CENTRAL NEW MEXICO CLIMATE CHANGE SCENARIO PLANNING PROJECT

ANALYSIS OF ADDITIONAL GREENHOUSE GAS MITIGATION STRATEGIES

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TABLE OF CONTENTS

1 INTRODUCTION

This report evaluates several additional greenhouse gas (GHG) mitigation strategies that were not evaluated during the scenario evaluation phase of the Central New Mexico Climate Change Planning Project. Table 1 provides a list of potential GHG mitigation strategies that were identified by the Mid-Region Council of Governments (MRCOG) in the early phases of the project. The UNM research team evaluated the list and provided an initial ranking on the GHG mitigation potential of each strategy, whether the strategy was a short, medium, or long term measure, and how well the GHG mitigation potential of the strategy could be evaluated with the data and models currently available to MRCOG and UNM.

Four strategies with high GHG mitigation potential were previously evaluated (Table 1) using MRCOG's integrated land-use, travel demand, and emission factor models. These strategies changed land-use zoning to allow greater mixed-use, transit oriented, and infill development and also improved transit service by decreasing headways, expanding routes, and adding new bus rapid transit lines. The preferred scenario achieves 3.7 percent fewer vehicle miles traveled (VMT) and 5 percent fewer GHG emissions than the trend scenario in the year 2040. However, considering absolute changes from today (2012), VMT increased by 37 percent and GHG emissions increased by 18 percent. VMT grew faster than GHG emissions because the region's vehicle fleet is expected to become more energy efficient over time. While the decline in VMT and GHG emissions relative to the trend scenario are significant, to address climate change GHG emission will eventually need to fall below current levels. This report considers additional strategies that may help further reduce regional GHG emissions from the transportation sector.

In this report an additional set of high priority or potentially highly effective GHG mitigation strategies (Table 1) are considered that could be applied on top of the land-use and transit strategies included in the 2040 preferred scenario developed by MRCOG through the scenario planning process. The strategies in Table 1were selected by the UNM research team because they have a high GHG mitigation potential or because there was strong regional interest in evaluating the strategy. For example, incident management was rated by UNM, prior to conducting a detailed analysis, as having a relatively low GHG mitigation potential but is considered in this report since there is regional support for considering incident management to reduce traffic congestion. The lower priority set of strategies identified in Table 1 are likely to have only a small GHG mitigation potential, are not likely to be implemented in the Albuquerque metropolitan area, or are very difficult to evaluate. These strategies will be discussed in a second part to this report (forthcoming) in a more qualitative discussion. The GHG mitigation potential of the strategies evaluated in this report were quantified to the extent possible given the available evidence and resources (i.e., time and funding).

Table 1 Potential GHG Mitigation Strategies

Strategy	GHG Mitigation Potential	Analysis Capability
Analysis Completed During the Scenario Planning Phase		
Zoning changes	●●●●● L	●●●●● U
Infill development	●●●●○ L	●●●●○ U
Transit oriented development	●●●●○ L	●●●●○ U,C
Improving public transportation	●●●○○ S	●●●○○ C
Higher Priority or Higher Potential GHG Mitigation Effectiveness (Evaluated in This Report)		
Urban growth boundaries	●●●●● M	●●●●● U
"Wheels" tax (VMT charging) & Gas Tax	●●●●● S	●●●●○ C
Bicycle and pedestrian infrastructure improvements	●●●○○ S	●●○○○ O,P,Q

Incident management	●●○○○ S	●○○○○ Q
Traffic signal enhancement	●●●○○ S	●●●○○ C,P
Establishing roadway connectivity standards	●●●○○ L	●●●●○ C
Lower Priority or Lower Potential GHG Mitigation Effectiveness (Evaluated in Follow-on Report)		
Bike sharing	●○○○○ S	●○○○○ Q
HOV facilities	●○○○○ M	●○○○○ Q,P
Building design standards	●●○○○ L	●○○○○ Q
Establishing a complete streets policy	●●○○○ L	●○○○○ Q
Road pricing (HOT lanes/congestion charging)	●●●○○ S	●●○○○ C,P
Parking management	●●●○○ S	●●●○○ C
Car sharing	●○○○○ S	●○○○○ Q
Ride sharing	●○○○○ S	●●●○○ Q,C
Travel demand management-educational	●○○○○ S	●○○○○ Q
Travel demand management-transit incentives	●●●○○ S	●●○○○ Q,P
Intersection improvement	●○○○○ S	●●●●○ P,C
Electric vehicle infrastructure support	●●○○○ M	●○○○○ Q,M
Heavy-duty vehicle retrofit	●○○○○ M	●●●●○ Q,M
Truck-stop electrification technologies	●○○○○ S	●●○○○ M

●○○○○ → ●●●●●
Low High

L = long term
M = medium term
S = short term

U = UrbanSim, C = CUBE,
M = MOVES, O = Off Model,
P = Post Process, Q = Qualitative

The additional GHG mitigation strategies considered in this report were only evaluated for their ability to reduce GHG emissions. How they may affect other regional goals or transportation system performance metrics was not considered. Most strategies reduce GHG emissions by reducing travel demand or improving traffic flow and are therefore expected to generally improve the region's traffic conditions. Many of the GHG mitigation strategies also produce benefits in addition to reducing GHG emissions. For example, an urban growth boundary preserves open space and may protect valuable ecosystem services or agricultural land. Multi-use paths not only help mitigate GHG emissions by encouraging bicycle trips but may also increase cyclist's safety and enjoyment and provide a place for non-motorized recreation and exercise. These types of additional benefits are not considered in this report. While this report may indicate little or no GHG mitigation potential for a particular strategy, that does not necessarily mean the strategy is poor public policy – it only means that the strategy is unlikely to mitigate GHG emissions.

Each strategy is evaluated for its effectiveness at mitigating regional GHG emissions. Some strategies may be highly effective at reducing per trip GHG emissions but not at reducing regional GHG emissions. For example, riding a bicycle produces no direct GHG emissions (a 100 percent reduction from driving a car) but only a small portion of trips occur using bicycles (about 2 percent) so the regional effect on GHG emissions of a strategy that doubles bicycle model share would still be relatively small. It is also important not to confuse effectiveness with the efficiency of a strategy. If a strategy to increase the share of trips made by bicycle has a very low cost per quantity of GHG reduction then that strategy may be very efficient even though it is not particularly effective on a regional scale. This report only considers the effectiveness of GHG mitigation strategies but not their efficiency. Evaluating the efficiency of each strategy requires a cost analysis that is beyond the scope of the present study.

Finally, this report uses the terms GHG and carbon dioxide equivalents (CO_2-eq) somewhat interchangeably. CO_2-eq is calculated by transforming the quantity of non-carbon dioxide GHGs such as methane, nitrous oxide, and hydrofluorocarbons into an equivalent quantity of carbon dioxide based on their global warming potentials[1]. These calculations where performed automatically by US EPA's Motor Vehicle Emission Simulator (MOVES) model.

2 Evaluation of High Priority Strategies or Strategies with Higher Potential GHG Mitigation Effectiveness

2.1 Urban Growth Boundaries

The land-use plans developed during the scenario planning phase of this project evaluated changes to existing zoning allowances and the land-use simulation model also included policy shifters designed as a proxy for the effect of municipal infill and transit oriented development incentives. Both of these strategies, zoning and policy incentives, guided more development away from the region's periphery and into more developed areas. Except for areas where development is currently not allowed, mostly protected open spaces, parks, and national forests, the preferred scenario developed through the scenario planning process did not prohibit the current trend of low to medium density suburban development at the urban fringe (i.e., urban sprawl). Rather, the land-use and transit strategies were designed to provide incentives aimed at reducing or slowing sprawl. Growth boundaries aim to address sprawl more directly by prohibiting development beyond a predetermined boundary defining the urban area. This strategy was selected by the UNM project team for its potential to further constrain suburban development patterns and increase density in areas that are already developed. While there is currently no plan to implement a growth boundary in the metropolitan area, this scenario is evaluated because it could be highly effective.

The effectiveness of an urban growth boundary in the Albuquerque metropolitan area is evaluated by identifying areas beyond the region's existing development footprint and then prohibiting any further development in those areas. The growth boundary is modeled using only MRCOG's travel demand model. The UrbanSim land-use model is not used. Using only the travel demand model simplifies the analysis since any zoning changes that would be required to accommodate more growth in the existing development footprint do not need to be identified to evaluate the potential VMT and GHG reduction benefits at this point[2].

The existing development footprint is defined as any travel analysis zone[3] (TAZ) with population density greater than 0.5 persons per acre. This criterion was developed based on a visual analysis of aerial photography available through ArcGIS that shows the approximate extent of current development and mapping the current population density of each TAZ. Based on this visual analysis 0.5 persons per acre appeared to be a reasonable proxy for mostly developed TAZs. A growth boundary was then drawn to create contiguous core urban areas of existing development. Contiguous areas were created by reclassifying as developed, TAZs that did not meet the development criterion defined above if they were surrounded on all sides by TAZs that met the development criterion. A similar process was used to reclassify developed TAZs as undeveloped if they were surrounded by undeveloped TAZs (i.e., leap-frog development). The final growth boundary is shown in Figure 1.

[1] List of global warming potentials for GHGs: http://unfccc.int/ghg_data/items/3825.php
[2] A careful analysis of zoning changes required for accommodating more urban growth should be conducted if a growth boundary will be developed or seriously considered. UrbanSim provides a good platform for conducting a more refined analysis.
[3] Travel analysis zones are used to aggregate population, housing, and employment data for use in the travel demand model. The travel demand model uses these data to predict the number of trips within and between each zone. Travel analysis zones are similar, and in many cases identical, to census tracks.

Population, housing and employment growth that was forecast to occur beyond the growth boundary in the 2040 preferred scenario is redistributed within the growth boundary. Figure 1 shows the preferred scenario population growth that occurs within and beyond the growth boundary. Growth occurring beyond the boundary is redistributed within the boundary by adding population, households, students, and employment to TAZs in proportion to each TAZ's current share of each of these attributes. This procedure directs more growth to higher density areas and less growth to lower density areas. The intent is to maintain the existing pattern of development and character of neighborhoods within the growth boundary.

The updated TAZ data replaces the TAZ level population and employment data in the preferred scenario travel demand modeling files; all other inputs and parameters are unchanged. MRCOG's travel demand model is run with the updated data and the output is evaluated using the MOVES emission factor model to determine changes in GHG emissions that occur from changes in mode share, traffic speed, and the number and distance of trips. The MOVES GHG analysis follows the same procedure that was used by UNM in the scenario evaluation phase of the project.

The growth boundary reduces regional VMT per capita by 2 percent (19.6 VMT per captia) and GHG emissions by 3.8 percent (511.6 tonnes per day CO_2-eq). These reductions are on top of the reductions achieved through changes to land-use zoning and transit investments in the preferred scenario. These are significant reductions considering that the 2040 preferred scenario results in a 5 percent reduction in GHG emissions from the 2040 trend scenario. If a growth boundary were given serious consideration, more detailed analysis is required to ensure that existing land-use policies and re-development opportunities could absorb the new growth.

An actual growth boundary could also be drawn more restrictively or more loosely than what was assumed here which would then affect the boundary's GHG mitigation potential. Growth boundaries could also be defined to protect sensitive ecological areas, natural and cultural resources, and prevent development in areas that have a high flood or fire risks, providing additional benefits beyond GHG mitigation. Growth boundaries could also be defined to limit the intensity or type of development outside of the urbanized area; for example, allowing agricultural land-uses but not residential or commercial development which provides some flexibility and economic development opportunity. Additionally, a more detailed growth boundary analysis should consider the potential for leap frog development beyond the boundary in locations that are outside of the control of regional municipalities participating in the growth boundary.

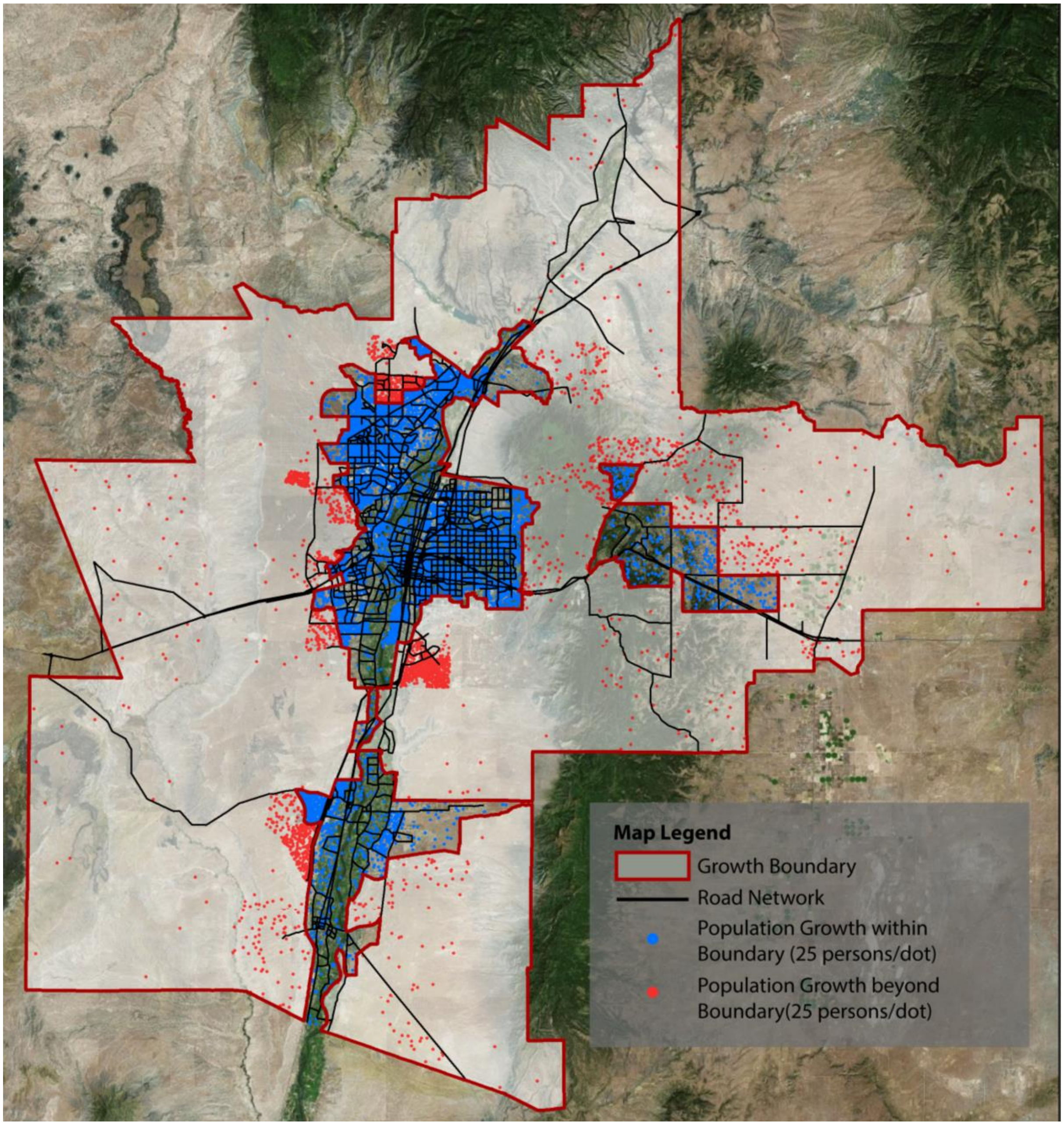

Figure 1 Growth Boundary and Population Growth from 2012 to 2040 for the Preferred Scenario (points show the location of modeled population growth from 2012 to 2040 under the Preferred Scenario without a growth boundary)

2.2 "Wheels" Tax (VMT Charging) and Gasoline Tax

Like all goods and services, demand for travel declines when price increases. A "wheels tax" or "VMT charge" is a per mile tax that could replace or supplement the current gasoline excise tax (gas tax). Any increase in the gasoline tax or adoption of a new VMT tax would have to be made at the state or federal level and is outside of the control of municipal governments and metropolitan planning organizations like MRCOG. Oregon and California have both recently adopted new state legislation setting up VMT tax pilot programs (Oregon Senate Bill 810 and California Senate Bill 1077) and several states have recently increased their gas tax.

A new VMT tax could be set so that the average tax collected equals today's gas tax. Under this scenario, individuals who drive vehicles that are more fuel-efficient than average would end up paying more tax, while those with less fuel-efficient vehicles would pay less tax. A distance-based tax would be more predictable and stable than the current gas tax, which has been eroded over time by the increasing fuel economy of vehicles and the introduction of alternatively fueled vehicles such as natural gas and electric vehicles. A VMT tax would provide a more reliable source of transportation funding than the current gas tax. Raising the VMT tax, rather than the gas tax, would also be a more direct and equitable approach for reducing travel demand since each driver pays the same amount per mile driven regardless of their vehicle's fuel efficiency. There are also benefits to increasing the gas tax. Over time, an equivalent gas tax would affect travel behavior differently than a VMT tax since it would encourage drivers to minimize fuel consumption rather than just travel. Purchasing a more fuel-efficient vehicle or an alternatively fueled vehicle can minimize fuel consumption and the amount of tax paid. A gas tax is a more direct and efficient method for discouraging the production of GHGs since fuel consumption produces GHG emissions and not travel. An optimal approach for controlling GHG emissions and congestion would include a carbon tax to account for the expected future costs caused by GHG emissions and a VMT tax to pay for transportation infrastructure and externalities related to driving such as congestion.

The evaluation in this section considers the adoption of a VMT tax that is on average higher than today's gas tax to achieve greater GHG mitigation. However, the travel demand model used to evaluate how a VMT tax would affect GHG emissions cannot distinguish between a higher gasoline tax and a VMT tax. The model simply considers the average per mile increase in vehicle operating costs. That is, the model does not consider how fuel prices affect vehicle purchase decisions or decisions about where to live. Therefore, this analysis considers both the effectiveness of raising the current gasoline excise tax or introducing a new VMT tax that replaces the gasoline excise tax. In the short run there will be little difference between the GHG mitigation potential of the two tax options but over the long run they will have different affects on consumer and travel behavior which will affect the efficiency of GHG mitigation.

A range of VMT tax rates are considered which are higher than the equivalent per mile rate of the current combined New Mexico ($0.1888 per gallon) and federal ($0.1840 per gallon) gasoline excise tax. Using an average fleet fuel economy of 20.6 miles per gallon (assumption used in the MRCOG travel demand model (Systra Mobility 2010)), the VMT tax rate equivalent of the current gas tax is $0.018 per mile. The main purpose of state and federal gas tax is to generate revenue for state and federal highway trust funds that provide funds for roadway construction and maintenance. These taxes are not designed as Pigouvian taxes, designed to internalize external costs that are produced by driving or using gasoline such as traffic congestion, noise, accidents, toxic air pollution, and GHG emissions. From an economic perspective, an optimal tax would include the marginal cost of damages that occur from each of these externalities and the cost of providing and maintaining transportation infrastructure. Additional revenue raised through a new VMT tax or higher gas tax could be used to increase investment in transportation infrastructure, mitigate the harmful effects of externalities (e.g., re-align roadways at risk from flooding due to climate change), or reduce other taxes (e.g., the income tax or gross receipts tax).

A range of VMT tax rates (Table 2) are used in this analysis since estimating the marginal cost of each externality is very challenging, particularly the cost of damages from future global warming caused by today's GHG emissions. The range of VMT tax rates considered brackets Parry and Small's (2005) calculation of the optimal VMT tax rate which they estimate is $0.18 per mile in 2008 dollars. Their optimal tax rate considers roadway infrastructure costs and the full range of externalities and is one of the more comprehensive estimates currently available.

MRCOG's travel demand model is used to evaluate the VMT taxes by adjusting the model's per mile vehicle operating cost parameter setting. Currently, the model uses a vehicle operating cost of $0.164 per mile in 2008 dollars (Systra Mobility 2010) which includes $0.018 in state and federal gas tax. The current vehicle operating cost assumes that the region's vehicle fleet achieves an average fuel economy of 20.6 miles per gallon and that a gallon of gasoline costs $3.38 per gallon. The VMT tax rates in Table 2 are added to the current operating costs. The travel demand model is used to evaluate the 2040 preferred scenario at each of the higher per mile operating costs. GHG emissions are estimated from the model output with MOVES using the same methods that were used in the scenario evaluation phase of the project.

The modeling results shown in Table 2 indicate that a VMT tax set at a rate higher than the equivalent average per mile cost of the current gasoline excise tax can reduce GHG emissions. The effectiveness of a VMT tax or higher gasoline tax depends on the ability to raise fuel or VMT taxes. The reductions in GHG emissions in Table 2 occur with tax rates that are much higher than today's and would likely face significant political and popular opposition. The effect of a smaller (or larger) VMT tax on GHG emissions can be evaluated by using elasticities derived from the modeling results. The price elasticity of CO_2-eq ranges from -0.26 to -0.32. Using the median elasticity (-0.29) and a more modest 25 percent increase in the current gasoline tax (approximately a half cent per mile VMT tax, a 2.7 percent increase in the cost of driving) GHG emissions would decrease by only 0.8 percent. Using the same elasticity, maintaining CO_2-eq emissions at 2012 levels (11,358 tonne/day) would require a VMT tax of $0.084 per mile in additional to today's gas tax, or equivalently, increasing the gas tax by $1.74 per gallon.

Table 2 Distance Based Tax Effects

Additional VMT Tax	Equivalent Gas Tax ($/gallon)	Daily VMT per Capita	CO_2-eq (tonne/day)	% Change in CO_2-eq from 2012
$0.00	$0.00	20.0	13,352	0%
$0.03	$0.62	19.4	12,572	-6%
$0.06	$1.24	18.5	11,959	-10%
$0.12	$2.47	17.1	10,968	-18%
$0.25	$5.15	15.0	9,616	-28%
$0.50	$10.30	12.3	7,955	-40%

The travel demand model has several limitations that may bias the results in Table 2 downwards. The location of trip destinations (trip length) and mode choice are sensitive to changes in vehicle operating costs imposed by the VMT tax or gasoline tax. These sensitivities are what drive the modeled GHG emission reductions. However, changing travel costs do not affect the number of trips made by each household or the location of households, businesses, and other travel productions and attractions in the model. Iterating the travel demand model with the land-use model would overcome these limitations.[4] Despite these limitations the elasticities calculated from the results fall within the range found in prior studies which range from -0.02 in the short run to -0.3 in the long run, with most long run results falling between -0.2 and -0.3 (Litman 2013). A more recent study evaluating the change in VMT as gas prices rose over the past decade in California estimates an elasticity of -0.22 (Gillingham 2014), similar to the range found in prior studies and the modeling results in Table 2.

[4] The land-use model was not available for this portion of the analysis.

2.3 Bicycle and Pedestrian Infrastructure Improvements

The land-use and transportation plans developed during the scenario planning phase of this project did not evaluate changes to bicycle and pedestrian infrastructure. This infrastructure is not defined in either the land-use or travel demand models. While the travel demand model does estimate the number of non-motorized trips (walking and cycling), the estimate is mostly influenced by household characteristics (income and vehicle availability), transportation costs, and trip distance. The presence of bicycle and pedestrian infrastructure such as bicycle lanes and wide sidewalks are not a factor in the travel demand model estimates, a common limitation of most region's travel demand models.

The logic embedded in the current travel demand model for predicting bicycle and pedestrian trips is based on a 1992 household travel survey conducted in the Albuquerque metropolitan area. In that survey respondents indicated how they traveled during the survey period. Some respondents indicated that they make some trips by walking or riding a bicycle. From the survey data, equations were developed that estimate the probability of choosing to make a trip by walking or riding a bicycle. The equations associate household and trip characteristics from survey respondents with their travel mode choices. The availability and quality of pedestrian and bicycle infrastructure in 1992 likely influenced the survey respondents travel choices. The availability and quality of bicycle and pedestrian infrastructure has since changed, and because the availability and quality of pedestrian and bicycle infrastructure are not factors in the mode choice equations within the travel demand model, current and future changes in these infrastructure are not accounted for in any way. This limitation is addressed by using the results of previous studies reported in the peer reviewed literature to estimate how the extent of new bicycle lanes and paths may affect VMT and GHG emissions.

2.3.1 Bicycle Infrastructure

The GHG mitigation potential of building additional bicycle facilities is evaluated by estimating the effect of building out the City of Albuquerque's 2014 draft bicycle plan (City of Albuquerque 2014). Comprehensive plans for building bicycle facilities in other parts of the region were either unavailable or not up to date. The City of Albuquerque's bicycle plan at full build out increases the length of bicycle lanes by 99 percent and multi-use paths by 75 percent (Table 3).

Elasticities that relate the extent of bicycle lanes and multi-use paths to bicycle mode share are obtained from a recent study by Buehler and Pucher (2012). Their study of the relationship between cycling rates and bicycle infrastructure in 90 U.S. cities is the most comprehensive study currently available. Their elasticities are derived from a regression analysis that relates bicycle commute mode share in each city to a number of explanatory variables including the extent of bicycle lanes and bicycle paths. The elasticity for bicycle lanes is 0.25 and is 0.091 for multi-use paths. These elasticities indicate that bicycle mode share increases less than proportionally with an increase in bicycle infrastructure. For example, the bicycle lane elasticity of 0.25 indicates that a 10 percent increase in the miles of bicycle lanes results in a 2.5 percent increase in bicycle mode share. These elasticities are used to estimate the change in bicycle mode share in Albuquerque from building new bicycle lanes and multi-use paths, which can then be used to estimate the change in the number of vehicle trips, VMT and GHG emissions.

While the elasticities from Buehler and Pucher (2012) represent the best available information at this time, there are a number of limitations. The elasticities are for bicycle commute mode share, there is no comparable information for other trip purposes. In this analysis these elasticities are applied to all trip purposes. The elasticities are also estimated at the mean level of each explanatory variable in their regression analysis. The elasticities therefore represent the relationship between providing more bicycle infrastructure and bicycle mode share under average conditions. It's unclear how conditions in

Albuquerque compare to the average conditions of the cities in Buehler and Pucher's study. For example, a higher than average traffic fatality rate or greater amount of sprawl would result in a lower elasticity while more temperate weather than average would increase the elasticity. While it is possible to compute elasticities using Buehler and Pucher's results that are more tailored to Albuquerque's characteristics the current analysis uses the average values given the time constraints for completing this analysis. Finally, Buehler and Pucher's study is a cross sectional design, it does not evaluate how bicycle mode share changes after the construction of bicycle facilities. Instead, their analysis considers how mode share varies with the amount of bicycle infrastructure (and other characteristics) across the cities in their sample. This type of analysis can find a correlation but cannot prove causation. It is possible that demand for cycling in some cities has caused those municipalities to provide more bicycle infrastructure. It is also possible that individuals who prefer to ride a bike have preferentially relocated to cities with good bicycle infrastructure (i.e. residential self selection bias). If either of these situations are occurring then the elasticities are biased upwards and the effect of providing more bicycle infrastructure is overstated.

Based on MRCOG's most recent 2013 household travel survey, approximately two percent of trips are made by bicycle in the region. The travel demand modeling results for the 2040 preferred scenario indicates that 6.1 percent of trips are non-motorized. For this analysis we assume that 2 percent of the modeled trips are bicycle trips and the remaining 4.1 percent are walking trips. Considering the percentage change in the miles of bicycle lanes and multi-use bicycle paths from completing Albuquerque's bicycle plan and using Buehler and Pucher's elasticities, bicycle mode share is estimated to increase from 2 percent to 2.6 percent in 2040 (Table 3).

Table 3 Bicycle Mode Share and GHG Reduction Calculations

	Bike Lanes	**Multi-Use Paths**
Mode Share Calculation		
Current Miles (2014)	197	154
Additional Miles	196	115
Current Bike Mode Share	2.0%	2.0%
Elasticity (mode share, facility miles)	0.25	.091
% Increase in Bike Mode Share	24.9%	6.8%
New Bike Mode Share	2.5%	2.1%
Emission Reduction Calculation		
Regional Trips (trips/day)	3,699,195	3,699,195
New Bicycle Trips (trips/day)	9,201	2,514
Average Trip Length (miles)	9.8	9.8
VMT Reduction (miles/day)	89,794	24,532
Average CO_2-eq Emission Factor (g/mi)	429.9	429.9
CO_2-eq Reduction (tonnes/day)	38.6	10.5

The reduction in vehicle trips is calculated by multiplying the change in bicycle mode share (0.6 percent) by 50 percent of the total number of trips estimated by the travel demand model. Fifty percent of the trips are used to account for the new bicycle facilities only being added to the City of Albuquerque, which is assumed to contain half of the region's trips. It is also assumed that all new bicycle trips substitute for vehicle trips and not for walking or transit trips. The average trip length of 9.8 miles derived from the travel demand model results is then used to estimate the change in VMT. The average system-wide vehicle speed, also derived from the travel demand model, is used to calculate an average CO_2-eq emission factor using MOVES, which is then multiplied by the change in VMT to estimate the change in CO_2-eq emissions (Table 3).

The results indicate that building out Albuquerque's bicycle plan, approximately doubling the amount of bicycle facilities in the city, would result in a 0.4 percent decrease in VMT and GHG emissions from the 2040 preferred scenario (total VMT is 27 million and CO_2-eq is 13,352 tonnes per day). There is a lot of uncertainty in these estimates; however, the results indicate that bicycle infrastructure can be effective. Even though the effect is small, the relatively low cost of creating most bicycle facilities may make this a relatively efficient GHG mitigation strategy.

2.3.2 Additional Bicycle Facility Evidence

There are few studies that provide strong evidence on the ability of bicycle facilities to reduce vehicle trips. The study by Buehler and Pucher (2012) is only suggestive due to its reliance on a cross sectional design and national commute mode share data. The UNM research team has recently completed a study in cooperation with MRCOG and the City of Albuquerque on the effectiveness of past investments in bicycle lanes and multi-use paths in the region (the study is currently under peer review for publication in Transportation Research Part A: Policy and Practice). The study asked cyclists if they used a bicycle lane or multi-use path on a regular utilitarian trip and what they would do if the bicycle lane or path did not exist.

The study found that most Albuquerque area cyclists use multi-use paths (74 percent) and bike lanes (92 percent). It was also found that 30 percent of multi-use path users would not continue to bike if the path they regularly use did not exist. Most would choose to drive instead. Similarly, 25 percent of bike lane users would not continue to bike if bike lanes were not available. The results indicate that bicycle facilities are effective at reducing vehicle trips, though most cyclists would continue to cycle regardless of bike lane or path availability. Like most prior studies, safety was overwhelmingly the main concern of cyclists. The study also suggests the bicycle lanes and multi-use paths play a role in attracting new cyclists by providing a safer environment to ride. While this study does not indicate how much VMT could be reduced if more bike lanes or multi-use paths were built, it does provide the most recent and direct evidence of how bicycle facilities affect vehicle trips.

2.3.3 Pedestrian Facilities

Improving the quality of pedestrian facilities and adding facilities where none currently exist was not evaluated. There is little information available about the current extent and quality of the region's existing pedestrian facilities or plans to improve facilities. There is also little evidence available to estimate the effect of higher quality pedestrian infrastructure. The final report will provide a qualitative discussion of available evidence.

2.4 Incident Management

The UNM research team in not aware of any studies that have quantified the GHG mitigation potential of highway incident management programs. This is the same conclusion recently reached by a research team at the University of California Davis and Irvine preparing a policy brief on incident management systems for the California Air Resources Board (Boarnet, Weinreich, and Handy 2013). Several studies have estimated the potential criteria air pollutant emission reduction benefits of specific incident management programs (Guin et al. 2007; Chang et al. 2002; Skabardonis et al. 1998; Skabardonis et al. 1995) but GHG emission reductions are not estimated. Furthermore, the prior studies have not provided results that are generalizable; they report the specific quantity of emission reduction rather than relative reductions attributable to specific program features or highway conditions.

The existing evidence suggests that incident management programs can reduce GHG emissions if they reduce delays and increase speed. As Figure 2 shows, the average CO_2 emission rate of the vehicle fleet declines rapidly as speeds increase from slow, congested, speeds towards typical free flow highway speeds. The magnitude of potential GHG reduction depends on traffic volume, congestion and the frequency of incidents. Very congested corridors with high traffic volume that experience frequent incidents would benefit the most from an incident management program; these corridors have the most potential for increasing average speed. Estimating the GHG mitigation potential of an incident management program would require estimating the change in delay or traffic speed with and without the program. At a minimum, information describing the current average incident duration, incident frequency, and resulting traffic impacts are required to understand baseline conditions. From the baseline conditions, hypothetical incident management systems that reduce the duration of incidents could be evaluated for their GHG mitigation potential.

One caveat noted by Boarnet, Weinreich, and Handy (2013) is that since an incident management program decreases average travel time, it will also tend to induce new travel demand in much the same way as adding highway capacity (Duranton and Turner 2011). Induced demand would be strongest where programs are most effective; corridors that are highly congested with frequent incidents. The frequency of incidents on these corridors, and the delays they cause, also reduce travel time reliability which in many cases has been found to be valued more than travel time (Carrion and Levinson 2012). Over time, induced demand driven by improvements in average speed and travel time reliability may partially, if not completely, erode the traffic flow and GHG mitigation benefits of an incident management program. Based on the existing evidence and the caveat noted above, an incident management program may have a small short run potential to mitigate GHG emissions which will likely erode over time due to induced demand. With the information that is currently available to the UNM research team it is not possible to quantify a range of potential GHG mitigation.

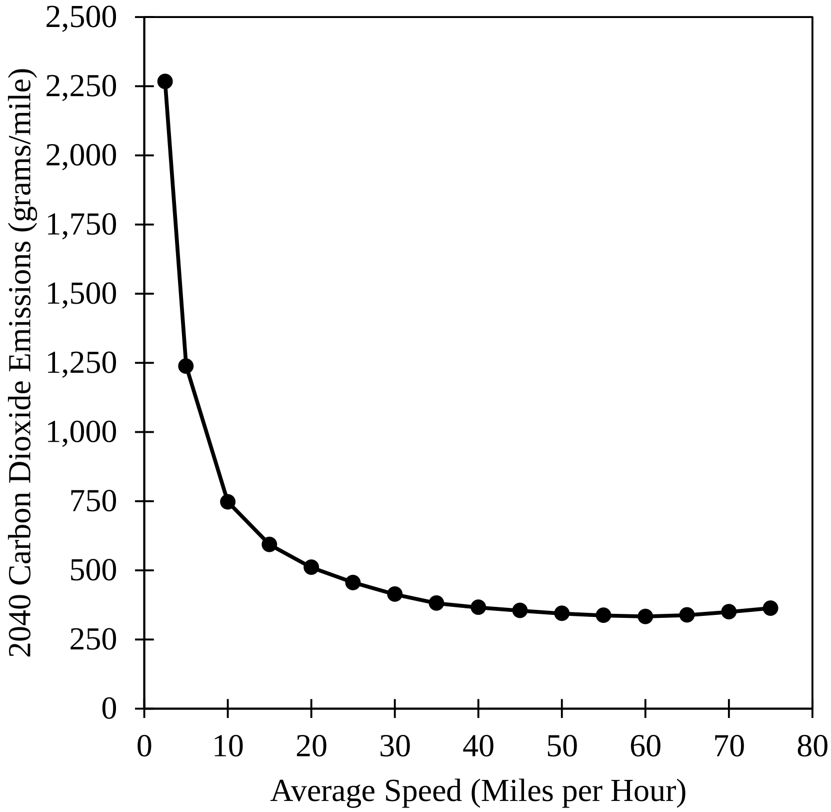

Figure 2 Fleet Average CO2 Emission Rate Vs. Average Speed from US EPA's MOVES Emission Factor Model

2.5 Traffic Signal Enhancement

There are many strategies and systems for improving traffic signal control to improve traffic flow. One strategy that is being adopted in the Albuquerque metropolitan region is adaptive signal control. Adaptive signal control continuously collects and evaluates traffic data from sensors along the roadway to optimize the timing of traffic signals to minimize signal delay. Prior research, as reviewed by Rodier et al. (2014) for the California Air Resources Board, finds that signal coordination can reduce GHG emissions by 1 to 10 percent. An additional study by De Coensel et al. (2012) estimates GHG reductions from 10 percent up to 40 percent under ideal conditions (that are unlikely in practice) using a simulation model. None of the studies consider the potential for induced demand, which in the long run could offset some or all of the control system's traffic flow and GHG mitigation benefits.

Recently, Bernalillo County installed an adaptive traffic control system on a portion of Alameda Boulevard in the Albuquerque metropolitan area. Traffic data was collected before and after the adaptive control system was installed. The control system has reduced morning peak travel time by 21 percent, evening peak travel time by 11 percent and increased off peak travel time by 1 percent (Sussman 2013). The UNM research team used the travel time reductions along with reported traffic speeds and flow rates to estimate the reduction in GHG emissions attributable to the new control system. MOVES was used to produce CO_2-eq emission factors based on average speeds before and after the control system was installed. The Alameda adaptive control system reduced GHG emissions by 5.9 percent along the improved section of roadway (Table 4).

To further investigate the GHG mitigation potential of adaptive traffic control systems, the reported percentage change in travel times from the Alameda study were applied to traffic traveling the entire Montgomery/Montano corridor and Coors Boulevard. These two heavily used roadways carry significant traffic volume, are much longer than the section of Alameda that was studied, have many signalized intersections, and do not currently have adaptive traffic control systems. These roads were selected to gauge if upgrading the signal systems on these relatively long and heavily used corridors would produce regionally significant GHG reductions.

Traffic flow and speed data for each roadway segment were obtained from the MRCOG travel demand model for the 2040 preferred scenario. Emission factors were obtained from MOVES for the average speed on each link before and after the speeds were adjusted to account for the expected improvements of an adaptive signal control system. The results indicate that applying adaptive traffic control systems to these two roads would result in a 3 percent to 4 percent reduction in GHG emissions from each road. Regionally, the effect is a 0.2 percent reduction in GHG emissions. The actual Alameda results and the results of applying a similar travel time reduction to the Coors and Montgomery/Montano fall around the median of GHG reductions reported in prior studies.

Table 4 Potential Changes in GHG Emissions from Implementing an Adaptive Traffic Control System

	Distance	CO_2-eq (tonnes/day)				
Road	**(miles)**	**Before**	**After**	**Change**	**% Change**	**% of 2040 Total**
Alameda*	2.3	60.8	57.2	-3.6	-5.9%	-0.03%
Montgomery/Montano	12.8	288	276	-12.0	-4.2%	-0.09%
Coors	24.7	442	426	-15.6	-3.5%	-0.12%

* Only the portion of Alameda where adaptive traffic signals were installed was studied.

The estimated GHG mitigation potential of installing an adaptive traffic control system on Coors or Montgomery/Montano should be considered an order of magnitude estimated. There are many factors that affect these estimates, the largest being how effective an adaptive traffic control system would be on these longer and more complex corridors. The estimates in Table 4 do not account for broader network effects on improvements made to these specific roadways. For example, reduced travel times along improved corridors could cause bottlenecks in other parts of the network. Furthermore, like most prior studies, induced demand is not evaluated. A traffic simulation study that investigated an improvement to a signalized intersection by Stathopoulos and Noland (2003) find that induced demand is likely to eliminate initial emission reduction benefits. There have not been any empirical studies to support simulation findings but the results agree with travel demand theory and empirical evidence on induced demand from highway capacity projects (Duranton and Turner 2011). Adaptive traffic control systems increase a roadway's capacity and reduce travel time just as expanding highway capacity does. The decrease in travel time increases the attractiveness of the roadway and reduces the cost of making trips. The reduction in congestion is likely to result in additional travel demand combined with a return to congested conditions which may increase GHG emissions overtime, potentially reducing or eliminating the initial benefits of this strategy.

2.6 Roadway Connectivity

Regular street grids generally provide the shortest path from any one point to any other point in a street network while irregular street patterns, particularly those with cul-de-sacs and dead ends, increase the distance required to travel through the network. Street networks with regular grids are also more redundant, there are many alterative paths through the network which can reduce congestion and provide alternatives when there is an incident on a particular network link. Achieving shorter network distances between various origins and destinations can reduce VMT by reducing trip length and also increase walking, bicycle and transit mode share since these modes are most sensitive to distance. Regular grids or other street designs with a high level of redundancy that reduce traffic congestion could also mitigate GHG emissions by increasing traffic speeds (see Figure 2 for CO_2-eq – speed relationship).

Several prior studies have evaluated the effect of greater street network connectivity and travel demand (see Handy et al. (2014) for a comprehensive review). Prior studies generally indicate that better connectivity leads to less VMT and more bicycle, walking and transit trips (Handy et al. 2014; Ewing and Cervero 2010). However, results vary across studies which have been conducted at different times, in different places and have used various definitions of street connectivity. Ewing and Cervero (2010) completed a comprehensive review and meta-analysis of the existing evidence and report an average VMT elasticity of street connectivity using two common street connectivity definitions: percent of four-way intersections and intersection density. Both definitions have the same elasticity, -0.12.

A VMT elasticity of -0.12 for intersection density is used to evaluate four typical street network patterns in Albuquerque to illustrate the GHG reduction potential of greater street connectivity. Intersection density is used rather than the percentage of four way intersections because intersection density appears more robust to different street patterns. For example, in Figure 3 the NE Albuquerque and Downtown Albuquerque neighborhoods both have 100 percent four way intersections; however, the NE Albuquerque neighborhood has much lower intersection density because it has much longer block lengths. Longer block lengths increase average network distances between points. Intersection density metrics control for differences in block size.

Four different Albuquerque neighborhoods were selected that represent typical street network designs in the area (Figure 3). The intersection density of each neighborhood was calculated by including intersections on the boundary of each neighborhood but excluding intersections that only contained cul-de-sacs or dead ends since these provide no connectivity. The percentage change in intersection density was then calculated between the SW Albuquerque neighborhood which had the lowest interstation density and each of the other neighborhoods. The results shown in Table 5 indicate that increasing the density of street intersections from a typical suburban subdivision layout, which can be accomplished with different street patterns, may significantly reduce VMT and therefore GHG emissions. Additional GHG mitigation benefits may occur if the street pattern also reduces congestion, increasing average speed.

Figure 3 Examples of Different Albuquerque Area Street Network Designs and Intersection Density

Table 5 Intersection Density and VMT Calculation

Neighborhood	**Area (km^2)**	**Intersections**	**Intersection Density**	**% Change in VMT from SW Albuquerque [a]**
SW Albuquerque	0.78	51	65.6	0.0%
NW Albuquerque	0.71	50	70.6	-0.9%
University Area	0.67	56	83.9	-3.3%
Downtown Albuquerque	0.45	52	116.8	-9.4%

[a] VMT elasticity of intersection density used in calculation equals -0.12 (Ewing and Cervero 2010)

The regional effectiveness of adopting a street connectivity standard is difficult to quantify. The potential GHG mitigation beyond what is forecast for the 2040 preferred scenario is unclear since the travel demand model does not contain local streets. Local streets are represented by "centroid connectors" in the travel demand model that represent the average distance from households in a TAZ to a roadway link in the model (collectors, arterials, and highways). For TAZs in the metropolitan area that have not yet been developed and where no roadway network exists, it is unclear what assumptions were used to create the centroid connectors. For example, what street pattern was assumed in calculating the average distance and travel time from each TAZ to the nearest network link? Since the preferred scenario focuses more growth into already developed areas, new street connectivity standards, which would only affect new development, may only have a small regional GHG mitigation potential. However, changing the street pattern of yet to be built roadway networks should be a very low cost mitigation strategy and therefore may be a very efficient GHG mitigation strategy even if it is not regionally significant over the forecast horizon.

The estimates in Table 5 are also subject to many uncertainties. While there have been many studies of street network design and changes in travel behavior, it's difficult to generalize these results including the meta-analysis by Ewing and Cervero (2010). The effect of intersection density likely depends on population and employment density, land-use mix, bicycle and pedestrian infrastructure, quality of transit service, and the extent of the network patterns (only a few blocks or is the whole city designed in a similar pattern?). There are also many unique street designs that do not match up well with designs considered in prior studies. For example, some neighborhood designs have greater pedestrian and bicycle connectivity than vehicle connectivity due to bicycle paths and features that block vehicle access. Figure 4 shows a typical network design in Davis, California. Most neighborhoods in Davis, excluding the downtown area, have irregular street network designs with many cul-de-sacs and dead ends; however, many of these neighborhoods also have a multi-use path network interlaced with the street network as shown in Figure 4. The multi-use path network adds connectivity to cul-de-sacs and dead ends for non-motorized modes, and in many places has grade separated railroad, street and highway crossings. Some neighborhoods in Albuquerque contain similar features, though on a much smaller and less frequent scale. For example, Albuquerque's multi-use path network adds some connectivity to dead end streets and cul-de-sacs, but only a very small percentage of them. Some neighborhoods also have pedestrian access through sound and privacy walls that surround many of the region's subdivisions.

Figure 4 Example of Network Design for Greater Pedestrian and Cyclist Connectivity (Red Lines are Bicycle and Pedestrian Paths, GIS Data from the City of Davis, California[5])

3 SUMMARY AND CONCLUSIONS

The strategies where GHG mitigation potential could be quantified are summarized in Table 6. Growth boundaries and VMT or gasoline taxes have the greatest potential for achieving significant additional GHG reductions. Bicycle infrastructure and traffic signal enhancement, while having a smaller effect, would face much less opposition in being implemented and provide popular co-benefits (recreation and less congestion). The mitigation potential of improved street connectivity and incident management programs could not be quantified but each strategy is expected to have a small GHG mitigation potential. Greater street connectivity for new developments comes at little to no cost (those less land for real estate development is a cost for developers) and could therefore be a very efficient policy even if only having a small mitigation potential. Improving street the connectively of existing neighborhoods could be very expensive if additional right of way is required.

[5] City of Davis GIS Data Library: http://maps.cityofdavis.org/library/

Table 6 Summary of GHG Mitigation Potential

	CO2-eq	Reduction
Growth Boundary	512	3.8%
VMT Tax 0.005 per mile[a]	107	0.8%
VMT Tax 0.03 per mile	780	5.8%
VMT Tax 0.12 per mile	2384	17.9%
Bicycle Infrastructure	49.1	0.4%
Traffic Signal Enhancement	27.6	0.2%

[a] Equal to a 25 percent increase in the current state and federal gasoline excise tax
[b] Building out the City of Albuquerque's 2014 Draft Bicycle Plan
[c] Implementing adaptive signal control on Montgomery, Montano, and Coors, and ignoring induced demand

The results in Table 6 also illustrate that by only adopting the relatively popular and low cost GHG mitigation strategies, GHG emissions in the region will still grow higher than today's level. Achieving GHG mitigation that reduces emissions from the the 13,352 tonnes/day expected under the preferred scenario in 2040 to today's level of 11,358 tonnes/day requires adopting a VMT tax between 6 and 8.4 cents per mile. The lower VMT tax rate corresponds to a scenario where all other strategies are also adopted while the higher tax corresponds to scenario where only a VMT tax is adopted. A growth boundary would significantly reduce GHG emissions but would still not be enough to hold GHG emission at today's level.

Finally, the analysis in this report and most other studies fail to account for induced demand. Induced demand should be expected to occur for any strategy that reduces travel time or improve travel time reliability without also charging a fee or tax to pay for the improvement. Improved traffic signaling and incident management programs suffer from this limitation which has the potential to significantly reduce or completely eliminate their GHG mitigation potential over the long term. Interim GHG emission reductions from these strategies may still be valuable compared to a baseline of not implementing them as long as they do not lock the region into greater vehicle dependency or come at the expense of more effective strategies. The most durable strategies for reducing GHG emissions include reducing vehicle travel demand, improving vehicle fuel efficiency, and promoting the adoption of alternatively fueled vehicles. This report focuses on reducing travel demand which can be accomplished through two general strategies. Reducing the need for vehicle trips, which in this project is accomplished by changing land-use patterns and improving transit options, and increasing the cost of travel through taxes, fees and tolls.

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