistency in the analysis, we only analyzed and compared emissions from the first full year following the year that the lanes were implemented for each project, respectively (i.e., 2021 for I-880 and 2017 for I-580). This allowed us to compare the emissions reductions between both sets of toll lanes immediately following project implementation. Furthermore, considering that the tolled segment of the I-880 is much longer than that of the I-580, we also calculated the CO_2 reduced per mile for both projects to provide a normalized comparison of the effectiveness of each project at reducing CO_2 emissions.

Table 2 shows a comparison of the I-580 and I-880 express lane projects and the results of the analyses performed in this paper. The two have fairly similar emission reductions per mile of tolled segment in their first full year after project implementation, suggesting that our carbon analysis for the I-880 was reasonable.

Table 2

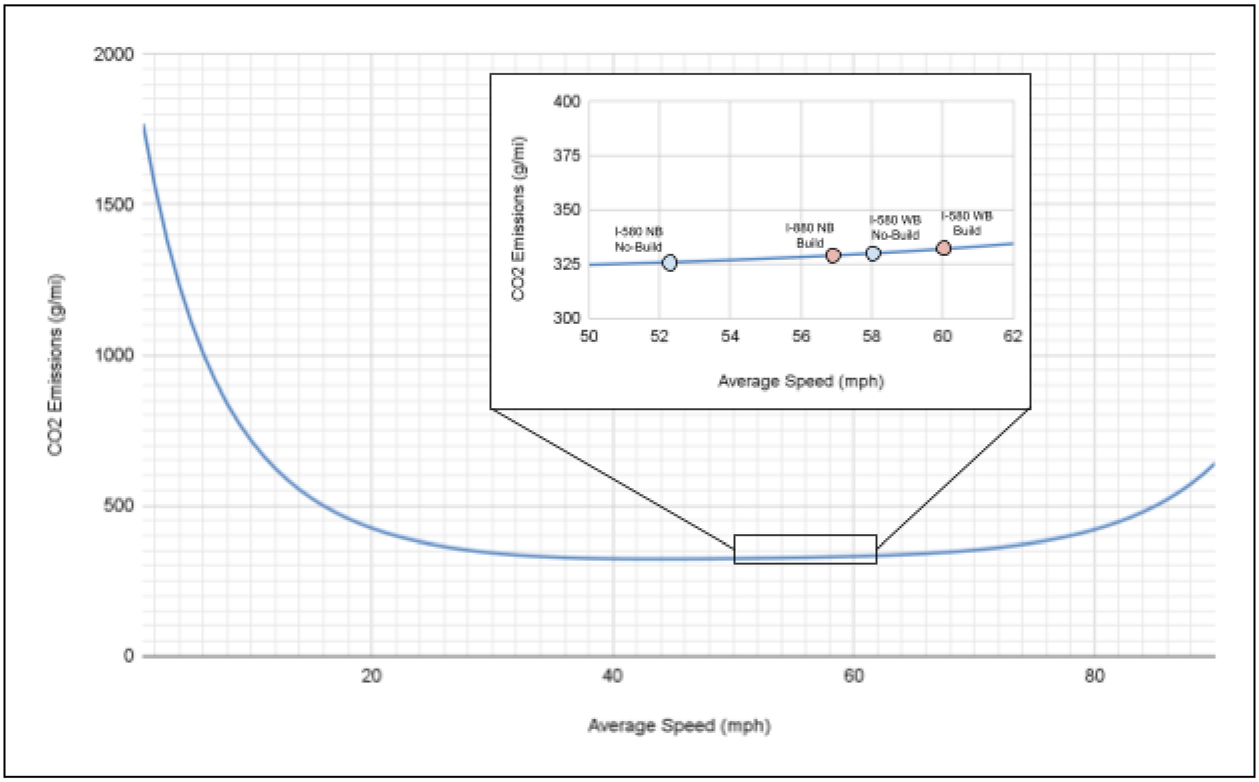
Comparison of Carbon Analyses for I-580 and I-880 Express Lanes

	Project (Year of Analysis)	
	I-880 (2021)	**I-580 (2017)**
Location	South/East Bay	Tri-Valley/East Bay
Length of Express Lanes (mi)	30.1	10-12
Total Estimated Cost	$139,000,000	$345,000,000
Total CO_2 Reduced (MT)	75,086	31,172
Total CO_2 Reduced per Mile of Tolled Segment (MT/mi)	1,247	1,417
Total Cost per Metric Ton CO_2 Reduced	$1,851	$11,068

We also note that although increases in average speed may improve vehicle throughput, this does not always translate to a reduction in CO_2 emissions, according to the Barth and Boriboonsomsin model. We see this in the analysis of the both the I-580 and I-880 toll lanes, as average speeds for the "build" scenarios were greater than that for the "no-build" scenarios, but the lower average speed in the "no-build" scenarios was more optimal for reducing emissions, as seen in Figure 5.

Figure 5

CO_2 Emissions for I-880 NB and I-580 WB Express Lanes

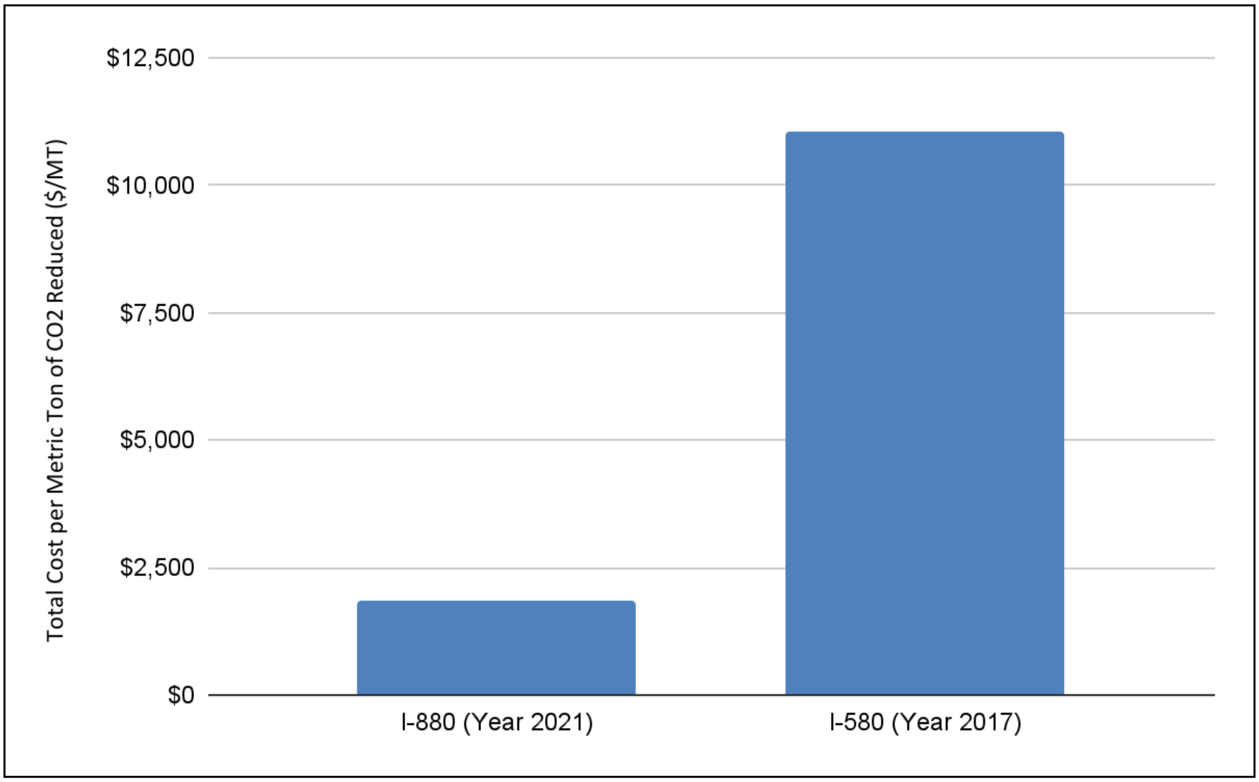


Note. This figure graphs the average speed estimates for the "build" and "no-build" scenarios for the I-880 in the northbound direction and the I-580 in the westbound direction on the Barth and Boriboonsomsin model, demonstrating how higher average speeds in the "build" scenario lead to greater per-mile emissions than the "no-build" scenario in both projects.

However, as we can see from Figure 5, the average speed for the "no-build" scenario for the I-580 leads to greater CO_2 emissions per mile than for the I-880; the same is also true for the "build" scenario. Thus, if we compare our results between the two projects, we are led to believe that the I-880 project is effective in that it leads to average speeds that are more conducive to emission reductions than the I-580 project. Additionally, as we can see in Figure 6, the I-880 toll lanes were more cost-effective at emission reduction than the I-580 lanes, as the I-580 lanes have a cost per metric ton of CO_2 reduced that is nearly six times that of the I-880 toll lanes.

Figure 6

Comparison of Total Cost per Metric Ton of CO_2 Reduced Between I-880 and I-580 Express Lanes



Recommendations

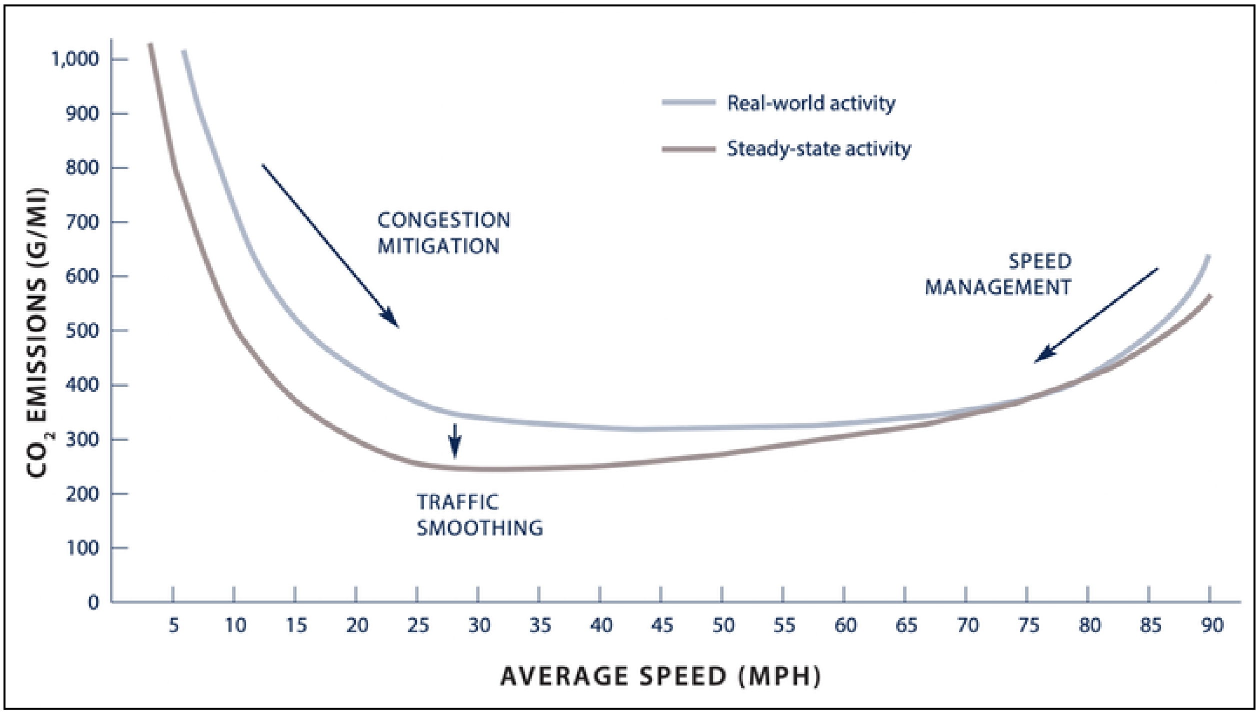
In conjunction with the express lanes, we recommend some other policies that could be considered to further reduce CO_2 emissions. Some traffic operation strategies that could help reduce on-road emissions include (Barth & Sperling, 2019):

- Congestion mitigation policies to reduce emissions when vehicles are traveling at lower average speeds
- Smoothing stop-and-go traffic, through methods like cooperative adaptive cruise control and speed harmonization
- Traffic speed reduction policies to reduce emissions when vehicles are traveling at higher average speeds

These can be visually seen in Figure 7 below.

Figure 7

Potential Effects of Traffic Operation Strategies on Reducing CO_2 Emissions



Note. Reprinted from Barth and Sperling, 2019.

6. Key Uncertainties

Much of our analysis relies on the validity of our assumptions as were described earlier. However, there are a few uncertainties that affect how our results should be interpreted. We have to keep in mind that the "no-build" scenario is now counterfactual, and the actual emissions that would have been emitted as a result of this scenario are now unknown, as these lanes have been implemented. We do not actually know what the real average speed or VMT on this stretch of I-880 would have been since 2015, had the construction and the project not occurred. As a result, our linear interpolations may not be the best approximation of what might have ensued in the "no-build" case. VMT, and average speeds – dependent on VMT and

VHT – have definitely changed, as travel patterns have changed during the pandemic. We also believe that average speeds in the “no-build” case would have been higher than our linear approximations given that many people were able to work from home. We attempted to account for these changes through our modification of the 2020 and 2021 values for the “no-build” scenario, though they may not have been completely accurate.

However, such a model might also incorrectly include effects from “induced demand” or the “rebound effect” that may have occurred in the “build” scenario, in the “no-build” scenario. If congestion was reduced in the “build” case due to the opening of these lanes, travel demand may have increased, which could have increased congestion and VMT and decreased speeds as a result. Thus, if we model our “no-build” average speeds taking into consideration trends from the “build” case, our estimates for average speed may still be lower than they might have been, which could either increase or decrease emissions depending on what the speeds are, in accordance with the curve in the Barth and Boriboonsomsin model. Keeping in mind that the lanes have only been open for a little over a year and during a pandemic, we believe that this might not be a significant issue in our analysis. But if we try to predict future use of these lanes (i.e., in the “build” case) in future analyses, then we must be more cautious when taking into account the rebound effect.

7. Conclusion

We believe that the I-880 express lanes have great potential for reducing CO_2 emissions. This is especially given the promising trend from 2020 to 2021, which indicates that the difference in emissions between the “build” and “no-build” scenarios may continue to increase, leading to meaningful emission reductions over time. Comparing this project with the I-580 lanes, we are more confident that the I-880 express lanes can have a positive environmental impact in the Bay Area. We also have to keep in mind that toll revenues were not considered, which, if they exceeded costs of construction and implementation, would indicate that this project is significantly more effective in reducing emissions, and actually leads to revenue, compared to the existing HOV lanes it replaced.

Several assumptions were made to determine values for the counterfactual, and we hope to revisit our analyses with greater information from MTC to create more informed models for our estimated values. Additionally, the pandemic has changed travel patterns significantly and we have found these difficult to account for as well, given that the pandemic is still ongoing. Despite these assumptions and slight uncertainties, we believe that our analysis is rigorous given the information and data we were able to access. Additionally, we recommend incorporating strategies such as those listed in our Analysis above to help further manage emissions and congestion on a heavy-trafficked highway like I-880, so that these express lanes may have a longer-lasting environmental impact, before they might be offset by factors like population and car ownership increases or induced demand leading to greater VMT.

8. References

BAIFA Newsletter—880 Opening. (n.d.). Metropolitan Transportation Commission. Retrieved February 23, 2022, from https://mtc.ca.gov/sites/default/files/BAIFA%20Newsletter%20-%20880%20Opening.pdf

Barth, M., & Boriboonsomsin, K. (2008). *Real-World CO2 Impacts of Traffic Congestion*. https://escholarship.org/uc/item/4fx9g4gn

Barth, M., & Sperling, D. (n.d.). Chapter 14: Environmentally Sustainable Transportation. In V. Ramanathan, A. Millard-Ball, M. Niemann, & S. Friese (Eds.), *Bending the Curve: Climate Change Solutions*. Regents of the Univ of California.

Final I-880 Express Lanes Sign Installation To Begin Next Week. (2020, August 21). *PR Newswire*. https://www.prnewswire.com/news-releases/final-i-880-express-lanes-sign-installation-to-begin-next-week-301116170.html

Gary Richards. (2016, August 12). New I-580 toll lanes: FasTrak Flex required for all drivers – The Mercury News. *The Mercury News*. https://www.mercurynews.com/2016/02/09/new-i-580-toll-lanes-fastrak-flex-required-for-all-drivers/

Linton, C., Grant-Muller, S. & Gale, W. F. Approaches and Techniques for Modelling CO2 Emissions from Road Transport. *Transport Reviews*, 35:4, 533-553. https://www.tandfonline.com/doi/pdf/10.1080/01441647.2015.1030004

I-580 Express Lanes. (n.d.). Alameda County Transportation Commission. Retrieved February 23, 2022, from https://www.alamedactc.org/programs-projects/expresslanesops/580expresslanes/

I-880 Express Lanes: HOV Lane Conversion. (2019). Bay Area Express Lanes.

MTC Express Lanes: Concept of Operations. (2015). Metropolitan Transportation Commission. https://mtc.ca.gov/sites/default/files/MTC%20CONOPS%20FINAL%20UPDATE%2020150701_0.pdf

Summary of I-880, SR-84 and SR-92 Express Lanes Project in Alameda and Santa Clara Counties Environmental Technical Analyses: Greenhouse Gas Emissions, Vehicle Miles Traveled and Use by Low-Income Populations (pp. 1–34). (2016). Metropolitan Transportation Commission. https://www.planbayarea.org/sites/default/files/pdf/I880_SR84_SR92_Express_Lane_Settlement_Summary_Final.pdf

9. Appendix

Appendix A

Average Speeds Along Northbound and Southbound Segments of I-880, for Build and No-Build Scenarios

		Average Speed (mph)	
		Northbound	**Southbound**
Existing (2012)		54	53
2015	**Build**	53	54
	No-Build	51	51
2035	**Build**	48	43
	No-Build	47	43

Note: Reprinted from "Summary of I-880, SR-84 and SR-92 Express Lanes Project," 2016.

Appendix B

Appendix B1. *Fourth-order polynomial model (Equation 1) for Appendix C1.*

$$ln(y) \ = \ b_0 + b_1x + b_2x^2 + b_3x^3 + b_4x^4 \ \textbf{(1)}$$

Note. Reprinted from Barth and Sperling, 2019.

Appendix B2. *Derived line-fit parameters for Equation 1*

	Real-world	Steady-state
N	241	9
R^2	0.668	0.992
b_0	7.613534995	7.362867271
b_1	-0.1385654675	-0.1498143158
b_2	0.003915102064	0.00421481051
b_3	-0.00004945136102	-0.00004925395146
b_4	0.000000238630156	0.000000217166574

Appendix C

Description of Model for Estimating CO_2 Emissions for the I-580 Express Lane Project

We relied on PeMS data to perform an estimate of the CO_2 emissions reduction and the cost per metric ton of CO2 reduced by the I-580 express lanes in 2021. First, we performed calculations to determine the average speed for both the “no-build” and “build” scenarios. Unlike for the I-880 analysis, there was no publicly available environmental report for the I-580 express lanes that allowed us to review the MTC’s estimates for the average speed or VMT for the “no-build” scenario. Therefore, we estimated average speed for this scenario by averaging speeds from PeMS data from 2010 to 2014, constituting the five-year period immediately preceding the year that construction of the HOT lanes began (i.e., 2015).

For VMT, we used PeMS data to calculate annual VMT for the “build” scenario. Meanwhile, to estimate the "no-build" VMT, the ratio between the "no-build" and "build" VMT for the I-580 was assumed to be the same as that for the I-880. Thus, VMT for the "no-build" scenario for the I-580 was calculated by scaling the "build" scenario VMT by the ratio between "no-build" and "build" for the I-880.

Then, similar to our I-880 analysis, to calculate CO_2 emissions in grams per mile, we input the average speed values for both directions and both scenarios into the polynomial model provided in the Barth and Boriboonsomsin paper (see Appendix B1). To obtain CO_2 emissions in grams, we multiplied the CO_2 emissions in grams per mile by the total annual VMT, individually for both directions. Then, we converted the results from grams to metric tons.

Finally, to obtain the total amount of CO_2 reduced, we subtracted the CO_2 emissions in the “build” alternative from the “no-build” alternative for both directions and then summed the differences. To calculate CO_2 reduced per mile, we divided the total amount of CO_2 reduced by the average length of the toll lanes (11 miles).

Appendix D

Link to Carbon Analysis Spreadsheet

https://docs.google.com/spreadsheets/d/1Tlr50HfwsBfeFagNz9lDGuF3k_IC7lL9a9fxo7nQziE/edit?usp=sharing

Appendix E

Contributions

Purva compiled many of the initial MTC reports detailing the I-880 project, as well as located the Barth and Boriboonsomsin paper that suggested the primary model for our analysis. Jackson collected VMT and VHT data from PeMS and reports on the I-580 project. The methods and the quantitative analysis were developed and performed together. Both contributed equally to writing this memo.

Appendix F

Revisions

In revising this memo for the final submission, we received feedback from Ellen Schwartz, Jayden Zhendong Long, and Adam Millard-Ball. Much of the feedback was similar across all three reviewers, so we mostly focused on clarifying these points that were in common. This included giving greater context about how the project would reduce emissions in the beginning of this memo, incorporating more figures throughout the paper, providing more detail on our assumptions (e.g., why we chose to ignore toll revenue) and what impact these assumptions could have on our results, explaining the main driver of emission reductions in the data (i.e., smaller VMT values in the "build" compared to the "no-build scenario), and explaining our comparison case study more. As we did not hear back from MTC in time, we made some changes to our model that tried to better account for the "no-build" scenario, especially in regards to how VMT and average speeds may have shifted as a result of the pandemic. We believe these modifications have also made for a more comprehensive paper with greater context and more seamless transitions between our sections, which hopefully makes for a better reading experience that facilitates greater understanding of our process and findings.