Projection of PM2.5, BC, NOx and VOCs from the Future Vehicle Fleet: Impact of Alternative Vehicle Penetration Versus Continual Reductions in Emissions from Traditional Vehicles

By

Fahad Alboaijan

A Thesis Presented in Partial Fulfillment
Of the Requirements for the Degree
Master of Science

Approved May 2019
Graduate Supervisory Committee:

Matthew Fraser, Chair
Klaus Lackner
Jean Andino

ARIZONA STATE UNIVERSITY

May 2020

ABSTRACT

Mobile sources emit a number of different gases including nitrogen oxides (NOx) and volatile organic compounds (VOCs) as well as particulate matter (PM10, PM2.5). As a result, mobile sources are major contributors to urban air pollution and can be the dominant source of some local air pollution problems. In general, mobile sources are divided into two categories: on-road mobile sources and non-road mobile sources. In Maricopa County, the Maricopa County Air Quality Department prepares inventories of all local sources [11], [12]. These inventories report that for Maricopa County, on-road mobile sources emit about 23% of total PM2.5 annually, 58% of the total NOx, and 8% of the total VOCs. To understand how future changes how vehicles might impact local air quality, this work focuses on comparing current inventories of PM2.5, black carbon (BC), NOx, and VOCs to what may be expected emissions in future years based on different scenarios of penetration of hybrid gas-electric vehicles (HEV) and electric vehicles (EV) as well as continued reduction in emissions from conventional internal combustion (IC) vehicles. A range of scenarios has been developed as part of this thesis based on literature reports [6], [8], air quality improvement plan documentation [5], projected vehicle sales and registration [3], [4], as well as using EPA's Motor Vehicle Emission Simulator (MOVES) [9]. Thus, these created scenarios can be used to evaluate what factors will make the most significant difference in improving local air quality through reduced emissions of PM2.5, BC, NOx and VOCs in the future. Specifically, the impact of a greater fraction of cleaner alternative vehicles such as hybrid-electric and electric vehicles will be compared to the impact of continual reductions in emissions from traditional internal combustion vehicles to reducing urban air pollution emissions in Maricopa County.

TABLE OF CONTENTS

CHAPTER Page

CHAPTER Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

1.0 INTRODUCTION

1.1 Motivation

On-road mobile sources include all light-duty and heavy-duty vehicles travelling on-roads in Maricopa County; the vast majority of these vehicles are light-duty. As of today, there are about three million vehicles in Maricopa County, and most of those cars are IC vehicles [1]. Continued efforts to improve local air quality through stringent emission standards as well as changing vehicle technology will drive changes to future emissions of fine particulate matter (PM2.5), particulate black carbon (BC), nitrogen oxides (NOx) and volatile organic compounds (VOCs) emissions. The type of light-duty vehicles in the Maricopa County fleet, including conventional internal combustion (IC) vehicles, gas-electric hybrid (HEV) vehicles as well as electric vehicles (EV) has a direct effect on the on-road mobile sources emissions expected in the future.

To understand what on-road mobile source emissions may look like in the future, predicting the composition of the future fleet is critical. This includes considering the total number of cars as well as what fraction of different vehicle technologies are in the fleet is critical for this research. In addition, improvement in vehicle technology as a result of stringent emissions standards is expected to reduce the emission rate from all vehicles in the future. By estimating the number of cars, the composition of the vehicle fleet by vehicle type, as well as the expected emissions from each vehicle type, scenarios can be created to illustrate what future emissions from on-road mobile sources may be. Expected emissions can be based on literature reports [6], [8], reports of expected emissions from air quality improvement plan documentation [5], or based on the EPA's Motor Vehicle Emission

Simulator (MOVES) [9]. With these inputs, a number of projections will be made of present and future possible emissions outcomes.

Projecting and simulating the emissions of PM2.5, BC, NOx and VOCs will give an idea of current and future emissions expected in Maricopa County. Since HEV and EV cars as well as cleaner IC cars were introduced in the market, the future emissions produced from on-road mobile sources are expected to decrease in all scenarios. However, by comparing the inputs into the scenarios and the expected emissions, it will be possible to evaluate what factors are the most important to reduce emissions in the future: conversion of the vehicle fleet from IC to lower emission HEV and EV vehicles, or improvements in vehicle technology to lower emissions from all vehicle types. Knowing how the emissions of PM2.5, BC, NOx and VOCs are expected to decrease in the future will demonstrate the environmental impact of on-road mobile sources as well as provide input on what policies – such as incentives for HEV and EV or continued stringent emissions on all vehicles – will make air quality better in the future.

1.2 Maricopa County Emissions Inventories

This research started by evaluating the emissions inventory of Maricopa County with two emission inventories based on PM and ozone precursors that was provided by Maricopa County Air Quality Department [11], [12]. Both reports gather the sources of emissions into five categories, including point sources, non-point sources, non-road mobile sources, on-road mobile sources and event sources [11], [12], [13]. These emission inventories are prepared based on data contained in the National Emissions Inventory (NEI), which is a comprehensive and detailed estimate of criteria pollutant emissions nationwide [13]. Point sources are large sources located at stationary locations such as power plants and large industrial facilities [13]. Non-point sources refer to all the smaller sources that are located at fixed locations but generally distributed throughout an urban area such as solvent use or paving activities [13]. On-road mobile sources refer to all of the vehicles operating on local roadways while non-road mobile sources are emissions sources from vehicles and equipment that use liquid fuels to operate but not on roadways including construction equipment and aircraft [13]. Biogenic and event sources are emissions from local vegetation and events like wildfires [12], [13].

1.3 Particulate Matter (PM2.5) and Black Carbon (BC)

On-road mobile sources in Maricopa County are an important source of PM2.5 [11]. While it is expected that on-road mobile sources are also significant contributors to BC emissions, the Maricopa County Emissions Inventory Report does not separate out carbonaceous particles such as BC [11]. As a result, to determine the impact of mobile sources to county-wide BC emissions, all sources in the PM emission inventory were scaled to estimate county-wide BC emissions using literature reports of the fraction of PM emissions that are organic carbon (OC) and BC [7], [10]. In this process, a number of sources of BC were modified based on reasonable assumptions. For example, reported PM2.5 emissions for construction and mining equipment in the non-road mobile sources category were divided into two sources: one based on fugitive dust emissions and a separate source based on tail pipe emissions [15]. For each of these two separate emissions, different chemical compositions were used based on literature reports [7], [10]. Also, tire wear, brake wear and exhaust were aggregated as one source in the emissions inventory report for on-road mobile sources [11]; to more accurately model the composition of on-road mobile sources, each of these three sources was separated and scaled by a chemical composition that was representative for that type of emission [7], [10], [14].

Today, Maricopa County has a fleet population of about three million light-duty vehicles that consist of 98% IC cars. By separating PM2.5 and BC emissions into separate categories for exhaust, brake ware and tire wear, it was determined that PM2.5 emission are dominated by exhaust fraction compared to brake and tire wear emissions [7], [10]. However, for total BC emissions, tire wear emissions were the dominant emission source compared to exhaust and brake wear BC emissions [7], [10]. Table 1. 1 represents the total PM2.5 and BC emissions respectively from every identified source based on Maricopa County Emissions Inventory Report [11]. On-road mobile sources emit 23% and 19% of the total PM2.5 and BC respectively in Maricopa County.

PM2.5 emission percentages were calculated by dividing the emission of every inventory reported by the total PM2.5 emission from all the inventories reported [11]. All data needed to conduct the calculations and to obtain the results shown in Table 1. 1 are presented in Table 1.6-9 of Emissions Inventory for PM10 for the Maricopa County report [11]. Prior to calculate every BC emission percentage shown in Table 1. 1 BC fraction of PM2.5 being emitted were calculated using the literature [7], [10]. All of the BC percent of PM2.5 mass values used are shown in Appendix A. The values of BC emissions fraction of PM2.5 were multiplied by every source reported in order to calculate BC emissions inventory of Maricopa County. Then, the same process discussed was followed to calculate the annual BC emissions percentages.

Table 1. 1: Annual PM2.5 and BC Emissions Percentages in Maricopa County, AZ, [7], [10], [11].

Emissions Inventory	PM2.5	BC
Point Sources	3.50%	3.81%
Fuel Combustion	10.8%	14.9%
Industrial Processes	20.3%	14.9%
Waste Treatment/Disposal	0.798%	0.562%
Miscellaneous Area Sources	30.9%	3.27%
Non-road Mobile Sources	11.0%	43.8%
On-road Mobile Sources	22.7%	18.8%

1.4 Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOCs)

On-road mobile sources are widely recognized as major contributors to local NOx and VOCs emissions. Unlike PM2.5 and BC emissions, NOx and VOCs emissions from vehicles are produced mainly from exhaust and not from any other parts of the vehicle like PM2.5 and BC emissions from vehicles. Concern over NOx and VOC emissions is primarily driven by the fact that they are ozone precursors and emissions of NOx and VOCs in urban centers results in ground-level ozone formation [16], [17]. Ground-level ozone is one of the six criteria pollutants regulated by U.S. EPA and nitrogen dioxide, one of two chemical species present in NOx, is also a criteria pollutant [16], [17]. As a result, to decrease local ozone concentrations, national and local efforts have developed emission control plans for both stationary and mobile sources to lower precursor emissions [16], [17]. These efforts include the U.S. EPA Light Duty Tier 2 Rule to reduce NOx and VOCs emissions from the fleet [16].

Table 1.2 details the total NOx and VOCs emissions from identified sources based on the Maricopa County Emissions Inventory Report [12]. On-road mobile sources emit

56% and 8% of the total NOx and VOCs respectively, county-wide. In the case of NOx emissions from on-road mobile sources, it represents the most important contributor to local concentrations of this important ozone precursor. On the other hand, VOCs emissions from on-road mobile sources represent just a small portion of the total emissions as the inventory predicts very significant emissions from biogenic sources as well as solvent use. NOx emission percentages were calculated by dividing the emission of every inventory reported by the total NOx emission from all the inventories reported [12]. All data needed to conduct the calculations and to obtain the results shown in Table 1. 2 are presented in Table 1.6-8 of the Emissions Inventory for Ozone Precursors of Maricopa County report [12]. The same process was followed to calculate VOCs emissions percentages in Maricopa County.

Table 1. 2: Annual NOx and VOCs Emission Percentages in Maricopa County, AZ [12].

Emission Inventory	NOx	VOCs
Point Sources	2.67%	0.413%
Fuel Combustion	8.00%	0.665%
Industrial Processes	0.863%	0.683%
Solvent Use	-	11.7%
Storage/Transport	-	1.424%
Waste Treatment/Disposal	0.0673%	0.0491%
Miscellaneous Area Source:	0.208%	0.0523%
Non-Road Mobile Sources	31.1%	3.28%
On-Road Mobile Sources	55.5%	7.65%
Biogenic Sources	1.60%	74.1%

2.0 METHODOLOGY

2.1 Estimating Future Vehicle Fleets

The first step to understand future emissions from mobile sources is to estimate the future fleet population as novel vehicle technologies are adopted and introduced into the mix of vehicles on the road. Currently, there are about three million light-duty vehicles in Maricopa County with a majority of those being conventional IC vehicles [1]. Alternative vehicle technologies, such as HEV and EV, are expected to expand and contribute a larger fraction of the vehicle fleet in the future. Two sources of information were used to estimate the fleet mix through the year 2035: sales records compiled by the U.S. Department of Energy [3], and literature reports of future vehicle composition [4]. To estimate future vehicle fleets, different fleet scenarios were based on these data sources to break down the percentage of vehicles that are IC, HEV and EV. From information contained within these two primary data sources, a total of five separate future fleet scenarios were developed.

Removal rates were calculated and used to estimate the number of cars that are going to be removed permanently from the fleet in the specified years. The calculated rates represent the IC, HEV and EV fleets separately. Also, the removal rates of Maricopa County fleet were estimated using the data found and calculated regarding the estimated fleet population of every milestone year in the research. The rates were calculated using the sales and registrations growth rates estimated from the sources mentioned previously [2], [3], [4]. Also, national data regarding vehicle sales of new and used cars as well as data about junked vehicles were used to calculate removal rates [19], [20], [21]. Finally, removal rates are critical for the research to produce estimations regarding the contribution of each technology to Maricopa County fleet which will affect the future emission results.

2.2 Literature Reports of Future Vehicle Emissions

In addition to estimating the composition of the vehicle fleet, the expected emission rate from each vehicle category in future years must be estimated to determine county-wide emissions from mobile sources in the future. The expected PM2.5, BC, NOx and VOCs emission rate from different vehicle types at different points in time in the future must be estimated. Emissions data for IC and HEV vehicles was the primary consideration for this task as EV cars do not directly emit emissions to the environment during use. Data for future emissions from these vehicles was obtained from literature reports and based on the expected percentage reduction in the future from current emission rates for IC and HEV vehicle types [5], [6], [8]. Based on two primary literature sources, three separate scenarios predicting future emission rate were determined [5], [8]. As a result of these three future emission rate scenarios applied to five different future fleet scenarios, a total of fifteen county-wide emission rate scenarios were developed.

2.3 Estimating Fleet Emissions Using MOVES

An alternative to literature reports predicting future vehicle emission rates are mathematical models developed to help air quality planning. The U.S. EPA developed the MOVES modeling system to estimate current and future emissions from on-road mobile sources [9]. As an alternative to literature reports to future emission rates, emissions of PM2.5, BC, NOx and VOCs were estimated for on-road mobile sources emissions in Maricopa County using MOVES. As part of this alternative approach to estimating future emissions using the MOVES model, three types of cars will be considered, which are IC, HEV and EV. A total of five runs were performed to estimate the species of concern emissions from IC vehicles for current and future years: 2018, 2020, 2025, 2030 and 2035.

However, as this modeling approach was developed to assist in air quality planning purposes, the MOVES model predicts total county-wide emissions (Ton per year) and does not separately predict emissions from individual vehicle type. To overcome this shortfall, the average vehicle fleet composition determined from literature sources [1], [3], [4], and then county-wide emissions from the MOVES model was used to estimate total emissions. As a result, the impact of different future vehicle fleet compositions (that is, what role the introduction of EV and HEV vehicles as on total county-wide emissions) could not be determined using MOVES. Thus, average fleet composition from the scenarios created in the first task were calculated to be applied in this task.

3.0 RESULTS AND ANALYSIS

3.1 Estimating Future Fleet Population

The composition of the future vehicle fleet will be different than it is today as cleaner vehicles such as HEV and EV become more prevalent. To assess the impact of this change in the vehicle fleet, different scenarios were analyzed to determine possible outcomes of this penetration of newer vehicle technologies into the current fleet which is heavily dominated by IC vehicles. In addition to the uncertainty about the vehicle fleet composition, the total number of vehicles present in Maricopa County is also uncertain and likely to be impacted by population change, changing customer behavior for vehicle ownership and other factors [1], [3], [4]. However, this change in the total number of vehicles is outside the fundamental question for this research project: what factors are the most important to reduce emissions in the future: conversion of the vehicle fleet from IC to lower emission HEV and EV vehicles, or improvements in vehicle technology to lower emissions from all vehicle types. So, for all scenarios, this work assumes a constant number of vehicles in Maricopa County through 2035. While this will not likely be the case, fixing the total number of vehicles improves the comparability between the scenarios developed and allows the question of what factor will drive lower total emissions to be determined.

3.1.1 U.S. Department of Energy Data Analysis

The fleet is divided into three types of vehicles as mentioned before, which are IC, HEV and EV cars, with IC vehicles dominating the vehicle fleet in Maricopa County. Currently, the total number of vehicles in Maricopa County is 3,302,600 vehicles, with approximately 50,000 HEV cars and nearly 7,300 EV cars [1]. The first approach to estimate future vehicle fleet composition was based on analysis of the percentage growth of US fleet population throughout the years as shown in Table 3. 1. Based on the national fleet growth throughout the years, the average growth was calculated and applied to the population of IC cars in Maricopa County to estimate the potential growth in this specific vehicle category.

Table 3. 1: Growth Percentage in United States Fleet Population from 1991 to 2016 [2].

5 Years' Time lapse	1991-1996	1996-2001	2001-2006	2006-2011	2011-2016	Average Growth
Growth Percentage	8.61%	10.6%	6.18%	0.894%	5.80%	6.41%

Then, the HEV and EV car sales data was obtained from the U.S. Department of Energy (DOE) to estimate the number of HEV and EV cars for future years [3]. In case of HEV cars, the national sales of this vehicle category from 2005 to 2015 are shown in Table 3. 2. Based on this data, the average sales growth was calculated and projected into the future on HEV cars fleet in Maricopa County. Past data has shown that every 5 years, the growth in HEV vehicles is approximately 24.1%. Using this average growth rate, future contribution of HEV vehicles to the fleet population in Maricopa County was projected out for every five years until 2035 using this as an approximate growth rate in the sales.

Table 3. 2: Sales Growth Rates in United States HEV Cars from 2005 to 2015 [3].

Five-Year Time Lapse	**2005-2010**	**2006-2011**	**2007-2012**	**2008-2013**	**2009-2014**	**2010-2015**	**Average Growth**
Sales Growth	23.0%	6.13%	15.6%	36.7%	34.6%	28.7%	24.1%

This same approach was used to estimate the future contribution of EV vehicles to vehicle fleets in the future. In the case of EV cars, the national data is only available for the past five years. For this reason, the one-year time lapse of sales growth was calculated and averaged. This one-year growth was multiplied by 5 to estimate the five-year rate of sales growth for EV vehicles. The result was calculated to be a 147% growth in EV vehicle sales every five years as shown in Table 3. 3. Again, this growth rate was used to estimate the contribution of EV vehicles to the vehicle fleet of Maricopa County through the year 2035.

Table 3. 3: Sales Growth Rates in United States EV Cars from 2011 to 2016 [3].

One-Year Time lapse	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Average Growth**	**Amplified Growth**
Sales Growth	66.7%	45.0%	18.6%	-4.31%	20.9%	29.4%	147%

After computing all the previous values, a scenario of future vehicle fleet composition was compiled. This scenario is called "U.S. DOE Sales" as it was based on extrapolation of past sales data compiled by the U.S. DOE to estimate the number of HEV and EV cars in the future [1], [3]. In this scenario, by 2035 the population of hybrid and electric vehicles is estimated to reach about 7% of the total fleet. Finally, as mentioned above, the total number of vehicles in the Maricopa County fleet has been held constant in the future for all scenarios after calculating the removal rates of this scenario. However, percentages of the three types of vehicles of interest will vary from one scenario to another.

All the values presented in Table 3. 1, Table 3. 2 and Table 3. 3 were calculated by dividing the fleet population of the end year by the population of the initial year, then subtracting the value from one and multiplying the result by a hundred. This process was followed to figure out how the national IC, HEV and EV fleets population increased or decreased in a five years period or one-year period, which was used to estimate the IC, HEV and EV population in Maricopa County. Finally, the average growth was found for each table through calculating the average of the values presented in each table.

3.1.2 Literature Reports of Future Fleet Composition

Based on the data obtained from relevant literature reports [4], a total of four projections for future vehicle fleet composition were created. Two of these scenarios were based on projections of sales data, and include a base and aggressive scenarios, and the other two scenarios were based on extrapolation of historic fleet registration, and also include a base and aggressive scenario [4]. Changes in fleet registration for the base scenario are reported in the literature until the year 2025 [4]. To reach the target year of

2035, the five-year change in percentage from 2020-2025 was applied to 2025-2030 and 2030-2035, assuming that the change in fleet composition was approximately the same as the 2020-2025 period through 2035 as shown in Table 3. 4. In this fleet registration base scenario, it is expected that the IC vehicles in Maricopa County will decrease by 2035 to approximately 2,800,000 cars while HEV cars will increase to reach slightly over 100,000 vehicles and EV will reach over 400,000 cars [4]. In the aggressive analysis of the vehicle fleet, literature reports assume a more rapid transition to electric vehicles [4], which translates into a slight decrease in numbers of HEV cars and increase in EV in future vehicle fleets [4]. Again, the same procedure was followed with the fleet registration aggressive scenario in order to calculate the growth percentages as shown in Table 3. 4.

Table 3. 4: Changes in Fleet Registration in US Vehicles from 2018 to 2025 [4].

Base Scenario	**2018-2020**	**2020-2025**	**Aggressive Scenario**	**2018-2020**	**2020-2025**
Gasoline car (IC)	-1.33%	-1.46%	**Gasoline car (IC)**	-1.27%	-1.77%
Hybrid gas-electric car (HEV)	15.1%	23.1%	**Hybrid gas-electric car (HEV)**	14.6%	21.8%
Electric car (EV)	43.5%	61.0%	**Electric car (EV)**	48.3%	67.4%

In literature reports of the change in fleet composition based on analysis of historic sales data, changes in the rate of sales of different vehicle types is compounded to impact the composition of the vehicle fleet [4]. All growth percentages of the sales base and agrressive projections are presented until the year 2025 as shown in Table 3. 5. Again, projection of sales data is available through 2025 and the change in sales from the period 2020-2025 is applied out to 2035, assuming that the rate of change in sales of vehicles is constant in the future. In the scenario of the sales base projection, the number of HEV cars in Maricopa County will be about 80,000 cars and the EV cars will reach about 240,000 cars by 2035. For the scenario based on a more aggressive sales projection, it is assumed that there will be a slight decrease in the rate of sales for HEV and EV vehicles [4]. In this sale's aggressive scenario, HEV vehicles will reach a population of about 70,000 cars in 2035 and EV will reach approximately180,000 cars.

Table 3. 5: Change in Sales of Different US Vehicles from 2018 to 2025 [4].

Base Scenario	**2018-2020**	**2020-2025**	**Aggressive Scenario**	**2018-2020**	**2020-2025**
Gasoline car (IC)	0.949%	0.601%	**Gasoline car (IC)**	0.284%	-1.38%
Hybrid gas-electric car (HEV)	19.1%	10.1%	**Hybrid gas-electric car (HEV)**	17.6%	5.26%
Electric car (EV)	22.3%	50.7%	**Electric car (EV)**	39.9%	50.8%

After computing all the previous values, a total of four scenarios based on literature were created to estimate the numbers of IC, HEV and EV vehicles through 2035 [4]. As mentioned previously, for this study the total number of vehicles in Maricopa County was assumed to be constant thorough 2035 after applying the removal rates with only the contribution of different vehicle types changing over time. As a result, based on the four different scenarios reported in the literature, it is estimated that by 2035, the contribution of HEV and EV will total between approximately 7% to 16% of the total fleet, see Appendix B.

All the values presented in Table 3. 4 and Table 3. 5 were calculated by dividing the fleet market sales or registration percentage of the end year by the percentage of the initial year based on the scenario. Then subtracting the value from one and multiplying the result by a hundred. This process was followed to figure out how the national IC, HEV and

EV fleets population increased or decreased in a five years period or two years period, which was used to estimate the IC, HEV and EV contribution to Maricopa County fleet.

3.1.3 Calculating and Applying Removal Rates

The first step to calculate removal rates is to gather data about new and used vehicles sales and junked cars. It is preferable to use local data if available and if the local data is not available, then national data should be used. U.S. Department of Transportation, Edmunds insights and reports and Argonne National Laboratory were used to obtain the needed data regarding the national fleet population, national car sales and junked vehicles [2], [19], [20], [21]. Also, growth rates calculated previously will be used to find the removal rates of the fleet. Removal rates is a term used to describe the number of cars being removed permanently over a period of time. The focus will be on IC vehicles removal rates since the average vehicle lifetime is 16.6 years and most of the alternative technology vehicles are relatively new and not enough data available yet [18]. Also, the national fleet population and the local fleet here in Maricopa County is dominated by IC vehicles [1], [18]. Moreover, an assumption was made after applying the rates, which is that the number of IC cars being removed in 2018 milestone year will be replaced with EV cars in the 2020 milestone year.

3.1.4 Summary of Scenarios Calculating Future Vehicle Fleets

Based on U.S. DOE and literature reports, five scenarios for the future vehicle fleet were determined [1], [2], [3], [4]. For these five scenarios, this work assumes that the total number of vehicles in Maricopa County remains the same after applying the removal rates to isolate what impact changing vehicle technology will have on the future emissions of

PM2.5, BC, NOx and VOCs in Maricopa County. For all scenarios, the fraction of IC vehicles in the fleet decreases steadily through 2035 as shown in Figure 3. 1. The greatest drop in IC vehicle fraction is predicted by the fleet registration aggressive scenario where the IC fleet will drop to approximately 83%. All future fleet population shows that IC cars will be subject to decrease in number in all created scenarios but one, which is the U.S. DOE scenario. It should be noted that this percentage drop in IC vehicles may be the result of the assumption in this work that held constant the total number of vehicles in Maricopa County: based on U.S. DOE sales data [3], this scenario may have the total number of IC vehicle sales increasing but increasing more slowly than the sales of HEV and EV vehicles. The observed decrease in IC vehicles percentage does not necessary mean that the population of IC cars will decrease in the future, it means that HEV and EV cars are growing as a fraction of the vehicle fleet.

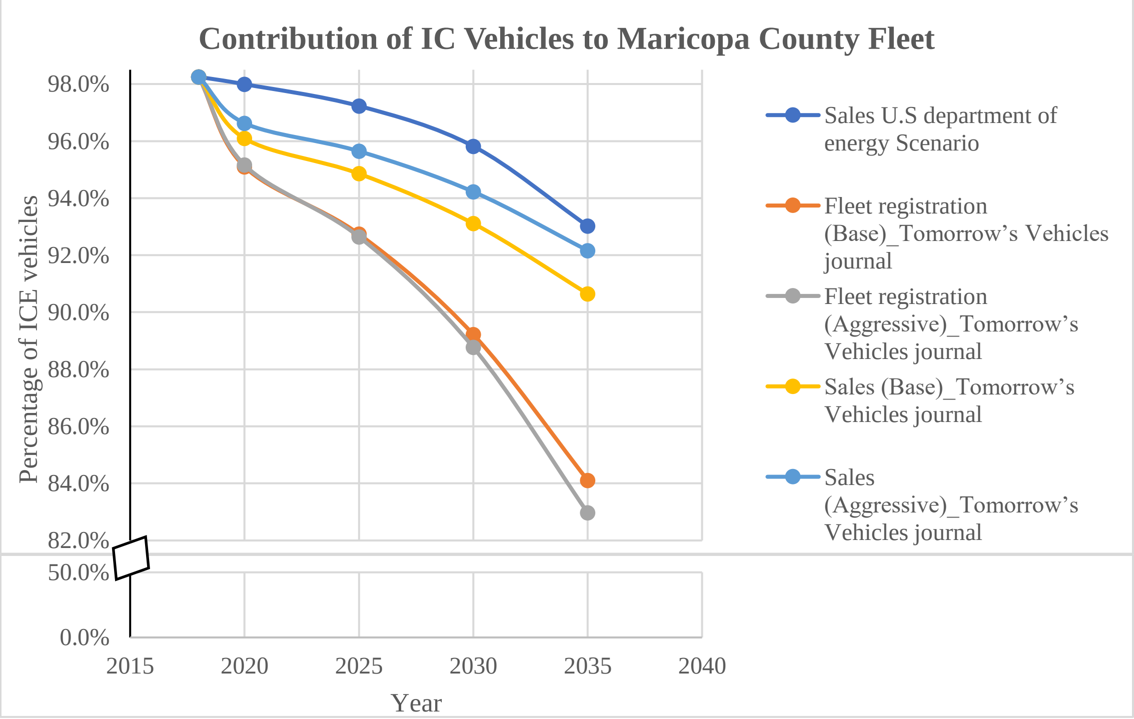

Figure 3. 1: IC Cars Expected Change in Fraction from the Years 2018 to 2035.

HEV fleet fraction is estimated to significantly increase through 2035 in the assembled scenarios as shown in Figure 3. 2. In the U.S. DOE sales scenario [3], as well as the aggressive sales scenarios from literature reports [4], HEV fleet population increased throughout time to reach less than 2.5% of the total vehicle fleet in 2035, see Figure 3. 2. However, in registration base and aggressive scenarios from literature reports [4], HEV fleet population is estimated to increase to more than 3% of total vehicles through 2035. While currently a very small fraction of the vehicle fleet, EV increase dramatically in all scenarios through 2035 as shown in Figure 3. 3. The most significant increase is predicted by analysis of the fleet registration aggressive data which suggest that EV will contribute up to 14% of the total vehicle fleet in 2035.

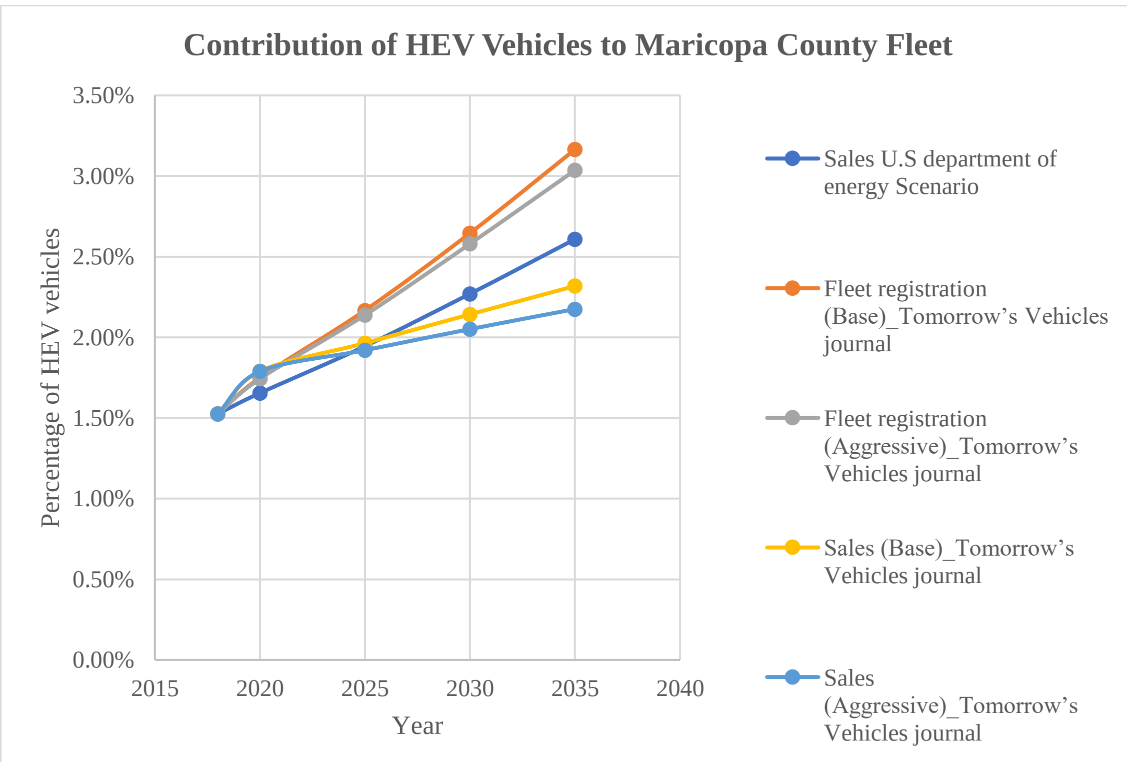

Figure 3. 2: HEV Cars Expected Change in Fraction from the Years 2018 to 2035.

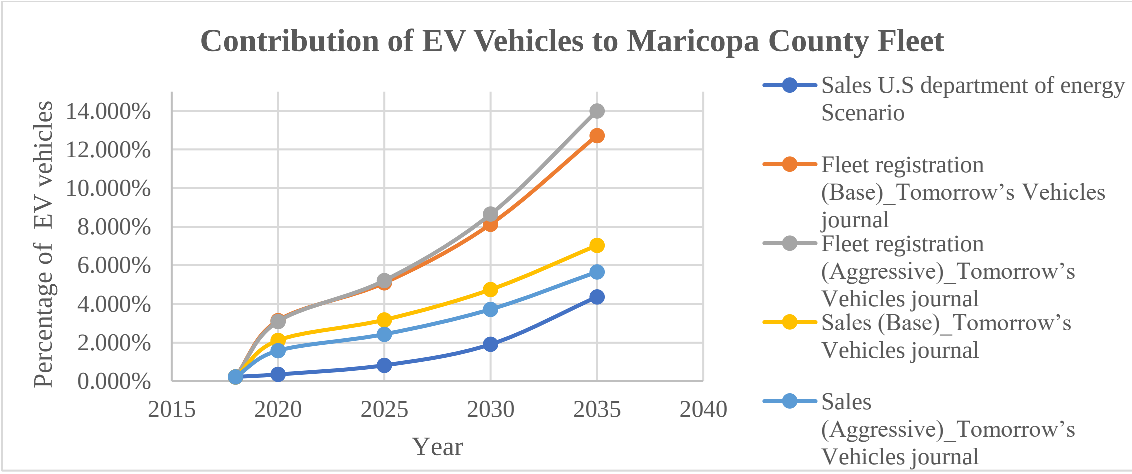

Figure 3. 3: EV Expected Change in Fraction from the Years 2018 to 2035.

When comparing the results found to other studies forecasting EV fleet population in the U.S a number of things must be stated. The EV fleet is estimated to contribute up to 7% of the national fleet by 2030 [22], which is close to what was estimated in the fleet registration base and aggressive scenarios in Maricopa County, see Figure 3. 3. The fleet registration base and aggressive scenarios both estimated that the EV fleet will contribute to over 8% of the total fleet by 2030 as shown in Appendix B. Moreover, The EV fleet is estimated to contribute up to 10% to 12% by 2035 in the U.S [23], which is close to what was estimated in the fleet registration base and aggressive scenarios for Maricopa County as shown in Figure 3. 3. The fleet registration base and aggressive scenarios estimated the EV fleet to be 12% and 14% respectively of the total fleet in Maricopa County by 2035, see Appendix B.

3.2 Estimating Future Vehicle Emission Rates

While all scenarios predict cleaner HEV and EV vehicles will make a larger fraction of the total vehicles in future fleets, traditional IC vehicles are subject to emission control standards such as the U.S. EPA Light Duty Tier 2 Rule [16]. To understand if the greatest impact to reduce future emissions is through replacing IC vehicles with HEV and EV vehicles or by continual efforts to reduce emissions of all vehicles through more stringent emission standards, predictions of future vehicle emission rates must be compiled. The most robust estimates of vehicle emissions based on literature reports are presented here in this chapter. Alternative approaches were investigated in an attempt to provide multiple independent approaches to predict future vehicle emission rates are presented in Appendix C.

3.2.1 Analysis of California's South Coast Implementation Plan Data

State Implementation Plans (SIPs) are documents that state not meeting ambient air quality standards are required to prepare indicating current and the future expected emission controls needed to lower ambient air pollution to safe levels [5]. Understanding future on-road mobile sources are vital to predicting future air quality, so SIPs are one source of information on predicted future emission rates. One of the most comprehensive sources of data is the SIP prepared for the South Coast Air Quality Basin where on-road mobile source emission rates of PM2.5, BC, NOx and VOCs are reported through the year 2031 [5]. The expected emissions obtained from this source are one scenario used to estimate the emissions for mobile sources in future years in Maricopa County.

A number of assumptions were required to translate reported data into a usable format. First, it was assumed that all emissions inventoried for on-road mobile sources can be attributed to exhaust emissions [5]. Second, the assumption made was that the reported emissions for the year 2031 are the same as years 2030 and 2035. While VOC and NOx emissions were inventoried out to 2031, PM2.5 emissions were not reported in the plan for the years 2030 and 2035 [5]. The third assumption attributed reported emissions to IC vehicles as they are expected to be the dominant contributor to on-road emissions. By comparison, HEV vehicles were calculated to have emission rates of PM2.5, NOx and VOCs that are 29%, 25% and 20%, respectively, lower than conventional IC vehicles based on literature reports [6], [8]. The fourth assumption was that this percentage reduction of emissions from HEV compared to IC vehicles is constant in future years. Finally, as was assumed for Maricopa County, it was assumed that the total number of vehicles in the fleet is constant in the future but that the percentages of vehicle technologies vary throughout the years as presented previously. With these assumptions, the reduction percentages of fleet emission were calculated by dividing the expected emission rates values by the initial value of 2018 and then subtracting the calculated emissions from 100% to obtain the expected emission rates.

With these assumptions, data from the South Coast Air Basin SIP are used and applied to future vehicle fleets with varying penetration of cleaner engines created in the first task. In case of IC vehicles, vehicle emission rates are equal to that reported in the South Coast Air Basin SIP [5]. However, for HEV vehicles, emission rates are 29%, 25% or 20% below emission rates for IC vehicles for PM2.5, NOx and VOC, respectively. The BC emission rates were calculated through multiplying PM2.5 emission values by BC percent of PM2.5 Mass obtained from literature reports [7].

The future scenarios calculated with this data source show that total PM2.5, BC, NOx and VOCs exhaust emissions are expected to decrease in all scenarios out to 2035. This is due both to the significant reduction in emission rates predicted for future years from IC and HEV cars as well as the increased contribution of cleaner vehicles to the future vehicle fleet.

3.2.2 Analysis of Data from Minnesota: Role of Plug-In Hybrid Vehicles

Another valuable source of data on future vehicle emission rates was an analysis of the impact of plug-in hybrid vehicles (PHEV) on local air quality in Minnesota [8]. Specifically, this study quantified the environmental benefit of replacing some IC vehicles with PHEV vehicles with different ranges. As PHEV vehicles can operate on electricity only as an EV over a limited range, or for an extended range using a small IC engine as a HEV vehicle, two scenarios were evaluated for local air quality impact with different charging range. First, very limited range for the PHEV of 20 miles was analyzed (PHEV-20) [8].

In analysis of this data source, a number of assumptions needed to be made before calculating the expected exhaust emissions. The first assumption was that the reported reduction in emissions could be attributed to reduction in exhaust emissions. The second assumption made applied the emission rate from PHEV-20 vehicles to all HEV vehicles in Maricopa County in future years. While this may not be accurate, it provides one scenario to evaluate the impact of penetration of PHEV vehicles on air quality in the future. The third assumption was that reported emission reductions in future years apply to all vehicles in those milestone years. And finally, as was done for other scenarios, it was assumed that the total number of vehicles in the fleet was constant and that only the composition of the vehicle fleet changed over time.

As this study focused solely on HEV vehicles [8], the emission rate for IC vehicles was obtained from South Coast Air Basin SIP [5]. As was the case for the South Coast Air Basin SIP analysis, this data yielded results that show total PM2.5, BC, NOx and VOCs exhaust emissions are expected to decrease in all scenarios out to 2035. This is due both to the significant reduction in emission rates predicted for future years from IC and HEV cars as well as the increased contribution of cleaner vehicles to the future vehicle fleet.

A third set of data was obtained from the same study from Minnesota but with an extended range for the PHEV vehicles out to 60 miles (PHEV-60) [8]. The impact of this extended range is that the PHEV vehicle operates for a larger fraction of the time on electricity only as an EV with more limited operation as a traditional HEV vehicle. The same assumptions as with the PHEV-20 scenario are made and the results of this interpretation also show total PM2.5, BC, NOx and VOCs exhaust emissions are expected to decrease in all scenarios out to 2035.

3.3 Predicted Future Fleet Emissions Results

Based on the expected fleet composition and the expected fleet emission rate, future emissions from the vehicle fleet as a whole can be determined. As the vehicle fleet size was chosen to be constant, the difference in total emissions based on fleet composition between the five scenarios can be compared to the magnitude of emissions reductions due to improved vehicle emission control technology. Also, emissions tabulated here are based solely on exhaust emissions; as EV do not emit exhaust during operation, they are not included in this analysis.

3.3.1 IC Fleet Emissions Results

Future scenarios all predict IC vehicles will remain the dominant vehicle technology through 2035. Based on expected emission rate from these vehicles, the PM2.5 and the BC emissions from on-road IC vehicles are estimated to decrease significantly in the future. Results for emissions for the five future vehicle fleet scenarios are shown in Figure 3. 4, Figure 3. 5 and Table 3. 6.

The difference in emissions between the different scenarios can be distinguished compared to the magnitude of the implied decrease in IC vehicle fleet PM2.5 and BC emissions; the future fleet scenario with the greatest fraction of IC vehicles in 2035 – based on extrapolating sales data as reported in the literature [4], [5], [8] – is predicted to have less than 5% greater emissions than the scenario where IC vehicles is the greatest fraction of the vehicle fleet based on U.S. DOE analysis [3], [5], [8].

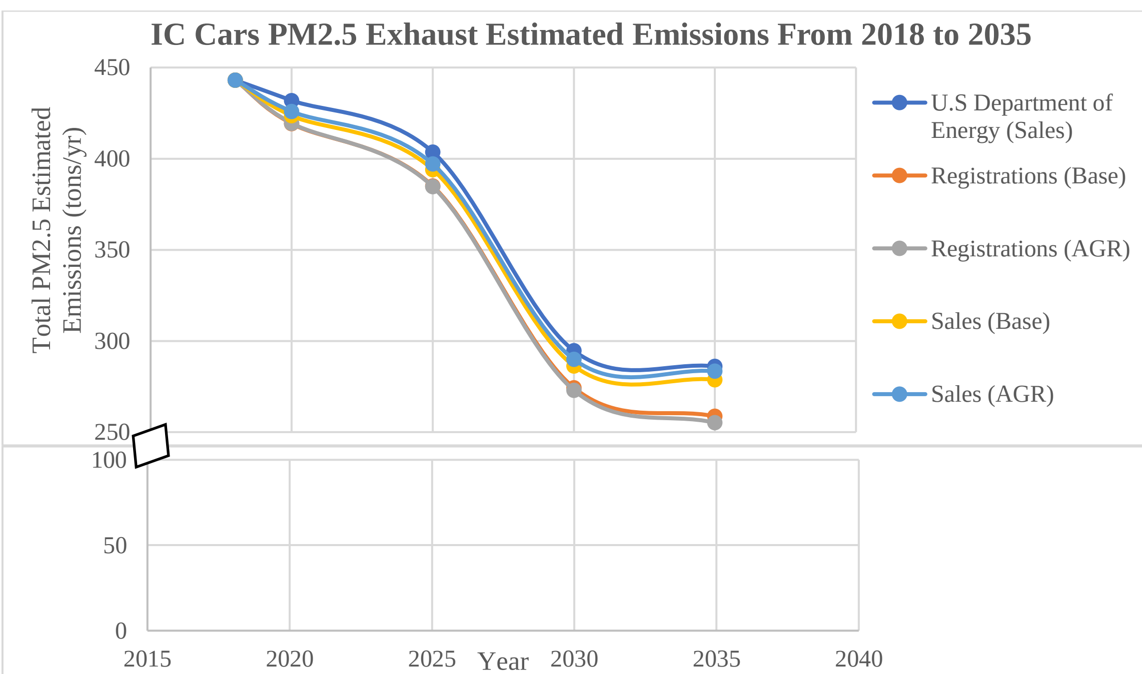

Figure 3. 4: The Estimated PM2.5 Emissions of the IC Fleet in Maricopa County in the Present Time and in the Future.

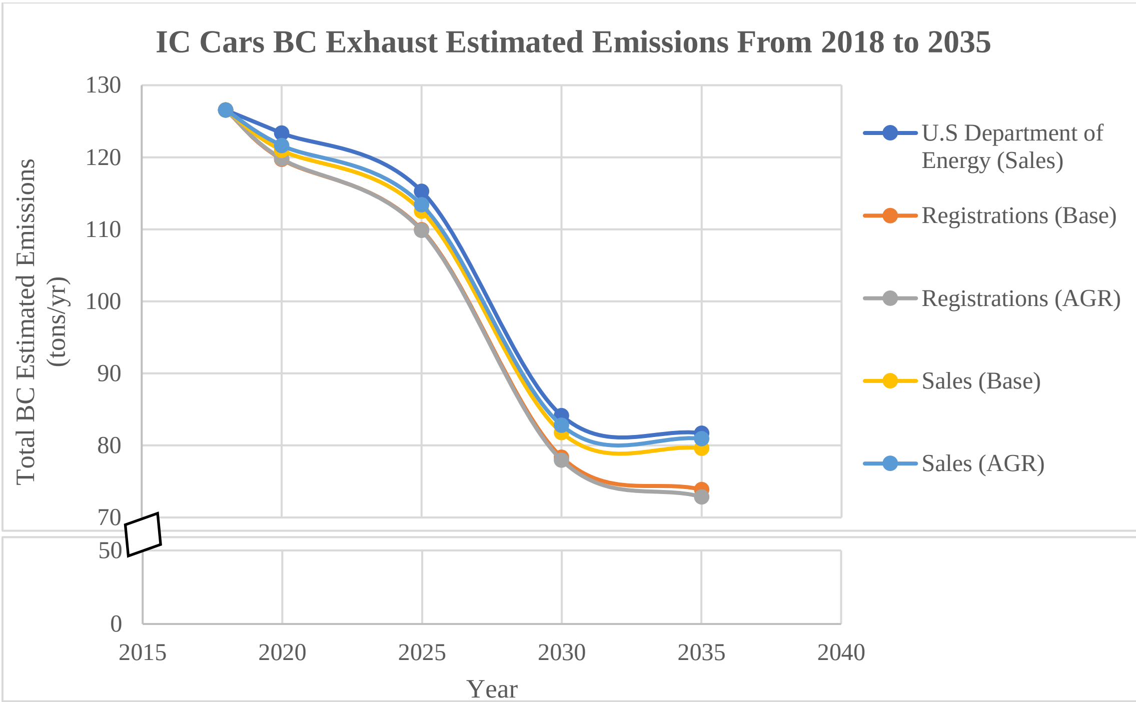

Figure 3. 5: The Estimated BC Emissions of the IC Fleet in Maricopa County in the Present Time and in the Future.

Similar to expected decreases in PM2.5 and BC, NOx and VOC are also predicted to decrease significantly through 2035 as shown in Figure 3. 6, Figure 3. 7 and Table 3. 6. All of the observed reductions in exhaust emissions predicted in these figures and table will be a direct result of IC vehicle emission reductions and alternative vehicle technologies expected expansion in the future, see Figure 3. 2, Figure 3. 3.

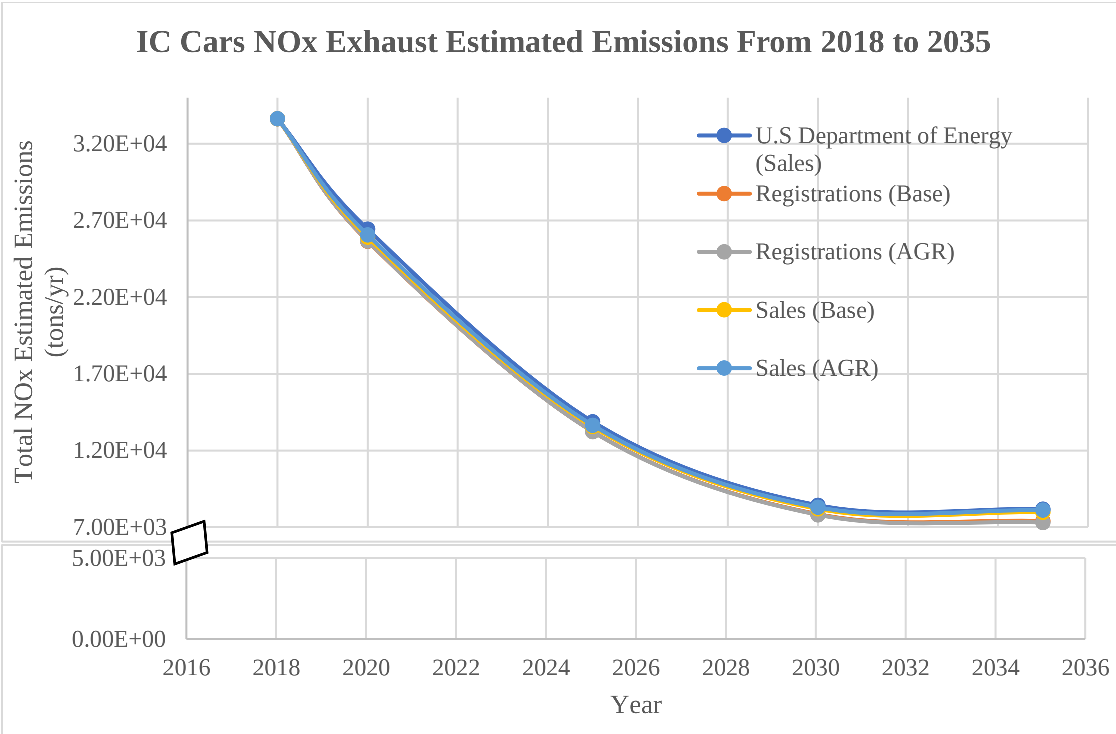

Figure 3. 6: The Estimated NOx Emissions of Maricopa County IC Fleet in the Present Time and in the Future.

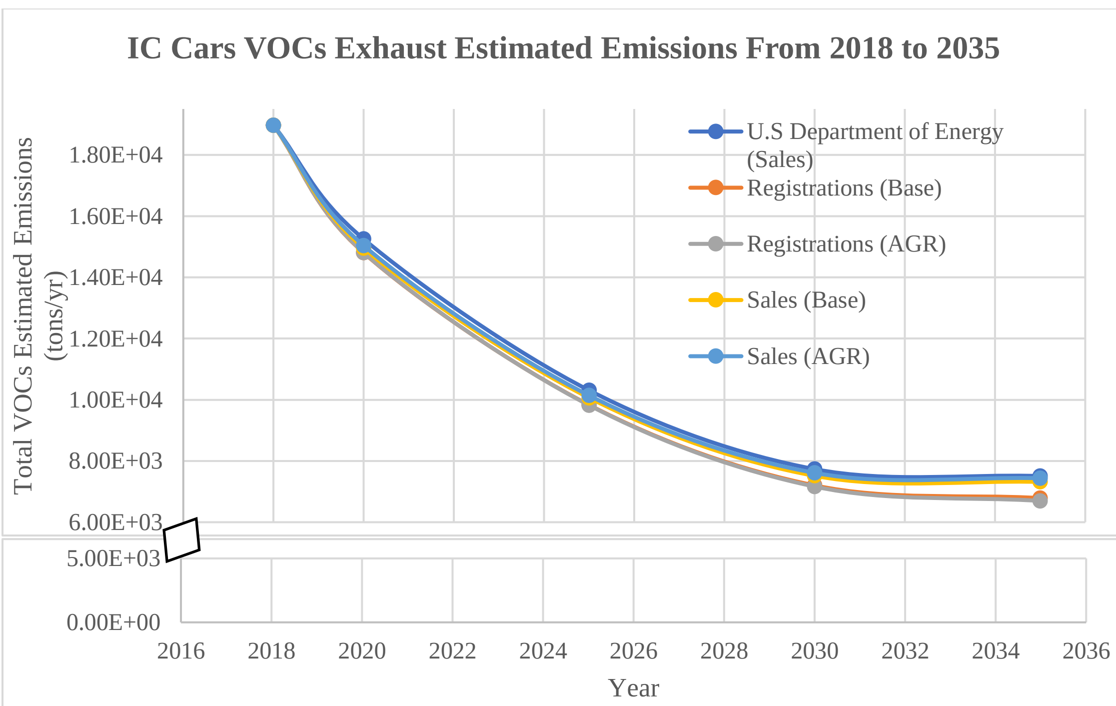

Figure 3. 7: The Estimated VOCs Emissions of Maricopa County IC Fleet in the Present Time and in the Future.

Table 3. 6: The County-wide IC Vehicle Fleet Emissions Averaged Results of the Five Fleet Scenarios.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	443	443	443	443	443
2020	432	419	419	424	426
2025	404	385	385	394	397
2030	295	274	273	286	290
2035	286	259	255	279	283
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	127	127	127	127	127
2020	123	120	120	121	122
2025	115	110	110	113	113
2030	84.2	78.4	78.0	81.8	82.8
2035	81.7	73.9	72.9	79.6	80.9
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**
2018	3.36	3.36	3.36	3.36	3.36
2020	2.64	2.56	2.57	2.59	2.61
2025	1.39	1.32	1.32	1.35	1.36
2030	0.843	0.785	0.781	0.819	0.829
2035	0.818	0.740	0.730	0.797	0.811
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year) $*10^4$**

2018	1.90	1.90	1.90	1.90	1.90
2020	1.53	1.48	1.48	1.50	1.50
2025	1.03	0.983	0.982	1.01	1.01
2030	0.773	0.720	0.716	0.751	0.761
2035	0.751	0.679	0.670	0.732	0.744

3.3.2 HEV Fleet Estimated Emissions Results

In the future, HEV vehicles will make up a greater number of the total vehicles in the Maricopa County fleet with a possible range between 2 and 3.5% of total vehicles. Scaling this range of number of vehicles by the expected future emission rate, the total emission results from HEV vehicles in the Maricopa County fleet indicates that future PM2.5 and BC emissions may possibly slightly decrease, or increase based on the assumptions contained within the scenarios developed as reported in Figure 3. 8 and Figure 3. 9. All three of extrapolation of recent sales data project a slight decrease in PM2.5 and BC emission between the years 2018 and 2035 as these cases represent HEV vehicles contributing the lowest fraction of total vehicles in the Maricopa County vehicle fleet in 2035 [3], [4], [5], [8]. However, both of the registration scenarios conclude that with a greater fraction of total vehicles in future vehicle fleets, HEV emissions of PM2.5 and BC will slightly increase in the future as a result of greater numbers of these vehicles [4], [5], [8].

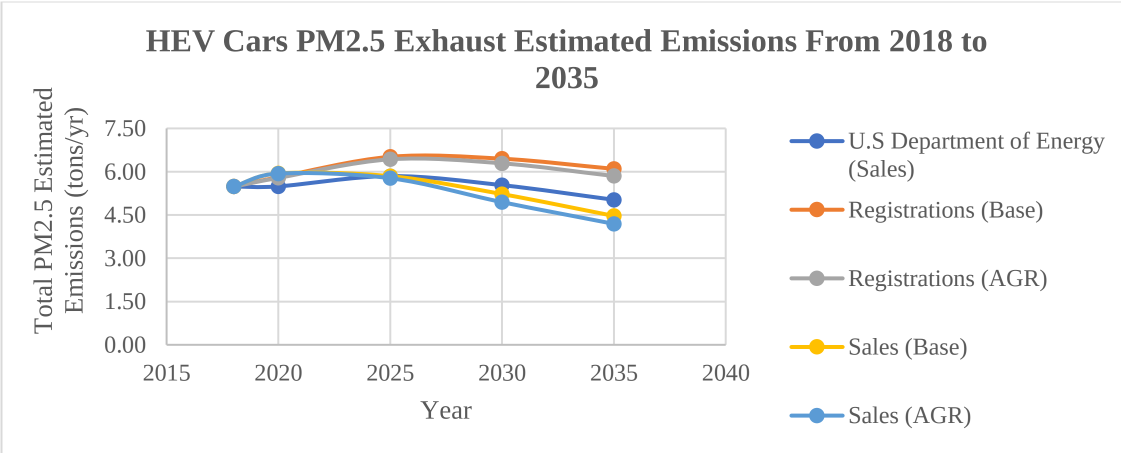

Figure 3. 8: The Estimated PM2.5 Emissions of the HEV Fleet in Maricopa County in the Present Time and in the Future.

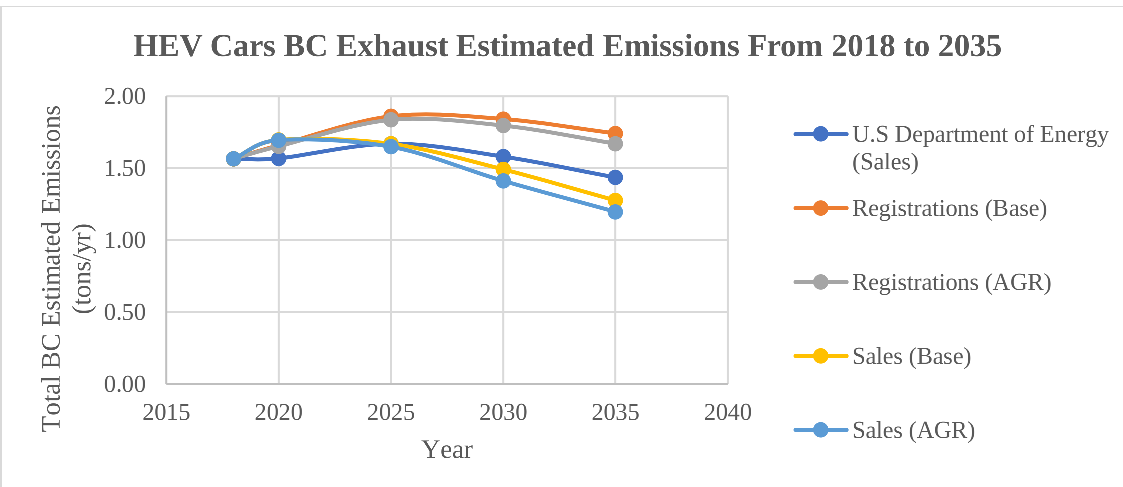

Figure 3. 9: The Estimated BC Emissions of the HEV Fleet in Maricopa County in the Present Time and in the Future.

While total county-wide PM2.5 and BC emissions from HEV vehicles may or may not increase based on the assumptions within the scenarios, all scenarios predict decreased NOx in the future as shown in Figure 3. 10 and Table 3. 7. Consistent with the results for county-wide emissions from HEV vehicles, the registration scenarios predict the highest total NOx emissions in the future [4], [5], [8].

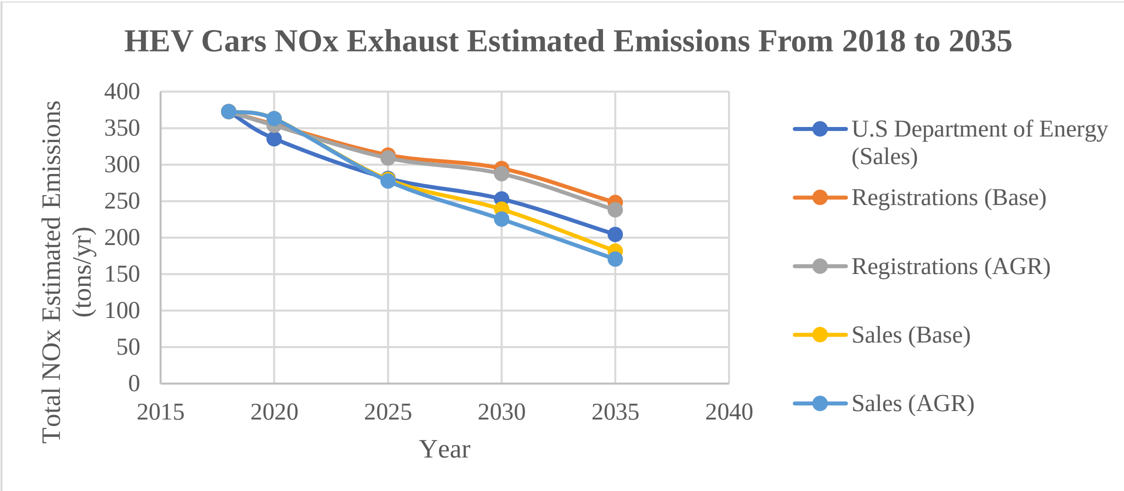

Figure 3. 10: The Estimated NOx Emissions of the HEV Fleet in Maricopa County in the Present Time and in the Future.

However, VOCs emissions from the Maricopa County HEV vehicle fleet may increase or decrease based on the assumptions within the scenarios developed as shown in Figure 3. 11 and Table 3. 7. Registration based scenarios [4], [5], [8], where HEV vehicles make a greater fraction of total Maricopa County vehicles in 2035, show the HEV vehicle fleet to have slightly greater VOC emissions in 2035 compared to today while a slight decrease in HEV vehicle fleet VOC emissions in 2035 compared to present time is observed for sales based scenarios [3], [4], [5], [8].

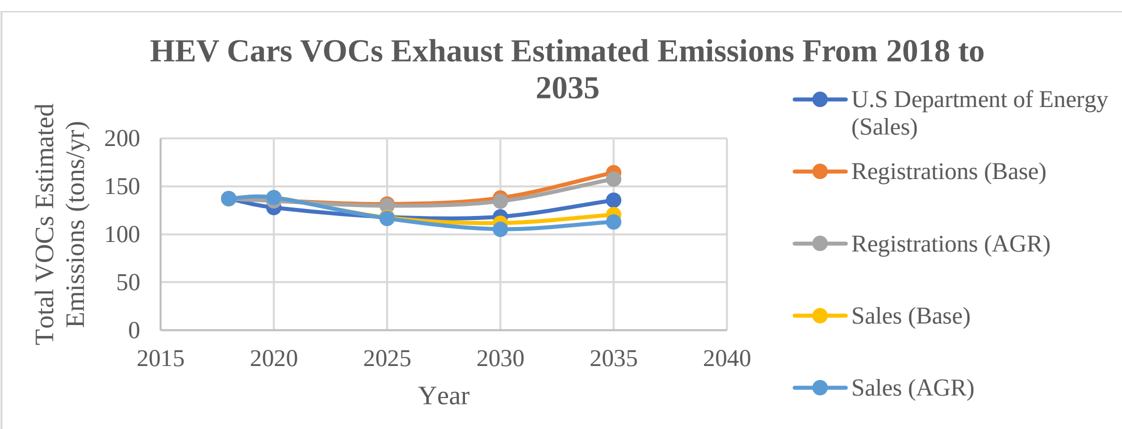

Figure 3. 11: The Estimated VOCs Emissions of the HEV Fleet in Maricopa County in the Present Time and in the Future.

Table 3. 7: The Aggregated County-wide HEV Fleet Emissions Results of the Five Fleet Scenarios Assembled.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	5.40	5.40	5.40	5.40	5.40
2020	5.32	5.80	5.77	5.87	5.83
2025	5.59	6.52	6.44	5.80	5.62
2030	5.21	6.55	6.42	5.12	4.85
2035	4.68	6.39	6.21	4.41	4.07
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	1.57	1.57	1.57	1.57	1.57
2020	1.57	1.66	1.65	1.70	1.70
2025	1.67	1.86	1.84	1.67	1.65
2030	1.58	1.84	1.80	1.49	1.41
2035	1.44	1.74	1.67	1.28	1.20
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	373	373	373	373	373
2020	336	355	354	363	363
2025	281	313	309	280	278
2030	253	295	287	239	225
2035	204	248	238	182	170
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**

2018	137	137	137	137	137
2020	128	135	135	138	138
2025	118	132	130	117	117
2030	118	138	134	112	105
2035	135	164	158	120	113

3.3.3 County-wide Emissions from IC and HEV Vehicle Fleet

Adding the county-wide IC and HEV vehicle emissions, the total emissions from the Maricopa County vehicle fleet indicate that all scenarios will have future air pollutant emissions that are lower than observed today. PM2.5 and BC emissions show decreases for all five fleet scenarios as shown in Figure 3. 12, Figure 3. 13 and Table 3. 8.

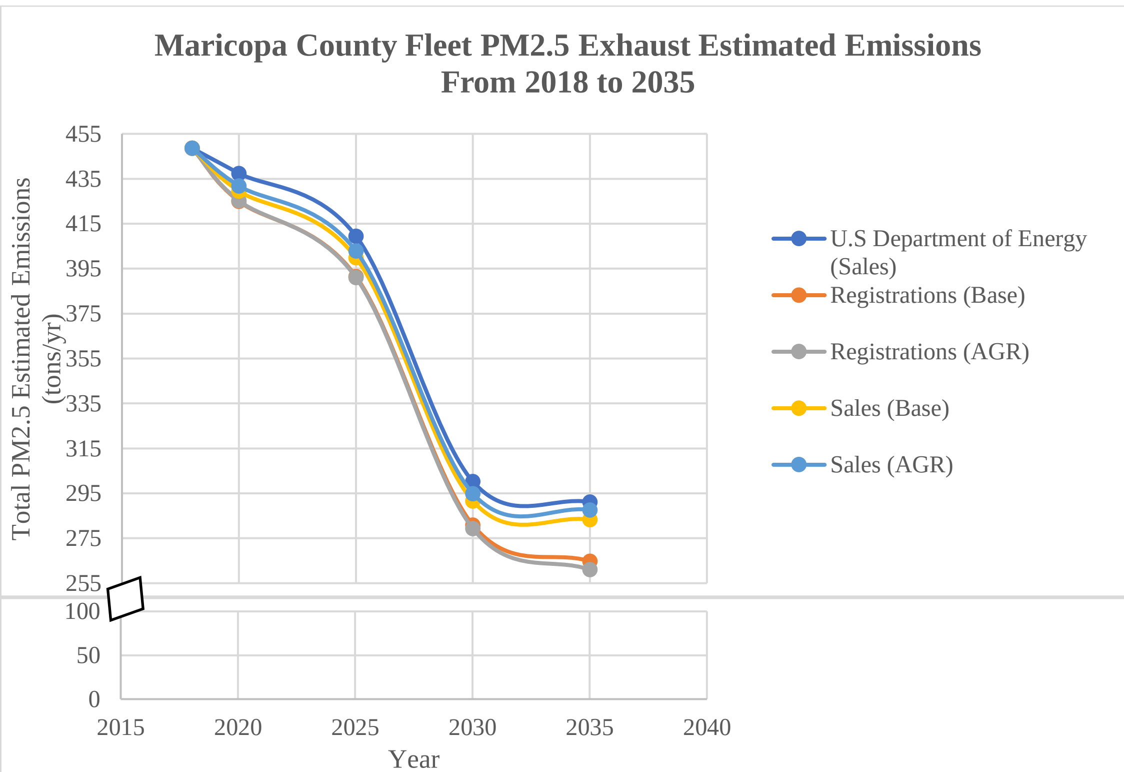

Figure 3. 12: The Estimated PM2.5 Emissions of Maricopa County Fleet in the Present Time and in the Future.

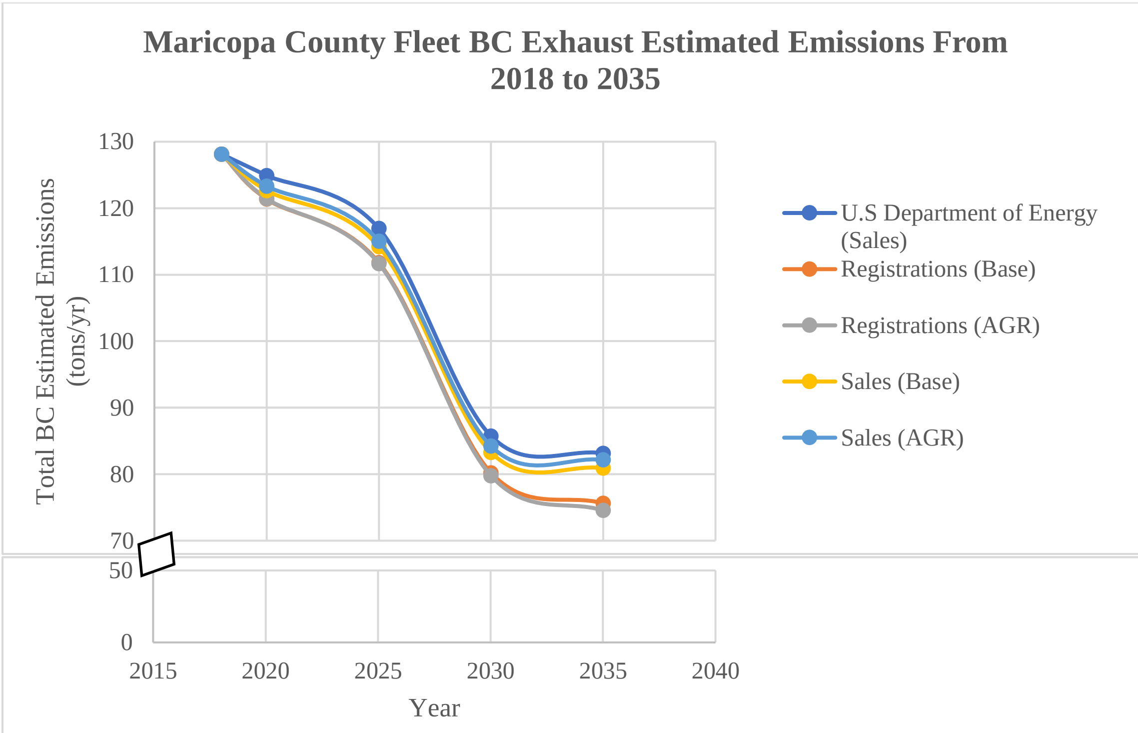

Figure 3. 13: The Estimated BC Emissions of Maricopa County Fleet in the Present Time and in the Future.

Maricopa County NOx and VOCs emissions from exhaust emissions of the entire on-road vehicle fleet will also decrease significantly in the future as shown in Figure 3. 14, Figure 3. 15 and Table 3. 8.

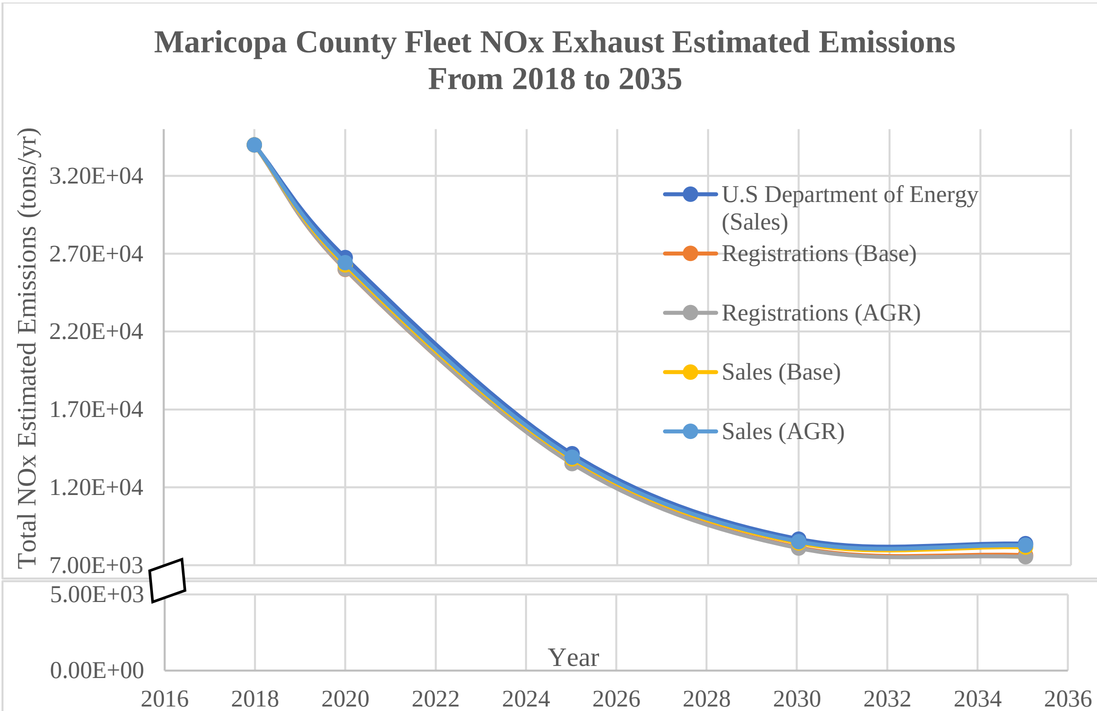

Figure 3. 14: The Estimated NOx Emissions of Maricopa County Fleet in the Present Time and in the Future.

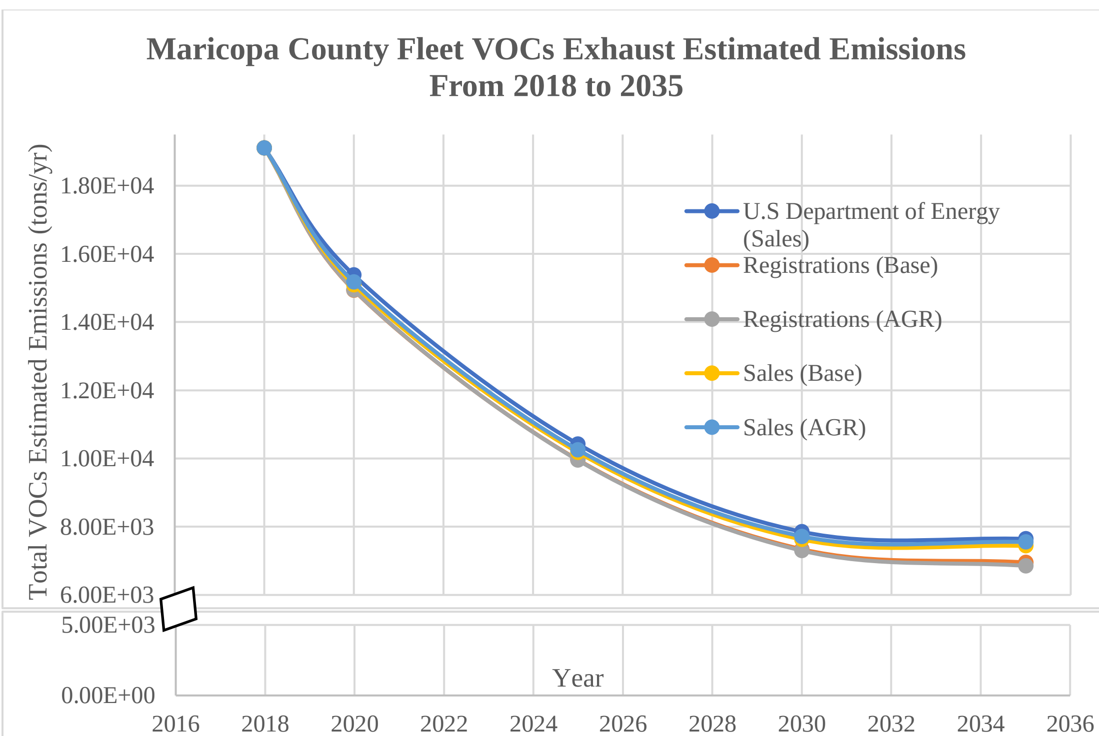

Figure 3. 15: The Estimated VOCs Emissions of Maricopa County Fleet in the Present Time and in the Future.

Table 3. 8: Maricopa County Total Estimated Emissions Results of IC and HEV Combined.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	449	449	449	449	449
2020	437	425	425	429	432
2025	409	392	391	400	403
2030	300	281	279	292	295
2035	291	265	261	283	288
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	128	128	128	128	128
2020	125	121	121	123	123
2025	117	112	112	114	115
2030	85.7	80.2	79.8	83.3	84.2
2035	83.1	75.6	74.5	80.9	82.1
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	3.40	3.40	3.40	3.40	3.40
2020	2.68	2.60	2.60	2.63	2.64
2025	1.42	1.35	1.35	1.38	1.39
2030	0.868	0.814	0.809	0.843	0.852
2035	0.839	0.764	0.753	0.815	0.828
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**

2018	1.91	1.91	1.91	1.91	1.91
2020	1.54	1.49	1.49	1.51	1.52
2025	1.04	0.996	0.995	1.02	1.03
2030	0.785	0.734	0.730	0.763	0.772
2035	0.764	0.695	0.685	0.744	0.755

3.4 MOVES Emission Results Data Analysis

An alternative independent approach to understand what future emissions for mobile sources in Maricopa County will be in the future is to use mathematical models used for air quality planning purposes. As noted above, this work is based on the U.S. EPA MOVES model [9].

3.4.1 Future Fleet Population for MOVES

One key input for future mobile source emissions calculations is to specify the fleet composition expected. For this, the average of the five fleet composition scenarios assembled and presented in Appendix B was calculated creating an average future fleet composition as reported in Table 3. 9. The averaged fleet scenario will be used for scaling MOVES model predictions for future years in Maricopa County.

Table 3. 9: Future Average Fleet for Maricopa County as an Average of the Scenarios Developed for This Work.

Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (IC)	98.2%	96.2%	94.6%	92.2%	88.6%
hybrid gas-electric car (HEV)	1.53%	1.75%	2.03%	2.34%	2.66%
electric car (EV)	0.225%	2.06%	3.35%	5.43%	8.76%

3.4.2 IC Cars Data Analysis

Conventional vehicles make up 98.2% of Maricopa County vehicles fleet, and it is critical to use MOVES to estimate IC vehicle future emissions. The MOVES model requires specific information as input to predict emissions such as the time scale, location, types of vehicles included, and pollutants required to be simulated [9]. For this work, annual emissions were selected for the time scale, the location was selected as Maricopa County, and the types of cars selected were the gasoline passenger cars. Also, the pollutant selected to be simulated was the total PM2.5, NOx and VOCs which includes emissions from exhaust, brake wear and tire wear. A total of five runs were performed to estimate the species of concern emissions from IC cars matching the milestone years as mentioned previously. From model results for PM2.5 emissions, BC emissions were determined based on studies done previously on PM2.5 composition from vehicle emissions as specified previously [7], [10]. The results from the MOVES model suggest that PM2.5, BC, NOx and VOCs exhaust emissions will decrease dramatically throughout the years as shown in Figure 3. 16 and Figure 3. 17. On the other hand, the obtained results showed that the conventional cars PM2.5 and BC brake and tire wear emissions will slightly increase in the future, as shown in Figure 3. 18.

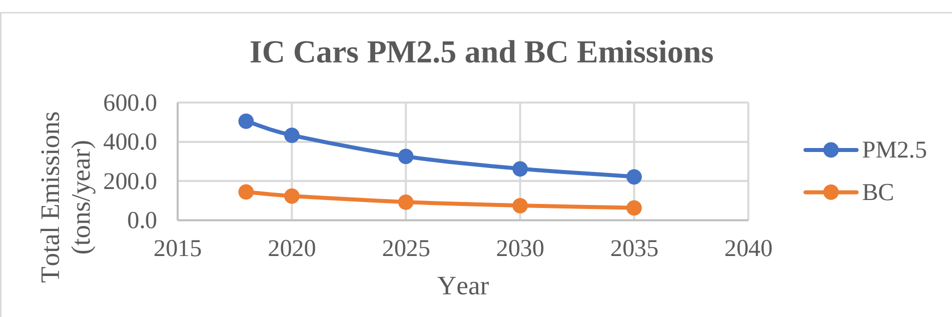

Figure 3. 16: MOVES Model Predictions for Maricopa County Passenger Cars PM2.5 and BC Estimated Emissions.

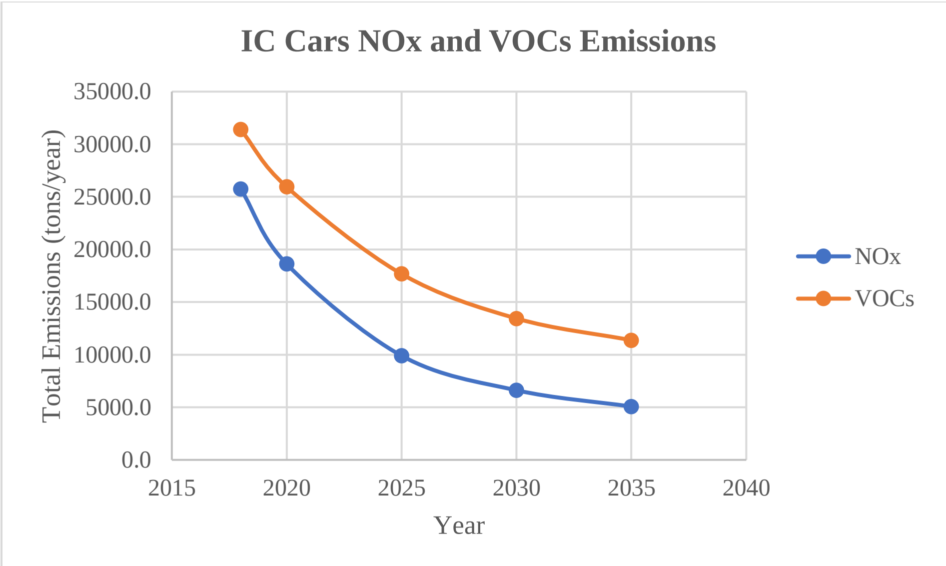

Figure 3. 17: MOVES Model Predictions for Maricopa County Passenger Cars NOx and VOCs Estimated Emissions.

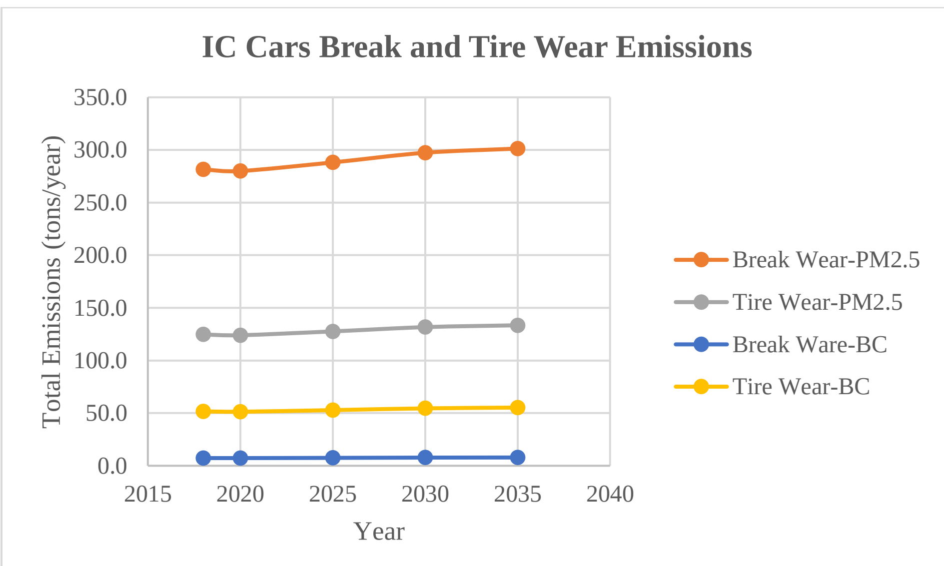

Figure 3. 18: IC Cars PM2.5 and BC Expected Emissions from Break and Tire Wear.

3.4.3 HEV Cars Data Analysis

Since MOVES does not offer the option to model HEV cars, a scenario estimating the emissions of hybrid cars in Maricopa County was created. As was done previously, reduction percentages calculating the difference between traditional IC and HEV vehicle emissions were calculated. This was used to scale PM2.5, NOx and VOCs exhaust emissions calculated by MOVES for passenger vehicles to estimate emissions from HEV cars. PM2.5 reduction percentage of the exhaust was assumed to be the same for the years 2018 and 2020. The results indicate that PM2.5, BC, NOx and VOCs exhaust emissions will decrease through 2035 for the HEV vehicle fleet in Maricopa County as shown in Figure 3. 19 and Figure 3. 20. On the other hand, the obtained results showed that the conventional cars PM2.5 and BC brake and tire wear emissions will increase in the future, as shown in Figure 3. 21.

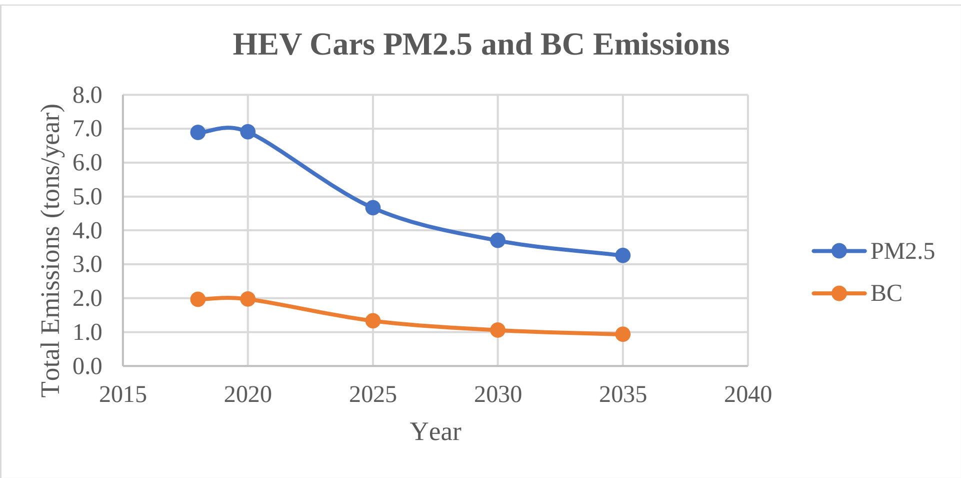

Figure 3. 19: HEV Passenger Cars, PM 2.5 and BC Expected Emissions.

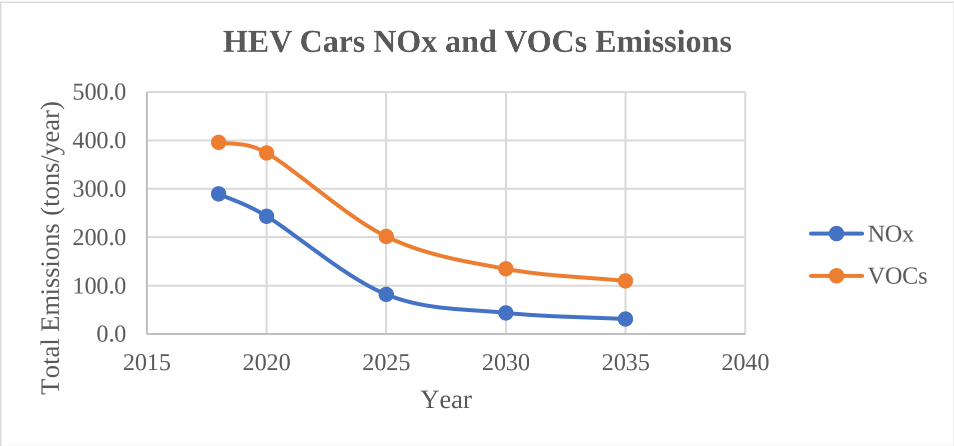

Figure 3. 20: HEV Passenger Cars, NOx and VOCs Expected Emissions.

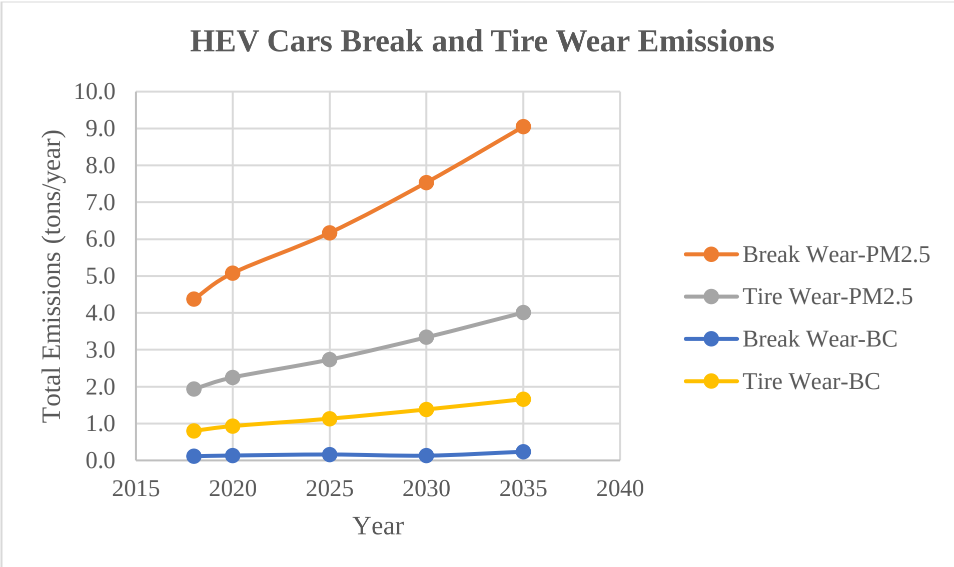

Figure 3. 21: HEV Cars PM2.5 and BC Expected Emissions From Break and Tire Wear.

3.4.4 MOVES Model Applied to EV Emissions

Attempts to model EV emissions using MOVES were not successful. The reason was that MOVES modeling system requires running exhaust to calculate the distance traveled by vehicles and then estimate PM2.5 exhaust, brake and tire wear emissions. Since there is no running exhaust in electric cars, no results were obtained from the runs performed. As a result, a scenario was created based on the results obtained from scaling MOVES predictions of emissions from IC vehicles. The scenario created estimated brake and tire wear emissions produced from EV based on results from MOVES for IC vehicles attributed to brake and tire wear. The results obtained showed that the electric vehicles PM2.5 and BC brake and tire wear emissions will increase in the future as shown in Figure 3. 22 and Figure 3. 23 as this vehicle type increases as a percentage of the total Maricopa County vehicle fleet. Since there is no running exhaust in EVs, all other species of concern exhaust emissions is zero.

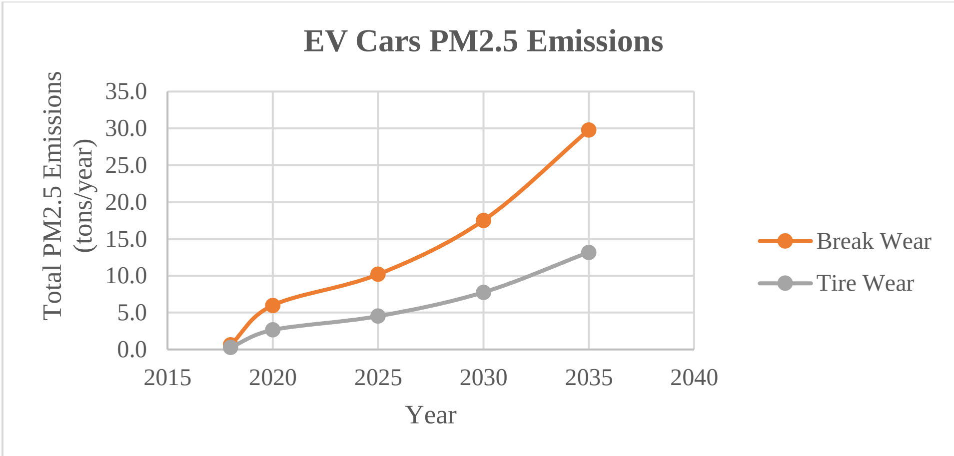

Figure 3. 22: EV Estimated PM2.5 Emissions in Maricopa County Now and in the Future.

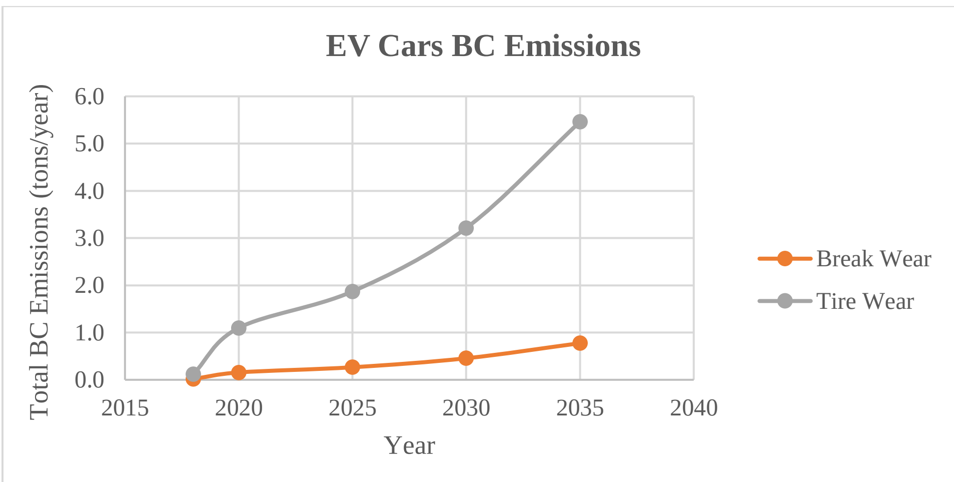

Figure 3. 23: EV Estimated BC Emissions in Maricopa County Now and in the Future.

3.5 Comparison Between Literature and MOVES Emission Results

A comparison between future county-wide emissions based on emission rates determined from literature reports versus modeled county-wide emissions based on MOVES model can provide insight into what will drive future emission inventories. Specifically, PM2.5 and BC fleet emission results based on literature reports suggest a current PM2.5 and BC annual emissions in Maricopa County of about 450 and 130 tons/year, respectively, as shown in Figure 3. 24 and Figure 3. 25. Between current time and 2035, the analysis based on literature reported emission rates suggest that the Maricopa County annual PM2.5 and BC emissions from on-road mobile sources will drop to about 261 and 74.5 tons/year, respectively as shown in Figure 3. 24 and Figure 3. 25. The modeling using MOVES inventories suggest a slightly higher value for Maricopa County emissions of 505 and 145 tons/year currently for PM2.5 and BC as shown in Figure 3. 24 and Figure 3. 25. For future years emissions, MOVES indicates that the emissions of PM2.5 and BC will decrease to reach about 245 and 70 tons/year respectively by 2035, in which is slightly lower than what was estimated based on reports from the literature, see Figure 3. 24 and Figure 3. 25.

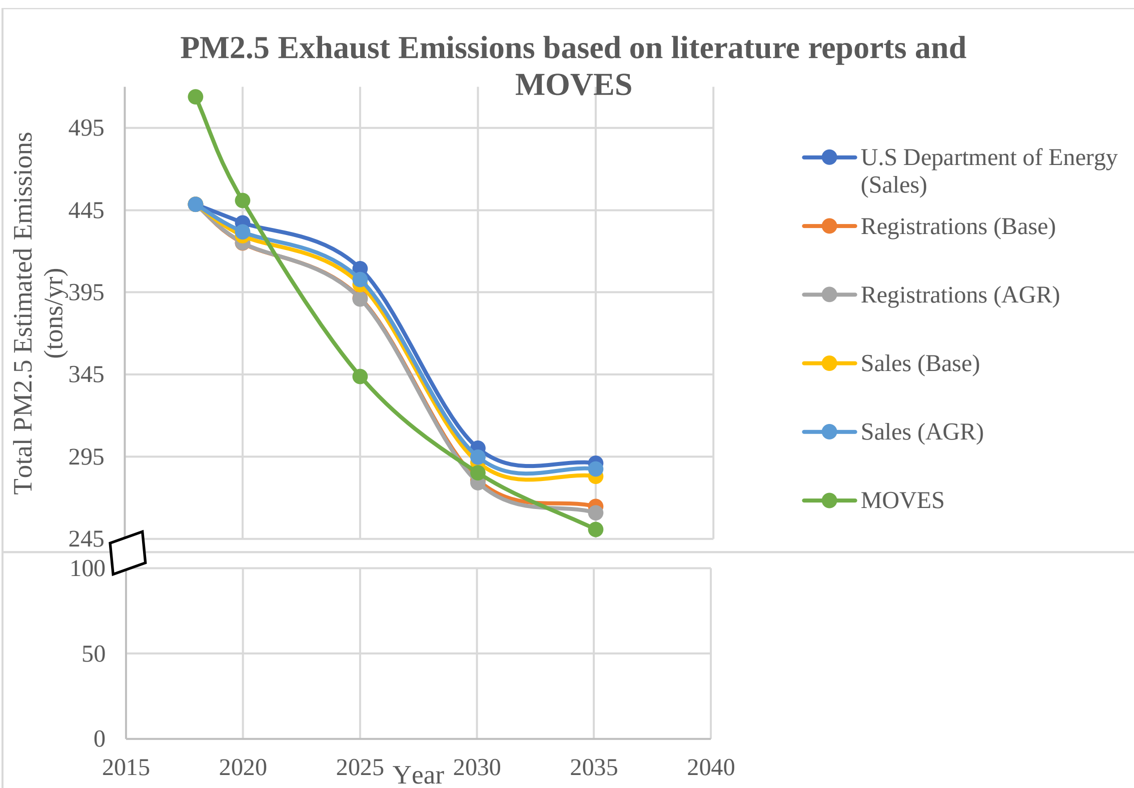

Figure 3. 24: Comparison Between Literature and MOVES Maricopa County Fleet PM2.5 Estimated Emissions Results.

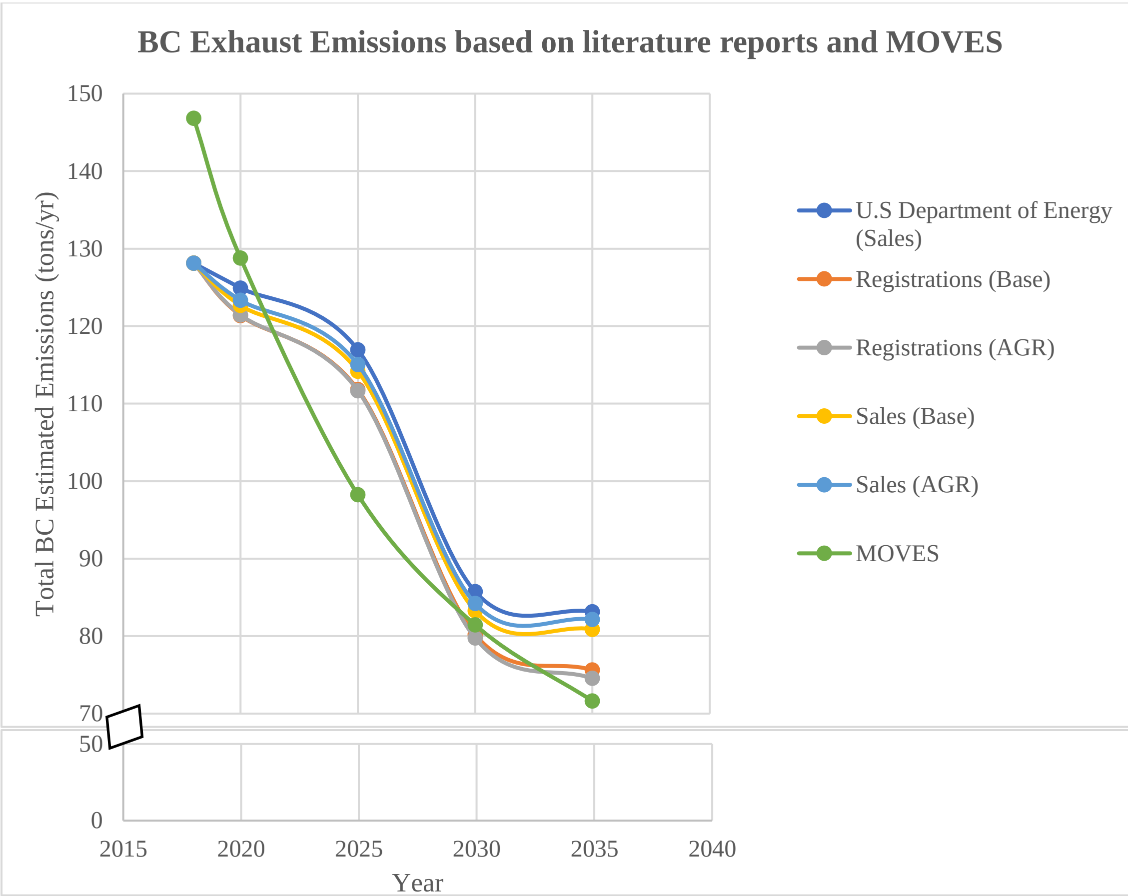

Figure 3. 25: Comparison Between Literature and MOVES Maricopa County Fleet BC Estimated Emissions Results.

Analysis of the Maricopa County fleet emissions based on literature reported emission rates indicates a total county-wide NOx emissions of about 35000 tons/year with annual emission rates decreasing to about 7500 tons/year in 2035 as shown in Figure 3. 26. However, analysis of results from MOVES suggest a lower county-wide inventory of only about 25000 tons/year in 2018 with a decrease in the future to about 5000 tons/year by 2035 as shown in Figure 3. 26. For NOx MOVES simulation both the current and future years emission are lower compared to the literature reports.

The county-wide fleet emission results based on literature emission values suggest current VOC annual emission of about 19000 tons/year in the present time decreasing over time to a total county-wide VOC on-road mobile source emissions about 7000 tons/year by 2035 as shown in Figure 3. 27. However, MOVES data suggest a higher estimation than the literature, where VOCs emissions currently of 32000 tons/year that will decrease in the future to reach about 10000 tons/year by 2035. In both cases, current and future emissions are higher in MOVES than based on emission rates in the literature.

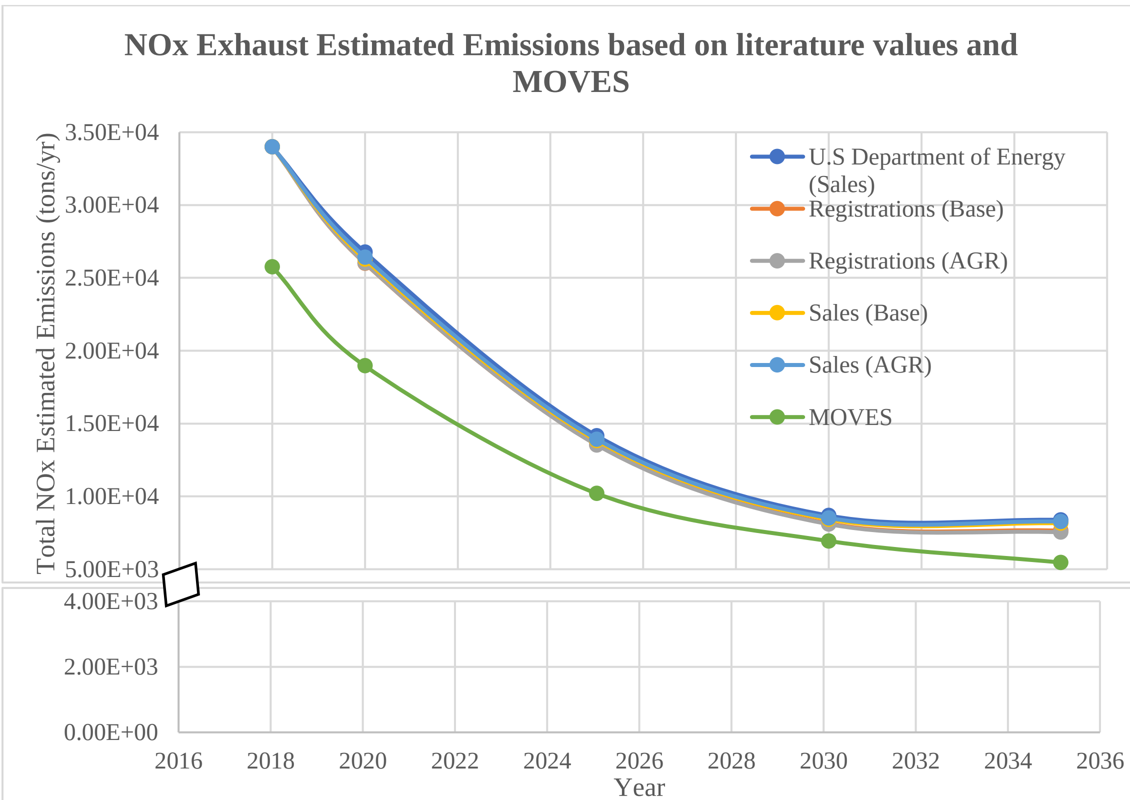

Figure 3. 26: Comparison Between Literature and MOVES Maricopa County Fleet NOx Estimated Emissions Results.

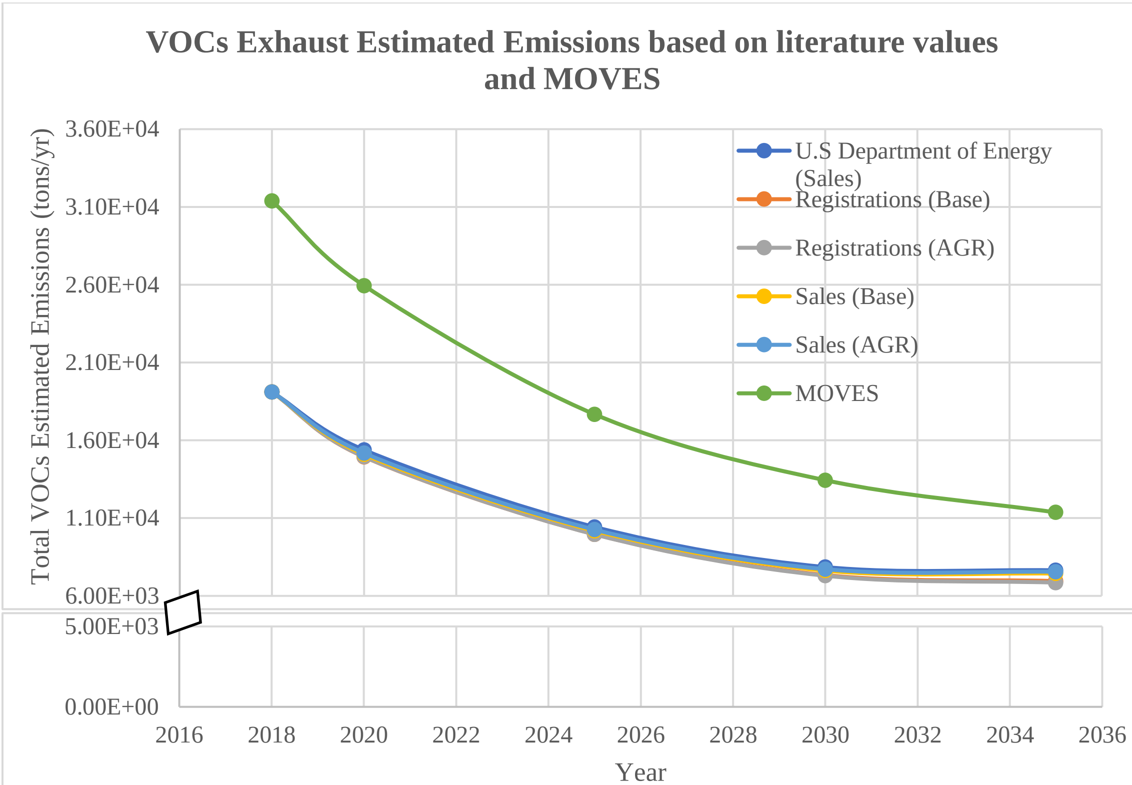

Figure 3. 27: Comparison Between Literature Reports and MOVES for Maricopa County Fleet VOCs Estimated Emissions Results.

4.0 SUMMARY AND CONCLUSION

4.1 Summary

Mobile sources are non-stationary sources that move and emit different pollutants, like PM2.5, NOx and VOCs. Therefore, on-road mobile sources emit carbonaceous particles as well, which include BC. Mobile sources are divided into two categories: on-road mobile sources and non-road mobile sources. Maricopa County air quality department emissions inventory reports were used as the base of the research [11], [12]. The focus was to estimate vehicle fleet composition now and in the future in Maricopa County. Also, to estimate PM2.5, BC, NOx and VOCs emissions produced from the fleet in the county. The milestone years were set to estimate the fleet population and the expected emissions. The milestone years will be used to reflect on whether the emissions of PM2.5, NOx and VOCs will increase or decrease based on a specific fleet scenario created using the literature or based on MOVES simulation runs.

The results based on the literature suggests that the exhaust emitted pollutants of concern are subject to decrease significantly as shown previously. Moreover, after obtaining results from MOVES brake wear, PM2.5 emissions from IC, HEV and EV fleet were increasing. Thus, brake wear BC emissions were rising slightly. Also, tire wear PM2.5 emissions were increasing and as a result the BC emission produced from tire wear were increasing dramatically. However, PM2.5 and BC exhaust emissions are subject to decrease by 2035 in Maricopa County. After running MOVES NOx emissions are expected to decrease in the future as well as VOCs emissions produced from on-road mobile sources.

4.2 Future Research

On-road mobile sources include all vehicles in Maricopa County in which most of those cars are light duty vehicles. As of today, there are more than three million vehicles in Maricopa County and most of those cars are IC vehicles [1]. The vehicle fleet composition is subject to change in future as well as PM2.5, BC, NOx and VOCs emissions produced from on-road mobile sources. In addition, the results from the literature and MOVES runs conclude that PM2.5, BC, NOx and VOCs produced from on-road mobile sources are decreasing in the future. However, PM2.5 and BC emissions from break wear and tire wear are increasing in the future base on the MOVES runs performed. Thus, establishing a research about the reasons behind the increase in break and tire wear emissions as well as how to control the increase of PM2.5 and BC would be ideal for the next steps. Finally, expanding the research to includes other regions, all of the US or even other countries would be recommended.

4.3 Conclusion

In conclusion, the emphasis of the research was about estimating the emissions of PM2.5, BC, NOx and VOCs. Also, to compare the literature reports emissions results with MOVES emission results. The fleet population in Maricopa County was estimated throughout the years as well as the fleet composition. Moreover, three types of vehicles were considered for this research: conventional vehicle, gas-electric vehicle and electric vehicle. The results of both the literature reports and MOVES shows that the pollutants of concern are subject to decrease significantly in the future. The main reason behind the decrease in exhaust emissions pollutants was detected to be that IC and HEV vehicles will be producing fewer PM2.5, BC, NOx and VOCs emissions. Also, HEV and EV fleet population is increasing in the future as observed. Moreover, the fleet population in Maricopa county was assumed to be constant in this research after applying removal rates. Finally, the literature reports results are somewhat in sync with MOVES results as observed.

REFERENCES

[1] “Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite” U.S. Department of Energy Alternative Fuels Data Center. [Online]. Available: https://www.afdc.energy.gov/evi-pro-lite. [Accessed: 1-Sept-2018].

[2] “Highway Statistics Series” U.S. Department of Transportation/Federal Highway Administration. [Online]. Available: https://www.fhwa.dot.gov/policyinformation/statistics.cfm. [Accessed: 1-Jun-2019].

[3] “Maps and Data” U.S. Department of Energy Alternative Fuels Data Center. [Online]. Available: https://www.afdc.energy.gov/data/. [Accessed: 1-Sept-2018].

[4] “Tomorrow’s Vehicles A Projection of the Light Duty Vehicle Fleet Through 2025” Navigant Research, 2017.

[5] S.-M. Lee, X. Zhang, S. Yan, S. Epstein, and M. Sospedra, “Appendix III Base and Future Year Emission Inventory 2016 Air Quality Management Plan,” South Coast Air Quality Management District, Mar. 2017.

[6] S. Boschert, “The Cleanest Cars: Well-To-Wheels Emissions Comparisons” New Society Publishers, pp. 1–19, May 2008.

[7] J. C. Chow, J. G. Watson, D. H. Lowenthal, L.-W. A. Chen, and N. Motallebi, “Black and Organic Carbon Emission Inventories: Review and Application to California,” Journal of the Air & Waste Management Association, vol. 60, no. 4, 2010.

[8] P. Ciborowski, I. Eyoh, J. Seltz, and C. Y. Wu, “Air Emissions Impacts of Plug-In Hybrid Vehicles in Minnesota’s Passenger Fleet” Minnesota Pollution Control Agency, Mar. 2007.

[9] “MOVES and Other Mobile Source Emissions Models” Environmental Protection Agency, 3-Dec-2018. [Online]. Available: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves. [Accessed: 7-Dec-2018]

[10] H. Cai and M. Wang, "Estimation of Emission Factors and Particulate Black Carbon and Organic Carbon from Stationary, Mobile, and Non-point Sources in the United States for Incorporation into GREET," 2014.

[11] "2014 Periodic Emissions Inventory for PM10 for the Maricopa County, Arizona, PM10 Nonattainment Area" Maricopa County Air Quality Department, Sept. 2017.

[12] "2014 Periodic Emissions Inventory for Ozone Precursors for the Maricopa County, Arizona, Eight-Hour Ozone Nonattainment Area" Maricopa County Air Quality Department, Sept. 2016.

[13] "National Emissions Inventory (NEI)" EPA, 29-Nov-2017. [Online]. Available: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei. [Accessed: 1-March-2019].

[14] S. Lawrence, R. Sokhi, K. Ravindra, H. Mao, H. D. Prain, and I. D. Bull, "Source apportionment of traffic emissions of particulate matter using tunnel measurements" Atmospheric Environment, vol. 77, 2013.

[15] S. Reid, D. Eisinger, P. Roberts, E. Pollard, Y. Du, and B. Chenausky, "Field Study of PM2.5 Emissions from a Road-Widening Project" Sonoma Technology, Inc. and Arizona Department of Transportation, 2010.

[16] H. Simon, A. Reff, B. Wells, J. Xing, and N. Frank, "Ozone Trends Across the United States over a Period of Decreasing NOx and VOC Emissions" Environmental Science & Technology, vol. 49, no. 1, pp. 186–195, 2014.

[17] A. Stojić, D. Maletić, S. S. Stojić, Z. Mijić, and A. Šoštarić, "Forecasting of VOC emissions from traffic and industry using classification and regression multivariate methods" Science of The Total Environment, vol. 521-522, pp. 19–26, 2015.

[18] D. R. Keith, S. Houston, and S. Naumov, "Vehicle fleet turnover and the future of fuel economy," IOP Environmental Research Letters, vol. 14, no. 2, p. 1001, Feb. 2019.

[19]“Vehicle Recycling” Argonne National Laboratory, Jun-2011. [Online]. Available: https://web.archive.org/web/20130216155834/http://www.transportation.anl.gov/materials/recycling_home.html. [Accessed: 13-Jun-2019].

[20] “Used Car Report 2017” edmunds, Santa Monica, CA, 2017.

[21] “July Sales Insights” edmunds, Santa Monica, CA, 2019.

[22] A. Cooper and K. Schefter, “Electric Vehicle Sales Forecast and the Charging Infrastructure Required Through 2030” Institute for Electric Innovation and Edison Electric Institute , Washington, D.C, 2018.

[23] A. Cooper, L. Wood, I. Rohmund, D. Costenaro , and A. Duer, “Forecast of On-road Electric Transportation in the U.S. (2010 - 2035)” Institute for Electric Efficiency , Washington, D.C, 2013.

APPENDIX A

BLACK CARBON EMISSION FRACTION OF PM2.5 VALUES USED

Table 1, Table 2 and Table 3 show all the values of BC emissions fraction of PM2.5. The values obtained from the literature were needed to calculate BC emissions inventory in Maricopa County. The values obtained will help to determine how much of PM2.5 emissions is being emitted as BC based on the source. For example, exhaust emissions from on-road mobile sources produces 28.6% of BC emissions in every ton of PM2.5 [7]. Also, it is estimated that fugitive dust sources produces 0.110% of BC from every ton of PM2.5 that is being emitted [7].

Table 1: Point Sources BC Emissions Fraction of PM2.5.

Point Sources [11]	**Black Carbon Fraction of PM2.5 [7]**
APS West Phoenix Power Plant	13.7%
Arlington Valley LLC	13.7%
Butterfield Station Facility	0.620%
CMC Steel Fabricators Inc	0.340%
Gila River Power Station	0.00%
Glendale Mun Sanitary Landfill	0.620%
Mesquite Generating Station	13.7%
New Harquahala Generating Co	13.7%
New Wincup Holdings Inc.	0.890%
Northwest Regional Landfill	0.620%
Oak Canyon Manufacturing Inc.	0.00%
Ocotillo Power Plant	13.7%
Redhawk Generating Facility	13.7%
Rexam Beverage Can Company	0.00%
Santan Generating Station	13.7%
SFPP LP Phoenix Terminal	0.00%
SRP Agua Fria Generating Station	13.7%
SRP Kyrene Generating Station	0.00%
Trendwood Inc.	0.00%

Table 2: Fuel Combustion, Industrial Processes and Waste Sources BC Emission Fraction of PM2.5.

Fuel combustion [11]	**Black Carbon Fraction of PM2.5 [7]**
Industrial distillate oil: boilers	10.0%
Industrial distillate oil: engines	15.0%
Industrial natural gas	13.0%
Industrial LPG	13.0%
Comm./inst. dist. oil: boilers	10.0%
Comm./inst. dist. oil: engines	15.0%
Comm./inst. natural gas	7.00%
Residential distillate oil	0.00%
Residential natural gas	38.0%
Residential LPG	38.0%
Residential wood combustion	10.0%
Industrial processes [11]	**Black Carbon Fraction of PM2.5 [7]**
Chemical manufacturing	1.83%
Commercial cooking	10.2%
Grain handling/processing	0.00%
Ammonia cold storage	0.00%
Secondary metal production	0.340%
Nonmetallic mineral processes	1.47%
Mining/quarrying	1.47%
Wood product manufacturing	2.63%
Rubber/plastic product mfg.	0.890%
Fabricated metals	0.340%
Residential construction	0.110%
Commercial construction	0.110%
Road construction	0.110%
Construction, other	0.110%
Electrical equipment mfg.	0.890%
Indust. paved/unpaved roads	0.440%
Industrial processes, NEC	0.890%
Secondary metal production	0.340%
Nonmetallic mineral processes	1.47%
Mining/quarrying	1.47%
Waste treatment/disposal [11]	**Black Carbon Fraction of PM2.5 [7]**
On-site incineration	32.5%
Open burning	19.3%
Landfills	0.620%
Publicly owned treatment works	0.00%
Other waste	0.00%

Table 3: Miscellaneous Area, Non-road and On-road Mobile Sources BC Fraction.

Miscellaneous area sources [11]	**Black Carbon Fraction of PM2.5 [7]**
Windblown dust	0.110%
Cotton ginning	0.00%
Tilling	0.350%
Harvesting	0.110%
Travel on unpaved ag. roads	0.110%
Fertilizer application	0.00%
Livestock	0.00%
Humans	0.00%
Backyard barbeques	10.0%
Structure fires	19.3%
Aircraft engine testing	76.1%
Vehicle fires	19.3%
Crematories, human	0.00%
Crematories, animal	0.00%
Accidental releases	0.00%
Wildfires	19.3%
Prescribed fires	19.3%
Travel on unpaved pkg lots	0.110%
Leaf blowers fugitive dust	0.770%
Offrd rec vehicle fugitive dust	0.110%
Non-road mobile sources]11]	**Black Carbon Fraction of PM2.5 [7]**
Agricultural equipment	56.3%
Airport GSE (+APU)	56.3%
Commercial equipment	56.3%
Construction/mining equipment-Fugitive Dust	0.110%
Construction/mining equipment-T	56.3%
Industrial equipment	56.3%
Lawn and garden equipment	56.3%
Pleasure craft	56.3%
Rail maintenance equipment	56.3%
Recreational equipment	28.6%
Aircraft	76.1%
Locomotives	200%
On-road mobile sources [11]	**Black Carbon Fraction of PM2.5**
Tire wear	41.4% [10]
Brake wear	2.60% [10]
Exhaust	28.6% [7]
Paved road fugitive dust	0.770% [7]
Unpaved road fugitive dust	0.110% [7]

APPENDIX B

PRESENTING AND DISCUSSING THE DATA OF THE FIVE FLEET SCENARIOS

After computing all the fleet scenarios presented in Table 1 and Table 2 to estimate the contribution of IC, HEV and EV cars in Maricopa County fleet several things must be noted. Table 1 represent all the sales scenarios of the different types of vehicles in the present time and in the future. Sales base scenario estimates the highest EV population by 2035, which is expected to reach 7% as shown in Table 1. Furthermore, HEV population is estimated to be roughly the same when compared between all the sales scenarios with the highest expected by the U.S. DOE Sales scenario to reach over 2% by 2035, see Table 1. Table 2 represent all the registration scenarios of the different types of vehicles in the present time and in the future. Registration aggressive scenario estimates the highest EV contribution to Maricopa County which is expected to reach 14% as shown in Table 2. Finally, HEV contribution to the fleet is almost the same in both registration scenarios with slightly higher population estimated in registration base scenario, see Table 2.

Table 1: All sales scenarios that was computed to estimate IC, HEV and EV contribution currently and in the future to Mricopa County fleet.

U.S Department of Energy Sales Scenario					
Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (ICE)	98.2%	98.0%	97.2%	95.8%	93.0%
hybrid gas-electric car (HEV)	1.53%	1.65%	1.94%	2.27%	2.61%
electric car (EV)	0.224%	0.352%	0.824%	1.91%	4.37%
Sales Base Scenario					
Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (ICE)	98.2%	96.1%	94.9%	93.1%	90.6%
hybrid gas-electric car (HEV)	1.53%	1.79%	1.96%	2.14%	2.32%
electric car (EV)	0.225%	2.12%	3.18%	4.75%	7.03%
Sales Aggressive Scenario					
Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (ICE)	98.2%	96.6%	95.6%	94.2%	92.2%
hybrid gas-electric car (HEV)	1.53%	1.79%	1.92%	2.05%	2.18%
electric car (EV)	0.225%	1.58%	2.43%	3.73%	5.66%

Table 2: All registration scenarios that was computed to estimate IC, HEV and EV contribution currently and in the future to Maricopa County fleet.

Fleet Registration Base Scenario					
Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (ICE)	98.2%	95.1%	92.7%	89.2%	84.1%
hybrid gas-electric car (HEV)	1.53%	1.75%	2.17%	2.65%	3.16%
electric car (EV)	0.225%	3.147%	5.094%	8.134%	12.72%
Fleet Registration Aggressive Scenario					
Type of car	**Percentage 2018**	**Percentage 2020**	**Percentage 2025**	**Percentage 2030**	**Percentage 2035**
gasoline car (ICE)	98.2%	95.2%	92.6%	88.8%	83.0%
hybrid gas-electric car (HEV)	1.53%	1.74%	2.14%	2.58%	3.04%
electric car (EV)	0.225%	3.10%	5.22%	8.65%	14.0%

APPENDIX C

PRESENTING AND DISCUSSING THE DATA OF SET 1, SET 2 AND SET 3

Table 1 represents all the data regarding Set 1, which were obtained based on California South Cost Implementation Plan [5]. On the other hand, Set 2 and Set 3 represent the results gained from Minnesota's Passenger Fleet journal [8]. Also, Set 2 and Set 3 results can be found in Table 2 and Table 3 respectively. As the results suggested for PM2.5, the emission range from 260 to 291 tons/year based on the scenario followed in Set 1 and Set 3 by 2035. Moreover, BC suggested emissions range from 74.2 to 83.0 tons/year based on the scenario followed in Set 1 and Set 3 by 2035. In addition, Set 2 represent a slightly higher PM2.5 and BC emissions, where the suggested results ranged between 263 and 75.0 tons/year to 292 and 83.5 tons/year of PM2.5 and BC respectively based on the scenario followed. As mentioned previously, NOx and VOCs emission from on-road mobile sources are subject to decrease in all of the three sets. In addition, NOx emission results ranges from 7300 tons/year as shown in Table 1 to 8610 tons/year in Table 2 based on the scenario followed by the year 2035. The proposed VOCs emission results ranges from 6800 tons/year as shown in Table 3 to 7720 tons/year in Table 2 based on the scenario followed by the year 2035. Finally, data in Table 1, Table 2, Table 3 calculated by simply adding the recorded IC cars emission to HEV cars emission in each set.

Table 1: Maricopa County Total Fleet Emissions Results of Set 1.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	449	449	449	449	449
2020	437	425	425	429	431
2025	409	391	391	399	403
2030	299	279	278	290	293
2035	291	264	261	283	287
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	128	128	128	128	128
2020	125	121	121	123	123
2025	117	112	112	114	115
2030	85.3	79.7	79.3	82.9	83.8
2035	83.0	75.5	74.4	80.8	82.0
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	3.40	3.40	3.40	3.40	3.40
2020	2.67	2.60	2.60	2.62	2.64
2025	1.40	1.34	1.33	1.37	1.38
2030	0.843	0.785	0.781	0.819	0.830
2035	0.819	0.741	0.730	0.798	0.811
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	1.92	1.92	1.92	1.92	1.92

2020	1.54	1.50	1.50	1.52	1.52
2025	1.04	0.998	0.996	1.02	1.03
2030	0.783	0.731	0.727	0.761	0.770
2035	0.762	0.692	0.682	0.741	0.753

Table 2: Maricopa County Total Fleet Emissions Results of Set 2.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	449	449	449	449	449
2020	438	425	425	430	432
2025	410	392	391	400	403
2030	301	282	281	293	296
2035	292	266	263	284	289
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	128	128	128	128	128
2020	125	121	121	123	123
2025	117	112	112	114	115
2030	86.1	80.6	80.2	83.6	84.6
2035	83.5	76.1	75.0	81.2	82.5
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	3.40	3.40	3.40	3.40	3.40
2020	2.68	2.60	2.61	2.63	2.65
2025	1.43	1.37	1.37	1.40	1.41
2030	0.888	0.837	0.832	0.861	0.870
2035	0.861	0.792	0.780	0.835	0.846
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	1.91	1.91	1.91	1.91	1.91

2020	1.54	1.49	1.50	1.51	1.52
2025	1.05	1.00	0.999	1.02	1.03
2030	0.792	0.741	0.737	0.769	0.777
2035	0.772	0.704	0.694	0.750	0.761

Table 3: Maricopa County Total Fleet Emissions Results of Set 3.

PM2.5	**U.S. Department of Energy (Sales) PM2.5**	**Registrations (Base) PM2.5**	**Registrations (AGR) PM2.5**	**Sales (Base) PM2.5**	**Sales (AGR) PM2.5**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	449	449	449	449	449
2020	438	425	425	430	432
2025	409	391	391	400	403
2030	301	281	280	292	295
2035	290	264	260	282	287
BC	**U.S. Department of Energy (Sales) BC**	**Registrations (Base) BC**	**Registrations (AGR) BC**	**Sales (Base) BC**	**Sales (AGR) BC**
Year	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**	**Emissions in (tons/year)**
2018	128	128	128	128	128
2020	125	121	121	123	123
2025	117	112	112	114	115
2030	85.8	80.3	79.9	83.4	84.3
2035	82.9	75.3	74.2	80.7	81.9
NOx	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year) $*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	3.40	3.40	3.40	3.40	3.40
2020	2.67	2.60	2.60	2.63	2.64
2025	1.42	1.36	1.36	1.39	1.40
2030	0.873	0.820	0.815	0.847	0.856
2035	0.836	0.761	0.750	0.813	0.825
VOCs	**U.S. Department of Energy (Sales)**	**Registrations (Base)**	**Registrations (AGR)**	**Sales (Base)**	**Sales (AGR)**
Year	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**	**Emissions in (tons/year)$*10^4$**
2018	1.90	1.90	1.90	1.90	1.90

2020	1.53	1.49	1.49	1.50	1.51
2025	1.04	9.90	9.89	1.01	1.02
2030	0.781	0.729	0.725	0.759	0.768
2035	0.760	0.689	0.680	0.739	0.751