South Coast
AQMD

# APPENDIX VII

# Socioeconomic Impact Assessment

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# SOCIOECONOMIC IMPACT ASSESSMENT

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# Introduction

The South Coast Air Basin Attainment Plan for the 2012 Annual PM2.5 Standard (hereafter, referred as PM2.5 Plan) outlines a suite of control strategies that are designed to attain the 2012 annual PM2.5 NAAQS no later than December 31, 2030. PM2.5 is known to cause substantial negative health impacts, including respiratory and cardiovascular disease, worsening asthma symptoms, and premature death. As such, the air quality improvements resulting from the control measures proposed in the PM2.5 Plan are expected to yield meaningful public health benefits. Following a similar methodology to the health benefit analysis performed for the 2022 AQMP, South Coast AQMD staff has worked closely with Industrial Economics, Inc. (IEc) to quantify the public health benefits associated with attainment of the 2012 annual PM2.5 NAAQS by 2030 and discuss the associated uncertainties in estimates. Despite these efforts, a full assessment of all clean air benefits in monetary terms is not possible until further advances occur in human health sciences, physical science, and economic disciplines that will allow monetary estimates to be made for currently unquantifiable areas.

The control strategy outlined in the PM2.5 Plan relies on previously adopted control measures from the 2022 AQMP and 2016 AQMP to reduce emissions of nitrogen oxides (NOx), ammonia (NH3), and directly emitted Particulate Matter with a diameter of 2.5 µm or less (PM2.5). The PM2.5 Plan models the impacts of these control strategies in the attainment year of 2030, a year in which emissions reductions and health benefits have not been previously quantified, and also reflects refined air quality modeling procedures[1]. As such, the health benefits quantified in this Socioeconomic Impact Assessment should be considered as supplemental to those previously discussed and quantified in the 2022 AQMP and 2016 AQMP, rather than incremental, as they present another data point on how health benefits are expected to accrue over time.

# Costs and Macroeconomic Impacts

Because the control measures in the PM2.5 Plan were previously adopted in either the 2022 AQMP or 2016 AQMP, the compliance costs, impacts on small business, and macroeconomic impacts of these control measures have already been analyzed and presented in the Socioeconomic Reports of the respective AQMPs. Since there are no incremental costs associated with the control measures in the PM2.5 Plan relative to the previous analyses, no additional assessment of costs or macroeconomic impacts has been prepared. For detailed discussions of costs and macroeconomic impacts associated with these control measures, please refer to the AQMP Chapters referenced in Table 1. Additional detailed socioeconomic analysis will be conducted as part of rule development for each control measure and presented to the Governing Board prior to its consideration of whether to adopt the rule.

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[1] See Appendix II of the PM2.5 Plan for a discussion of the modeling methodology: https://www.aqmd.gov/docs/default-source/clean-air-plans/pm2.5-plans/appendix-ii---air-quality-modeling.pdf?sfvrsn=10

# Projected Emission Reductions and Changes in Pollutant Concentrations

Ambient PM2.5 levels can be improved by reducing either direct PM2.5 emissions or PM2.5 precursor emissions. NOx is a precursor for both ozone and PM2.5. The 2022 AQMP committed to a strategy to reduce NOx emissions substantially to meet the 2015 8-hour ozone NAAQS. NOx emission reductions expected from the continued implementation of the 2022 AQMP and 2016 AQMP control measures are expected to contribute substantially to the attainment of the 2012 annual PM2.5 standard. Additional limited controls to meet federal Clean Air Act Section 188(e) requirements are proposed in this PM2.5 Plan. These include measures to marginally reduce direct PM2.5 and NH3 emissions.

The benefit assessment in this document analyzes the differences in the projected PM2.5 concentrations in the Basin between a baseline scenario (without the PM2.5 Plan control measures) and the control or policy scenario (with the PM2.5 Plan control measures) at the level of a 4km-by-4km grid. The control measures considered in this analysis and expected emissions reductions of PM2.5 and its precursors are listed in Table 1.

**TABLE 1: PM2.5 PLAN CONTROL MEASURES**

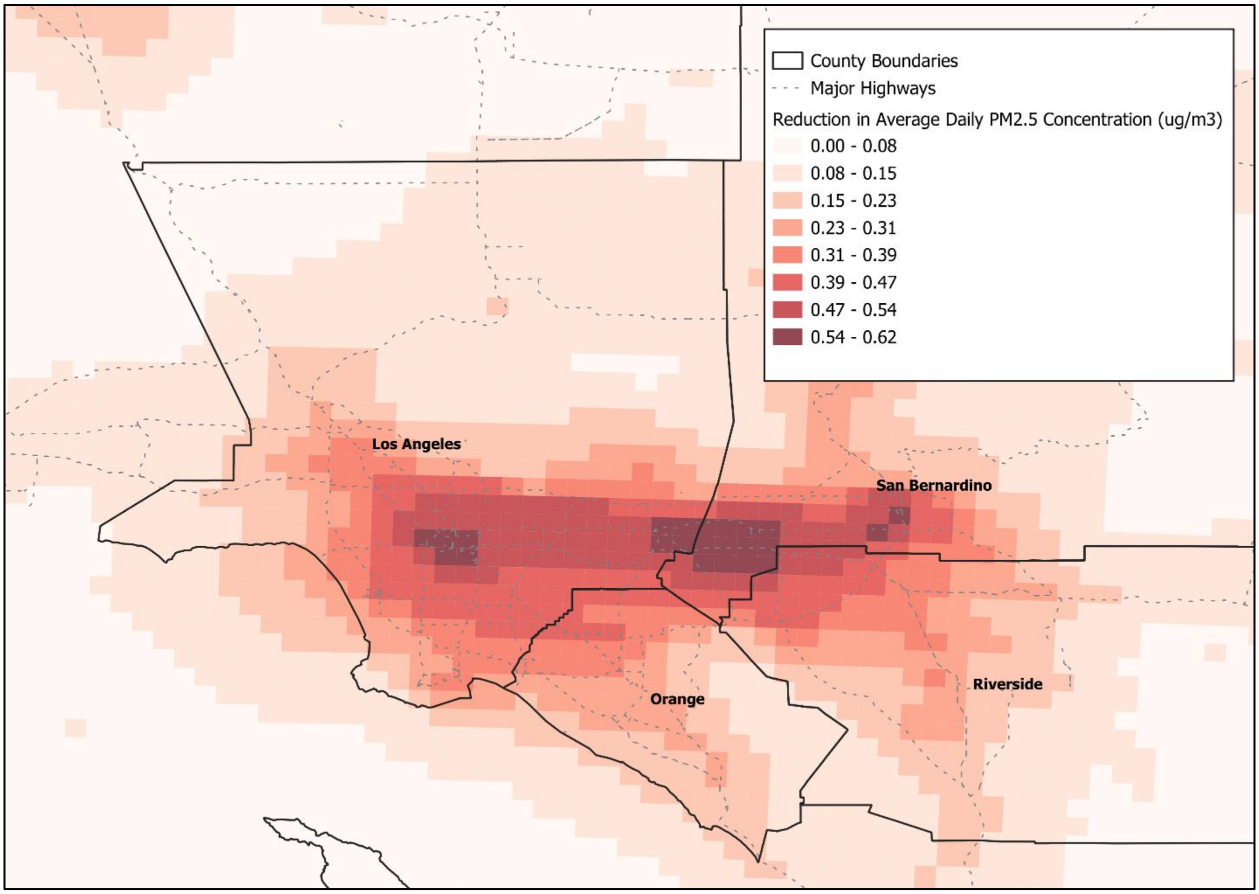
| PM 2.5 Plan Control Measure | Control Measure Name | Cost Previously Analyzed In | Emission Reductions [Pollutant] (2030 tpd) |
|---|---|---|---|
| BCM-05 | Emission Reductions from Emergency Standby Engines | 2022 AQMP[1] | 0.04 [PM2.5] |
| BCM-06 | Emission Reductions from Diesel Electricity Generating Facilities | 2022 AQMP[1] | 0.16 [NOx] |
| BCM-07 | Emission Reductions from Incinerators | 2022 AQMP[1] | 0.81 [NOx] |
| BCM-08 | Livestock Waste at Confined Animal Facilities (CAFs) | 2016 AQMP[2] | 0.27 [NH3] |
| BCM-10 | Chipped and Ground Greenwaste | 2016 AQMP[2] | 0.08 [NH3] |

Note: tpd = tons per day

1. Chapters 2 and 4 of the Final Socioeconomic Report for the 2022 AQMP: https://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/aqmp-2022-socioeconomic-report-main-final.pdf
2. Chapters 2 and 4 of the Final Socioeconomic Report for the 2016 Air Quality Management Plan: https://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/sociofinal_030817.pdf

The quantified public health benefits discussed in this Socioeconomic Impact Assessment are based on the projected change in PM2.5 concentrations within each grid cell. Figure 1 shows the modeled changes in PM2.5 concentrations due to the control measures proposed in the PM2.5 Plan. Note that air quality modeling methods in this analysis have already accounted for background concentrations of pollutants and thus concentrations projected in the control scenarios are above background concentration levels.

FIGURE 1: MODELED REDUCTIONS IN PM2.5 CONCENTRATIONS, 2030



Note: PM2.5 concentrations shown in this figure are the annual average of the 24-hour means.

# Quantified Public Health Benefits

Numerous epidemiological as well as controlled laboratory studies have demonstrated a positive association between ambient air pollution exposure and increases in illness and other health effects (morbidity endpoints) and increases in death rates from various causes (mortality endpoints) (U.S. EPA 2019). Groups that are most sensitive to the effects of air pollution are children, elderly persons, and people with certain respiratory or heart conditions.

Table 2 summarizes the likelihood of causal relationship between PM2.5 exposure and various health endpoints documented in the U.S. EPA Integrated Science Assessments (ISAs) (U.S. EPA 2019) [2]. Due to concerns of potentially double counting over the same health endpoint, not all causal or likely causal relationships listed in Table 2 are quantified in this Socioeconomic Impact Assessment.

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[2] Descriptions of the evidence for causal relationships between PM2.5 exposure and various health endpoints can be found in Appendix 3-A of the Final Socioeconomic Report Appendices of the 2022 AQMP, https://www.aqmd.gov/home/air-quality/air-quality-management-plans/air-quality-mgt-plan/socioeconomic-analysis

**TABLE 2: SUMMARY OF U.S. EPA'S CAUSAL DETERMINATIONS FOR PM2.5 EXPOSURE**

| Health Category | Causal Determination | Quantified? |
|---|---|---|
| ***Short-Term Exposure to PM2.5*** | | |
| Mortality | **Causal relationship**[1] | No |
| Cardiovascular Effects | **Causal relationship** | **Yes** |
| Respiratory Effects | **Likely to be a causal relationship** | **Yes** |
| Central Nervous System Effects | *Suggestive of a causal relationship* | No |
| ***Long-Term Exposure to PM2.5*** | | |
| Mortality | **Causal relationship** | **Yes** |
| Cardiovascular Effects | **Causal relationship**[2] | No |
| Respiratory Effects | **Likely to be a causal relationship** | **Yes** |
| Central Nervous System Effects | **Likely to be a Causal Relationship** | **Yes** |
| Reproductive and Developmental Effects | *Suggestive of a causal relationship* | No |
| Cancer, Mutagenicity, Genotoxicity | ***Likely to be a causal relationship*** | **Yes** |

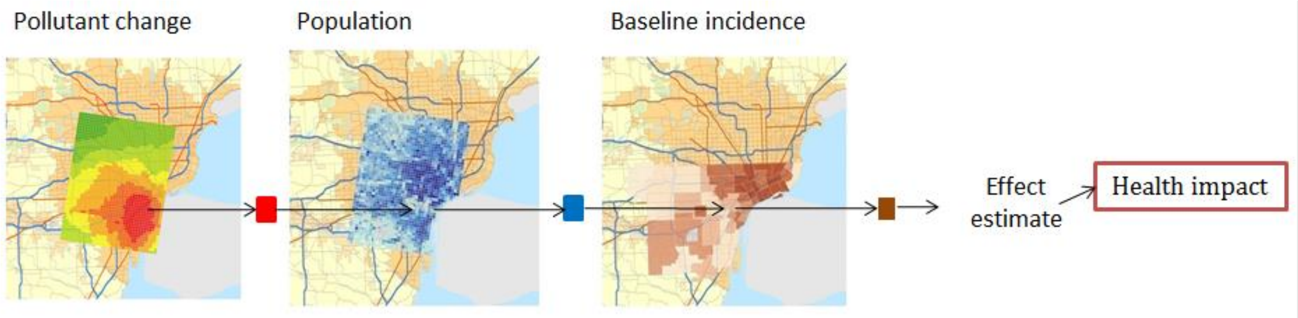
Notes:

1. Mortality due to short-term exposure to PM2.5 is not quantified because mortality due to long-term exposure to PM2.5 is expected to be inclusive of any short-term exposure impacts.
2. Although cardiovascular morbidity effects using risk models with long-term exposure to PM2.5 are not quantified, a number of cardiovascular effects modeled based on short-term exposure to PM2.5 are likely to have chronic impacts following the initial event (e.g., stroke, out-of-hospital cardiac arrest, and AMI). The valuation of the short-term cardiovascular endpoints reflects long-term, multi-year costs-of-illness.

Source: U.S. EPA ISA (2019)

The first step of a public health benefits analysis is the health effects quantification. Appropriate concentration-response (C-R) functions need to be selected, which numerically characterize the causal and likely causal relationships between exposure to a pollutant and various health endpoints. Specifically, as presented in Figure 2, the C-R functions used in this analysis relate changes in ambient air pollution concentration with changes in mortality or morbidity incidence, the magnitude of which also depends on the baseline incidence rate and the population exposed to a specific health risk being analyzed.

**FIGURE 2: HEALTH EFFECTS QUANTIFICATION**



Source: U.S. EPA BenMAP Community Edition User's Manual.

C-R functions were selected based on a systematic review of the epidemiological literature, where studies were evaluated for quality and applicability according to numerous criteria (See Appendix 3-C of the Final Socioeconomic Report Appendices of the 2022 AQMP; Industrial Economics and Thurston 2016a; Industrial Economics and Thurston 2016b). These criteria include: 1) peer-review; 2) date of the study; 3) geography and population characteristics; and 4) study design. Thus, the C-R functions applied in this analysis are mostly from recent, peer-reviewed articles, and derived from local studies of the Basin or studies that report separate estimates using sub-samples pertaining to the Basin, where feasible. Population projections from the 2020 Regional Transportation Plan/Sustainable Communities Strategy (RTP/SCS) were provided by the Southern California Association of Governments (SCAG) for each air quality modeling grid. When feasible, local health data based on public administrative records were utilized to obtain baseline incidence rates. The Technical Details section of this Appendix describes the input data and methodology used in greater depth, as well as analytical assumptions such as cessation lags for mortality effects associated with long-term PM2.5 exposure, which have implications for monetizing health benefits.

The public health benefit analysis described in this Appendix is implemented using U.S. EPA's Environmental Mapping and Analysis Program – Community Edition (BenMAP-CE) Version 1.5.8.29. BenMAP-CE is a free and open-source application maintained by the U.S. EPA. Earlier editions of BenMAP were used to quantify the public health benefits of the 2007, 2012, and 2016 AQMPs, as well as for numerous other studies.

## Health Effect Estimates

Table 3 presents a summary of the health effect estimates for each health endpoint. In total, approximately 665 premature deaths will be avoided in 2030 due to improved air quality by implementing the PM2.5 Plan control measures. Basin residents are also expected to benefit from the avoidance of large numbers of hospital admissions (HA), emergency department (ED) visits, school and work loss days, as well as various respiratory and cardiovascular symptoms.

## TABLE 3: HEALTH EFFECT ESTIMATES[1]

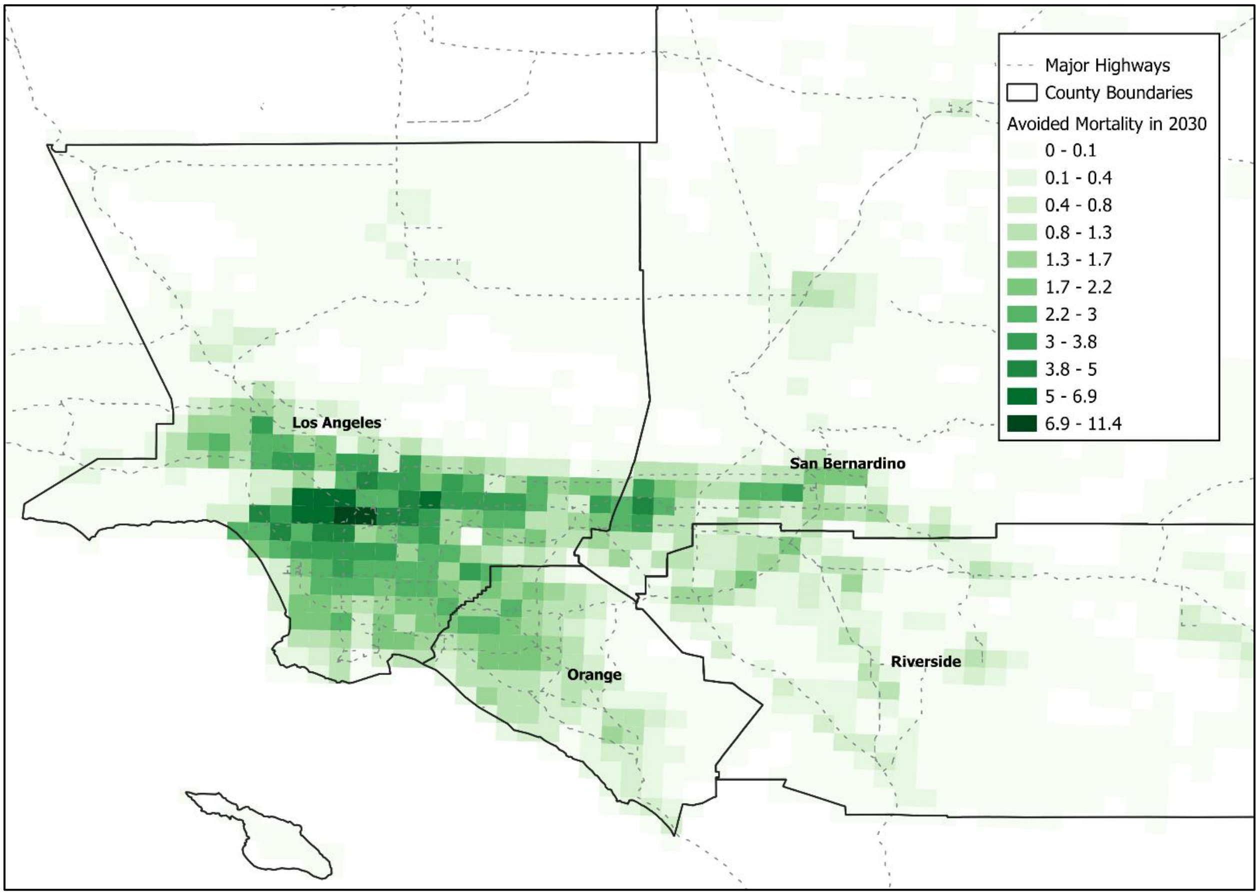
| | 2030 |
|---|---|
| **Premature Deaths Avoided, All cause** | |
| Long-term PM 2.5 Exposure | 665 |
| **Reduced Morbidity Incidence** | |
| **Long term PM 2.5 Exposure** | |
| Asthma, New Onset | 1,031 |
| HA, Alzheimer's Disease | 70 |
| HA, Parkinson's Disease | 28 |
| Incidence, Hay Fever/Rhinitis | 4,867 |
| Incidence, Lung Cancer (non-fatal) | 57 |
| **Short-Term PM 2.5 Exposure** | |
| Acute Myocardial Infarction, Nonfatal | 9 |
| Asthma Symptoms, Albuterol use | 170,343 |
| ED Visits, Asthma | 35 |
| ED Visits All Cardiac Outcomes | 72 |
| ED Visits, All Respiratory Minus Asthma | 172 |
| Emergency Hospitalizations (EHA, Asthma) | 2 |
| HA, All Cardiac Outcomes | 24 |
| HA, All Respiratory | 69 |
| Incidence, Ischemic Stroke | 37 |
| Incidence, Out-of-Hospital Cardiac Arrest | 7 |
| Minor Restricted Activity Days | 230,393 |
| Work Loss Days[2] | 39,204 |

Notes:

1. Each health effect represents the point estimate of a statistical distribution of potential outcomes. Please see the Technical Details section of this Appendix where the 95-percent confidence intervals are reported. The study population of each C-R function utilized can be found on page 3-B-7 of the Final Socioeconomic Report Appendices of the 2022 AQMP: https://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/aqmp-2022-socioeconomic-report-appendices-final.pdf?sfvrsn=6
2. Expressed in person-days. Minor Restricted Activity (MRAD) refer to days when some normal activities are avoided due to illness

Figure 3 displays the geographic distribution of avoided premature mortalities. Mortality risk will be reduced in each of the four counties, with the largest number of avoided premature deaths concentrated in the densely populated Los Angeles County area.

**FIGURE 3: SPATIAL DISTRIBUTION OF ESTIMATED PREMATURE DEATHS AVOIDED (YEAR 2030)**

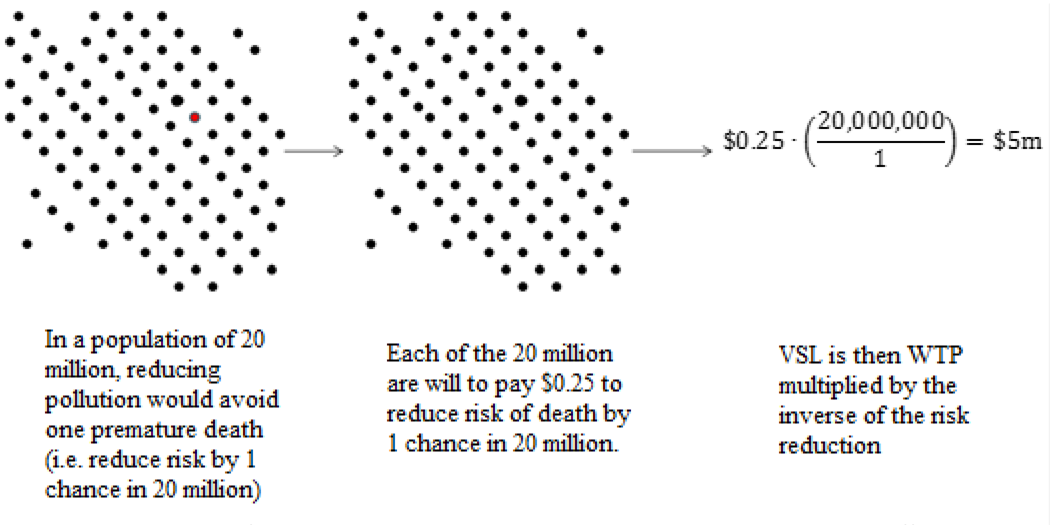


It should be noted that the health effect estimation does not use a concentration threshold below which the affected population would stop benefiting from further reduced exposure to ambient air pollution. In the analysis, health benefits will continue to accrue due to reduced exposure at all levels of pollutant concentration, even at levels below the latest NAAQS. This practice was recommended by Industrial Economics, Inc. and based on the latest scientific evidence, including those summarized in the ISAs (U.S. EPA 2019; U.S. EPA 2020). It is also consistent with the current analytical approach adopted by the U.S. EPA in its regulatory impact analyses (U.S. EPA 2021).

## Monetized Health Impacts

After the health effects are quantified, they are then translated into dollar values using two types of valuation methodologies. Benefits associated with avoided premature deaths are monetized based on a population's willingness-to-pay (WTP) for a small reduction of mortality risk in a year and generally expressed as the "value of statistical life (VSL)." As illustrated in Figure 4, the concept of VSL does not place a monetary value on saving a life with certainty; instead, it is an aggregate WTP of a population so that the associated risk reductions across this population are statistically equivalent to one case of premature death avoided. Then, the total monetized benefits of avoided premature deaths are calculated by multiplying the number of estimated premature mortalities reduced by the VSL.

**FIGURE 4: ILLUSTRATIVE EXAMPLE OF VALUE OF STATISTICAL LIFE**



Source: U.S. EPA, modified by Industrial Economics, Inc. and South Coast AQMD staff

To monetize reductions in morbidity risk, WTP is the preferred valuation method, but in many cases when such estimates are not yet available or reliable, cost of illness (COI) avoided were used instead. Avoided COI is conceptually regarded as a conservative estimate of monetized health benefits, as it only accounts for avoided resource costs including direct medical costs and indirect productivity losses, but generally cannot fully account for the benefits of preventing pain and suffering associated with health-related issues.

As shown in Table 4, the overall quantifiable and monetized annual public health benefits are estimated to be $9.0 billion[3] in 2030. About 99 percent of these public health benefits are attributable to mortality-related benefits. The estimates are based on a VSL of $12.4 million in 2023 dollars and the assumption that the WTP for mortality risk reductions will increase as per-capita income grows. Specifically, a one percent increase in income is assumed to raise VSL by 1.1 percent (i.e., an income elasticity of 1.1) (Industrial Economics and Robinson 2016a). Additionally, this estimate includes a cessation lag, which accounts for the timing differences between emission reductions and realized health benefits[4]. A more in-depth discussion, as well as sensitivity and uncertainty analyses regarding these public health benefits estimations, can be found in the Technical Details section of this Appendix.

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[3] Reported in 2023 US Dollars

[4] Consistent with South Coast AQMD practices, the cessation lag relies on a discount rate of 4% to discount the value of future benefits resulting from current-year emissions reductions.

**TABLE 4: MONETIZED PUBLIC HEALTH BENEFITS in 2030 (BILLIONS OF 2023 DOLLARS)**

| Endpoint Category | Monetized Benefit |
|---|---|
| Mortality-Related Benefits | $8.84 |
| Morbidity-Related Benefits | $0.13 |
| **Total** | **$8.97** |

The analysis is careful in avoiding potentially double counting health effects by using C-R functions that minimize overlapping health endpoints for the same age group or by subtracting health benefits from a health endpoint that could be potentially part of benefits associated with another broader health endpoint (for example, the avoided ED Asthma benefits are deducted from the avoided ED All Respiratory benefits). However, it needs to be emphasized that the health benefits presented here likely underestimate the total actual health benefits. This is because not enough information is currently available in scientific literature to allow for all adverse health effects identified to be measured and valued in dollars, mainly because sufficient data are not available to establish a quantitative relationship between these pollutant levels and some of these health effects.

Moreover, improved public health can generate direct economic benefits other than increased productivity and fewer lost workdays in the short-term. As an example of other health benefits that can occur, but are not quantified here, a 2017 study (Isen et al. 2017) showed that improvement in early childhood health has long-term economic benefits throughout adulthood. Reductions of in-utero and early-infancy exposure to air pollution were found to increase labor participation among the affected individuals 30 years later; that is, working-age adults are more likely to hold a job when they were less exposed to air pollution as an infant.

# Other Public Welfare Benefits

NAAQSs for criteria pollutants, set pursuant to the federal CAA, include both primary standards designed to protect public health and secondary standards to protect public welfare, including preventing damage to agriculture, ecology, visibility, buildings, and materials. In the previous section, the estimated public health benefits associated with the PM2.5 Plan for achieving attainment of the 2012 Annual PM2.5 Standard were discussed. The P2.5 Plan is additionally expected to provide benefits protective of public welfare. Although these additional benefits are not specifically quantified in this Appendix, a qualitative description of these public welfare benefits is provided. In addition, a discussion of the benefits estimated for these categories as described in the Socioeconomic Reports of previous AQMPs and the scientific literature that provided the methodological basis for quantification is included.

## Material Benefit

Material benefit is the benefit accrued by the reduction of damage to materials from air pollution. Studies have identified the types of damage that can occur from air pollution and estimated their monetary value. For total suspended particulate matter (TSP) in particular, it causes accelerated wear and breakdown of painted wood and stucco surfaces of residential and commercial properties (Murray et al. 1985). In addition, TSP leads to additional household cleaning costs due to soiling damages (Cummings et al. 1985).

In addition to these damages, a link exists between several pollutants (ozone, sulfur dioxide, PM2.5, and

NOx) and ferrous metal corrosion; erosion of cement, marble, brick, tile, and glass; and the fading of fabric and coated surfaces (Cummings et al. 1985; Murray et al. 1985). The damage and conversely the potential benefits from reducing the exposure to these items currently cannot be quantified and valued in dollars.

There will also be benefits of reduced damage to materials as a result of the PM2.5 Plan, which will reduce PM2.5 and correspondingly TSP. However, these material benefits are not quantified in this report. In 2013, South Coast AQMD contracted with Abt Associates Inc. to review the South Coast AQMD socioeconomic assessments for AQMPs with the goal of providing recommendations that could enhance South Coast AQMD's socioeconomic analyses[5]. In this report, Abt Associates recommended against quantifying material benefits until a systematic literature review of current research on this topic could be conducted, as the studies which South Coast AQMD relied upon in previous AQMPs to quantify material benefits were outdated.

## Visibility Benefit

Visibility benefits are the benefits individuals place on the ability to see distant vistas, in places where they live, work, and travel. In qualitative terms, an example of this for the Basin is the value people place on being able to see the San Gabriel Mountains, which were designated a National Monument, from much greater distances, more often. Studies have found that individuals place a monetary value on being able to see distant vistas (Smith and Osborne 1996). A local study by Beron et al. (2001), which estimated parameters that could quantify the value of these visibility benefits,[6] was applied to valuation of the visibility improvements of previous AQMPs. The visibility benefit of the 2007 AQMP was projected to be $5.2 billion (in 2000 dollars) for the year 2020, and $649 million (in 2005 dollars) as a result of the 2012 AQMP for the year 2023. The larger benefit from the 2007 AQMP is due to a greater reduction of PM2.5 concentrations than those achieved in the 2012 AQMP.

There will also be benefits to visibility because of the air quality improvements achieved from implementing the PM2.5 Plan. However, quantification of these benefits was not performed in this analysis based on a recommendation in the Abt report which argued that the local study used to monetize the visibility benefits in previous AQMPs had shortcomings and was outdated;[7] therefore, an updated methodology is needed to accurately estimate these benefits. This methodology update is planned for socioeconomic impact assessments conducted for future AQMPs.

# Technical Details

## Methodology

The methodology employed to quantify public health benefits consists of several components. The first component is the health impact analysis as presented in Figure 5. This analysis is based on the use of a health impact function to estimate the change in incidence of a particular endpoint which results from a

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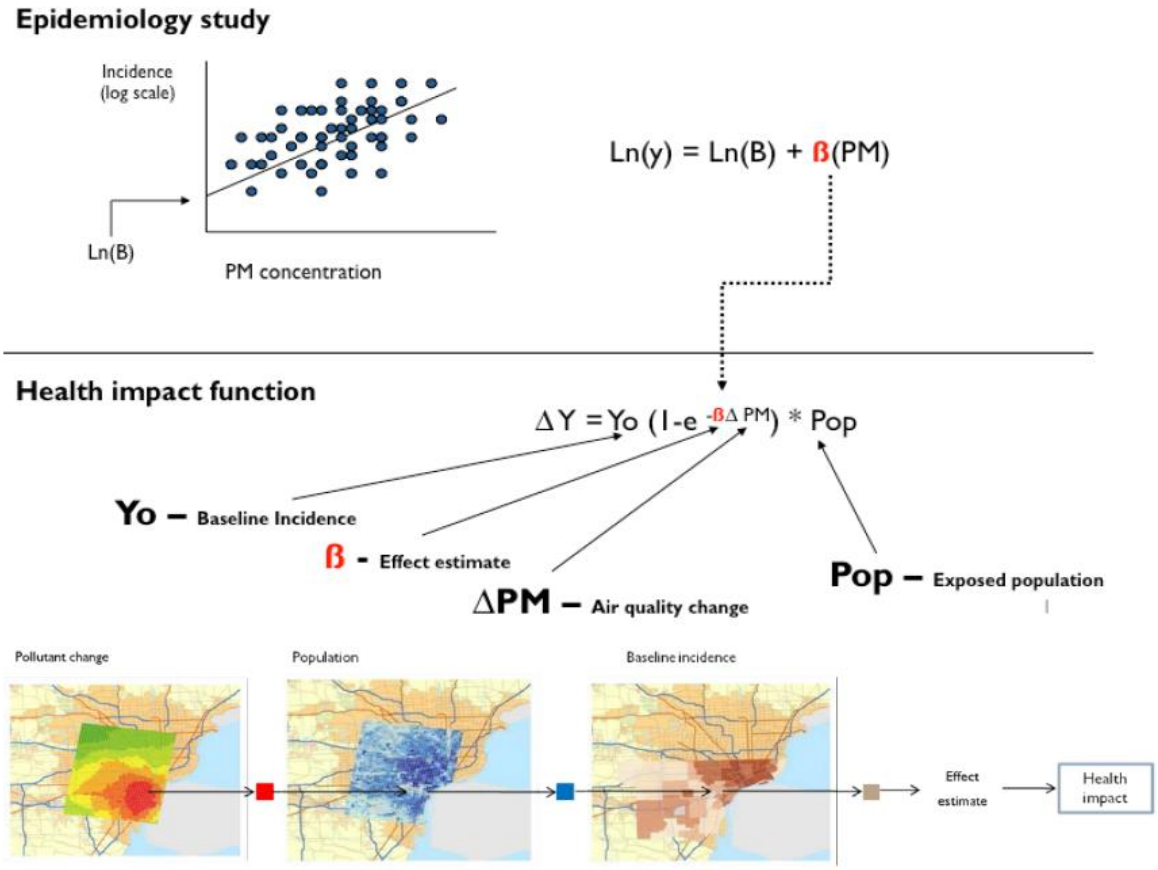
[5] Abt Associates Inc, August 2014, Review of the SCAQMD Socioeconomic Assessments, https://www.aqmd.gov/docs/default-source/Agendas/aqmp/scaqmd-report---review-socioeconomic-assessments.pdf, accessed April 5, 2024.

[6] This study used a method called hedonic price analysis, which uses property values along with a diverse set of attributes to estimate the implicit prices of attributes that are associated with a good exchanged in the market.

[7] The methodological improvements since Beron et al. (2001) was published addresses issues such as endogeneity in spatial sorting of communities, choice of functional form for the econometric model, and the difficulty of measuring amenities from available data that are likely present in that research.

change in air quality. The variables in the analysis include: 1) the change in air quality concentrations; 2) baseline incidence rates for each endpoint; 3) population exposed to a particular health risk; and 4) an effect estimate. The effect estimate is derived from epidemiology studies, which use health and air quality data to estimate C-R functions which relate the concentration of PM2.5 to a mortality or morbidity endpoint. With all of these data taken together, the health impact function can be evaluated to estimate the health effect for a given geographic unit. In the case where there are multiple different C-R functions in epidemiology literature that need to be considered, a pooling method can be used. Pooling allows for a calculation of change in incidence of particular endpoint using multiple effect estimates from different epidemiology studies combined together. Once the health impacts have been estimated (pooled or un-pooled), a valuation function is applied, which places a monetary value on the change in incidence of a given endpoint which is either a scalar value or a distribution of values for a given type of incidence. The valuation function can also be pooled together to account for differences among valuation studies.

**FIGURE: 5: HEALTH IMPACT METHODOLOGY**



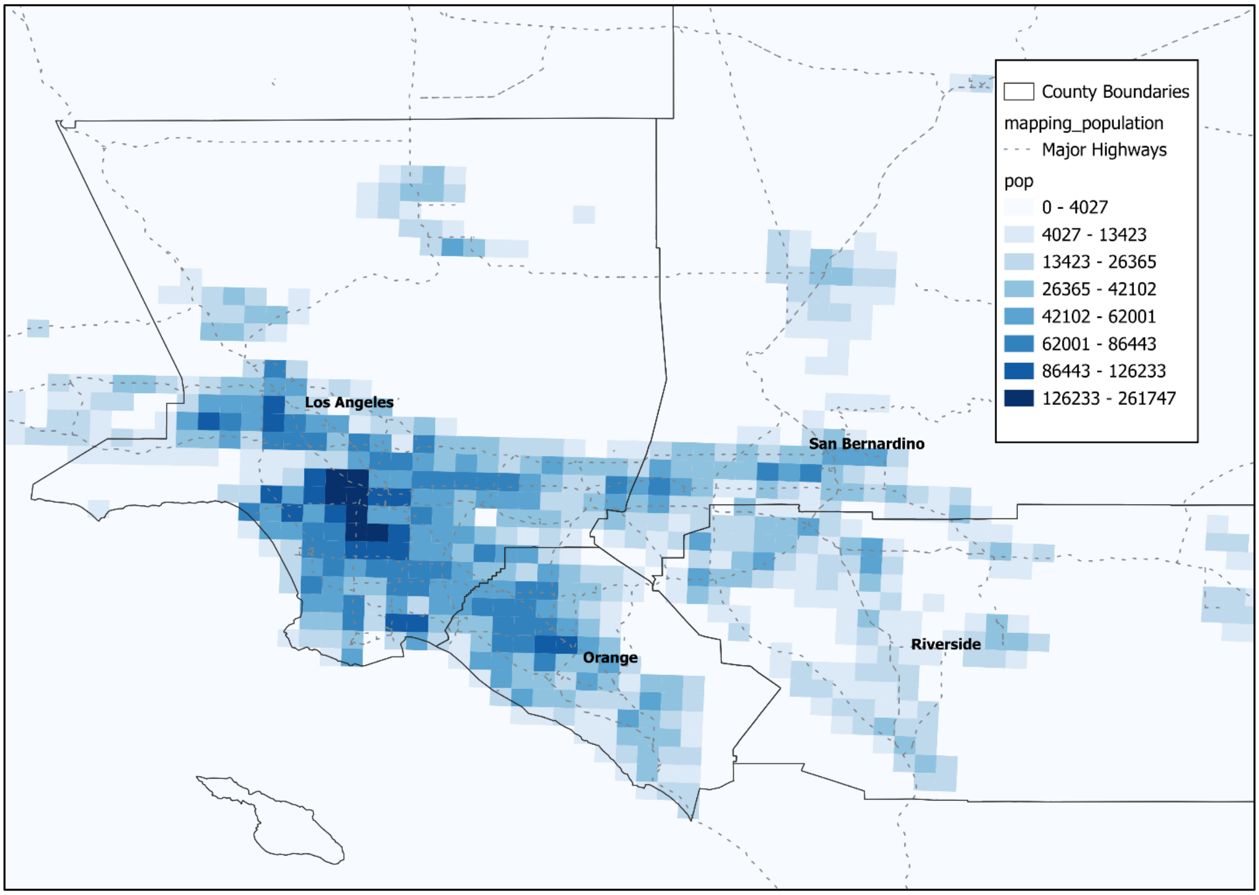
Source: BenMAP CE User's Manual, U.S. EPA

## Data

The first input into the health impact calculation is the projected changes in PM2.5 concentrations, which are derived from the difference between the "control" and the "baseline" air quality scenarios, or the scenarios with and without the 2024 attainment plan respectively. The projected baseline and control air quality scenarios are the result of emission inventories (see Appendix I of the PM2.5 Plan) and air quality simulations developed by South Coast AQMD staff based on these emission inventories and other variables (see Appendix II of the PM2.5 Plan). These air quality projections are produced at the level of a 4km x 4km grid for the Basin. The projections are hourly for each modeled year and consist of 365 days for PM2.5. These hourly data are converted into daily metrics of air quality changes for PM 2.5 (daily 24-hour mean), then loaded into BenMAP-CE for analysis.

The population projections in 2030 as displayed in Figure 6 are based on the 2020 RTP/SCS growth forecast (SCAG 2020) that were provided by SCAG staff at the 4km x 4km grid-cell level. For the purposes of this analysis, SCAG staff converted the population forecast, originally modeled at the level of Transportation Analysis Zones (TAZs), to the 4km x 4km grid-cell used for air quality modeling.

**FIGURE: 6: PROJECTED POPULATION IN 2030**



Due to the substantial amount of time required to produce updated incidence projections at the 4km grid level and the small changes in incidence across multiple years, the analysis relied upon the projected incidence rates for the year 2032 which had been produced for the 2022 AQMP. Since incidence rates for the health endpoints studied are projected to decline over time, the choice to use rates from 2032 will result in a smaller, and thus more conservative, estimated health effect than if rates from 2030 were used. Baseline all-cause mortality incidence rates are provided by the California Department of Finance (DoF) at the county level, by five-year age group, for the base year 2018 and projected through 2032. Historical baseline respiratory mortality incidence rates are collected from the U.S. Centers for Disease Control and Prevention (CDC)'s WONDER database at the county level, by five-year age group. Historical rates are projected to 2032 using an adjustment factor based on the DoF all-cause mortality projection. Baseline incidence for hospital admissions and emergency department visits are based on incidence rates provided by the California Department of Health Care Access and Information (HCAI) at the zip-code and county-level. County-level estimates of baseline incidence for nonfatal myocardial infarctions and ischemic stroke are obtained from the CDC Interactive Atlas of Heart Disease and Stroke. Baseline incidence rates for new onset of asthma in children are provided by IEc for the Los Angeles area for 2002-2005 from the Children's Health Study cohort (McConnell et al. 2010). Baseline incidence for all other endpoints not discussed here are based on the data included with BenMAP-CE.

## C-R and Valuation Functions

The effect estimates for each health impact function are from C-R functions as described in Table 5. Local estimates in the South Coast AQMD four-county region were selected whenever available and meeting other selection criteria recommended by IEc (see Appendix 3C of the 2022 AQMP Final Socioeconomic Report Appendices). The health effect is often estimated as a relative risk (RR), which is the ratio of the probability of an incidence of a particular endpoint in an exposed group to the probability of it occurring in an unexposed group. The RRs from the recommended studies for all-cause mortality from long-term PM2.5 exposure are: 1.14 (Jerrett et al. 2005), 1.104 (Jerrett et al. 2013), 1.17 and 1.14 from Krewski et al. (2009)'s Kriging and land-use regression estimates, respectively.

**Table 5: C-R FUNCTIONS, STUDY POPULATIONS AND VALUATION FUNCTIONS BY ENDPOINT GROUP**

| Endpoint | C-R Function | C-R Function Study Population | Valuation Function ($2015)[1] |
|---|---|---|---|
| ***Long-Term Exposure to PM2.5*** | | | |
| **Mortality, All Cause** | Pooling of: LA-specific estimates (Jerrett et al. 2005; Jerrett et al. 2013), Kriging and LUR (Krewski et al. 2009), Woodruff et al. 2008 (infants only, not pooled). | <1 year; > 30 years | VSL (Robinson and Hammitt 2016). $9.2 million ($4.3-$14.2 million) |
| **Incidence, Asthma** | Pooling of: Tetreault et al. (2016); Garcia et al. (2019) | 0-17 years | $17,232 (Belova et al. 2020) |
| **Incidence, Hay Fever/Rhinitis** | Parker et al. (2009) | 3-17 years | $600 (Soni 2008) |
| **Incidence, Lung Cancer** | Gharibvand et al. (2016) | > 30 years | $33,809 (Kaye et al. 2018) |

| Endpoint | C-R Function | C-R Function Study Population | Valuation Function ($2015)[1] |
|---|---|---|---|
| **Hospital Admissions, Alzheimer's Disease** | Kioumourtzoglou et al. (2016) | > 65 years | Average of: $156,920 (Alzheimer's Association 2020); $184,500 (Jutkowitz et al., 2017) |
| **Hospital Admissions, Parkinson's Disease** | Kioumourtzoglou et al. (2016) | > 65 years | $567,285 (Yang et al. 2020) |
| ***Short-Term Exposure to PM2.5*** | | | |
| **Minor Restricted Activity Days** | B. D. Ostro and Rothschild (1989) | 18-64 years | $70/day (Tolley et al. 1986) |
| **Hospital Admissions, All Cardiac Outcomes** | Pooling of: 7 study location-specific risk estimates (all from Talbott et al. 2014) | All ages | $16,045 (HCUP 2016) |
| **Hospital Admissions, All Respiratory** | Zanobetti et al. (2009); Ostro et al. (2009) | 0-17 years; > 64 years | $9,075 to $35,402 depending on age (HCUP 2016, Chestnut et al. 2006) |
| **Emergency Room Visits, All Cardiac Outcomes** | Ostro et al. (2016) | All ages | $1,161 (HCUP 2016) |
| **Emergency Room Visits, All Respiratory** | Ostro et al. (2016) | All ages | $875 (HCUP 2016) |
| **Incidence, Ischemic Stroke** | Shin et al. (2014) | > 65 years | $33,962 (Mu et al. 2017) |
| **Incidence, Out of Hospital Cardiac Arrest** | Ensor et al. (2013) | > 18 years | $35,753 (O'Sullivan et al. 2011) |
| **Emergency Hospital Admissions, Asthma** | Delfino et al. (2014) | 0-17 years | $6,564 (HCUP 2014) |

| Endpoint | C-R Function | C-R Function Study Population | Valuation Function ($2015)[1] |
|---|---|---|---|
| **Emergency Room Visits, Asthma** | Ostro et al. (2016) | All ages | Average of: $447/visit (Standford et al. 1999); $534/visit (Smith et al. 1997) |
| **Asthma Symptoms, Albuterol Use** | Rabinovitch et al. (2006) | 6-17 years | $0.35/inhaler use (derived from Epocrates.com and goodrx.com) |
| **Work Loss Days** | Ostro (1987) | 18-64 years | $167/day (BLS, 2015) |
| **Acute Myocardial Infarction, Nonfatal** | Wei et al. (2019) | > 65 years | $48,796 to $162,112 depending on age (Sullivan et al. 2011) |

Notes:

The values presented in this table are in 2015 dollars, consistent with the current base year / dollar year in BenMAP-CE. As such, the VSL estimates reported in this table appear to differ from the VSL estimates reported in earlier tables (in 2023 dollars). The built-in functionality in BenMAP-CE was relied upon to adjust all benefits estimates to 2023 dollars.

The valuation functions associated with each endpoint are also described in Table 5. The highest valued endpoint is premature mortality. Avoided premature deaths are valued using the concept of the Value of Statistical Life (VSL). VSL is a measure of the willingness-to-pay (WTP) of a society to reduce the risk of a mortality, aggregated up to the amount of risk reduction required to avoid one statistical death over the population. A range of VSL is recommended by IEc (2016) from $4.3 to $14.2 million, with a midpoint of $9.3 million, all of which are expressed in 2015 dollars and reflect 2013 income levels. These are subsequently adjusted to reflect growth in real income through 2030. This range is found in Robinson and Hammitt (2016) and falls within the range of Viscusi (2015). Avoided morbidity conditions are valued primarily based on the concept of cost of illness (COI) avoided, which includes the cost of healthcare and the cost of lost productivity, though a few endpoints do include a WTP component. The COI and WTP valuations functions for morbidity endpoints are based on recommendations from the IEc Report (2016). It is also recommended that WTP valuations be adjusted for income growth, based on the concept that the income elasticity ($\varepsilon_I$ ) of VSL is positive. The recommended income elasticity for VSL is 1.1 based on Viscusi (2015), with alternatives of 0 and 1.4 presented for sensitivity analyses. An income elasticity of 0.5 is recommended for WTP portions of morbidity endpoints.

Per-capita income growth data for historical years 2013-2022 and projections for 2023-2025 are from the California Department of Finance (DOF). The DOF publishes forecasts of total personal (nominal) income growth, a forecast of the consumer-product index (CPI-U), and a population forecast. Using the inflation forecast to adjust the nominal income forecast and the population forecast, a forecast of real per-capita income growth to 2025 was derived. The post-2025 per-capita income growth is estimated based on the forecasted 2025 total income growth rate and the DOF's population forecast, resulting in an average annual growth rate of per capita income of 1.4 percent.

## Results

Health impacts are categorized into two different types of exposure: short-term PM2.5 exposure, and long-term PM2.5 exposure. Annual health impacts from short-term PM2.5 exposure are calculated as the sum of daily impacts for 365 days of a year. Annual health impacts for long-term PM2.5 exposure are calculated based on the annual average of the mean daily concentrations.

Annual health impacts for all endpoints are estimated with no threshold effects for all types of PM2.5 exposure. This practice is recommended by Industrial Economics, Inc. and based on the latest scientific evidence, including those summarized in the Integrated Science Assessments (U.S. EPA 2019; U.S. EPA 2020).

Pooling methods are used to calculate the annual health impact from pollutant exposure for endpoints where multiple C-R functions are recommended as described in Table 5. The pooling method used in this analysis for overlapping C-R functions is either Fixed Effects or Random Effects as implemented in BenMAP-CE. The choice between using Fixed Effects or Random Effects for pooling is made automatically by BenMAP-CE based on a statistical test evaluated at an alpha of 5% (RTI International, 2015). The independent sum pooling method is used for C-R functions with non-overlapping age-groups.

The mortality and morbidity health impacts and 95% confidence intervals (CIs) based on the recommended C-R functions are shown in Table 6. The lower and upper bounds of the 95% CI are presented in parentheses in Table 6. Reduced long-term PM2.5 levels result in an estimated reduction of 665 premature deaths per year in 2030, as well as fewer school loss days, fewer hospital admissions related to all respiratory causes, and fewer asthma-related emergency room visits.

The valuation of reduced mortality and morbidity incidence is based on the valuation functions described in Table 5, along with an income elasticity and cessation lag. The valuation of avoided premature deaths is based on the recommended VSL and income elasticity as described above, along with a 20-year cessation lag for long-term PM2.5 exposure as recommended by IEc (2016a). Cessation lag describes how the avoided premature deaths from annual exposure are lagged over time, as some health impacts are not fully realized in the same year in which emission reductions occur. For a given emission year, the 20-year cessation lag assigns 30% of the total estimated mortality reduction to that emission year, an additional 13% in each of years two through five, and an additional 1% in each of the following years until the total estimated health benefit is fully realized. Using the estimated health impacts from Table 6, valuations were estimated by multiplying the number of avoided health outcomes in each endpoint by the associated monetized value per occurrence. The total monetized benefit attributed to avoided premature mortalities is $8.8 billion dollars. The monetized value of the various morbidity endpoints is summarized in Table 7, totaling $120.7 million.

### TABLE 6: ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES

| Endpoint | Health Benefit in 2030 (95% CI) |
|---|---|
| **Premature Deaths Avoided, All causes** | |
| Long-term PM 2.5 Exposure | 665<br>(104; 1,237) |
| **Reduced Morbidity Incidence** | |
| **Long term PM 2.5 Exposure** | |
| Asthma, New Onset | 1031<br>(991; 1,073) |
| HA, Alzheimer's Disease | 70<br>(52; 86) |
| HA, Parkinson's Disease | 28<br>(14; 41) |
| Incidence, Hay Fever/Rhinitis | 4867<br>(1,177; 8,405) |
| Incidence, Lung Cancer (non-fatal) | 57<br>(17; 94) |
| **Short-Term PM 2.5 Exposure** | |
| Acute Myocardial Infarction, Nonfatal | 9<br>(6; 13) |
| Asthma Symptoms, Albuterol use | 170,343<br>(-83,009; 413,656) |
| ED Visits, Asthma | 35<br>(6; 63) |
| ED Visits All Cardiac Outcomes | 72<br>(-28; 167) |
| ED Visits, All Respiratory Minus Asthma | 172<br>(4; 296) |
| Emergency Hospitalizations (EHA, Asthma) | 2<br>(0; 4) |
| HA, All Cardiac Outcomes | 24<br>(-167; 120) |
| HA, All Respiratory | 69<br>(37; 99) |
| Incidence, Ischemic Stroke | 37<br>(11; 67) |
| Incidence, Out-of-Hospital Cardiac Arrest | 7<br>(1; 12) |
| Minor Restricted Activity Days | 230,393<br>(186,818; 272,312) |
| Work Loss Days | 39,204<br>(33,054; 45,124) |

**TABLE 7: MONETIZED ANNUAL MORBIDITY BENEFITS**

| Morbidity Endpoint | Monetized Benefits (Millions of 2023 Dollars) |
|---|---|
| **Long term PM 2.5 Exposure (Total)** | **$87.0** |
| Asthma, New Onset | $51.4 |
| HA, Alzheimer's Disease | $13.3 |
| HA, Parkinson's Disease | $17.8 |
| Incidence, Hay Fever/Rhinitis | $3.3 |
| Incidence, Lung Cancer (non-fatal) | $1.3 |
| **Short-Term PM 2.5 Exposure (Total)** | **$33.8** |
| Acute Myocardial Infarction, Nonfatal | $0.6 |
| Asthma Symptoms, Albuterol use | $0.1 |
| ED Visits, Asthma | $0.02 |
| ED Visits All Cardiac Outcomes | $0.1 |
| ED Visits, All Respiratory Minus Asthma | $0.2 |
| Emergency Hospitalizations (EHA, Asthma) | $0.01 |
| HA, All Cardiac Outcomes | $0.5 |
| HA, All Respiratory | $2.3 |
| Incidence, Ischemic Stroke | $1.4 |
| Incidence, Out-of-Hospital Cardiac Arrest | $0.3 |
| Minor Restricted Activity Days | $21.2 |
| Work Loss Days | $7.2 |
| **Total Morbidity Benefits** | **$120.7** |

Note: Totals may not sum due to rounding

## Sensitivity and Uncertainty Analyses

It should be emphasized that, as with all scientific studies and evaluations, there are various sources of uncertainty surrounding the estimated public health benefits, including the uncertainty embedded in data inputs, uncertainty of the C-R functions chosen, and uncertainty of valuation. Given the substantial contribution of mortality-related benefits, two sensitivity and uncertainty analyses were conducted for three major sources of uncertainties in public health benefits estimations.

The first sensitivity analysis considers two sources of uncertainty: alternative VSL and income elasticities. The base VSL of $12.4 million represents the mid-point of the recommended VSL range of $5.8 million to $18.8 million, adjusted for inflation (Industrial Economics and Robinson 2016a). This VSL range is based on a review of peer-reviewed studies on the value of mortality risk reductions and is considered to be reasonable for conducting a regulatory analysis (Robinson and Hammitt 2016). In addition, a lower income elasticity of 0 (i.e., VSL does not change with income level) and a higher income elasticity of 1.4 (i.e., a one percent income growth increases VSL by 1.4 percent) were also recommended to be used in the sensitivity analysis, based on a study by Viscusi (2015). Table 8 shows the range of monetized public health benefits broken down by county, where the lower bound assumes a VSL of $5.8 million and an income elasticity of 0 while the upper bound assumes a VSL of $18.8 million and an income elasticity of 1.4. In 2030, the range of benefits is from $2.8 to $14.9 billion. The lower bound is about 32 percent of the midpoint benefits, while the upper bound is about 169 percent of the midpoint estimate.

**TABLE 8: SENSITIVITY OF MONETIZED PUBLIC HEALTH BENEFITS (BILLIONS OF 2023 DOLLARS)**

| | **VSL = $5.8M** | **VSL = $12.4 M** | **VSL = $18.8M** |
|---|---|---|---|
| **Mortality, All Causes** | $\varepsilon_I = 0.0$ | $\varepsilon_I = 1.1$ | $\varepsilon_I = 1.4$ |
| **By County** | **$2.8** | **$8.8** | **$14.9** |
| Los Angeles | $1.8 | $5.6 | $9.5 |
| Orange | $0.4 | $1.2 | $2.1 |
| Riverside | $0.3 | $0.9 | $1.4 |
| San Bernardino | $0.4 | $1.1 | $1.9 |

Note: Totals may not sum due to rounding

Mortality-related health benefit estimates are also sensitive to the C-R function selected, as this determines the magnitude of the health impact for a given change in air quality. To test the sensitivity of mortality-related health benefits to the recommended C-R functions for long-term exposure to PM2.5, two alternative sets of C-R functions are used to estimate the number of avoided premature deaths. These alternative C-R functions are estimated based on data from larger study populations that are not confined to the South Coast region. Specifically, the analysis includes two different sets of C-R functions as a sensitivity test: the first which pools studies using data from the entire state of California (Thurston et al 2016; Jerrett et al 2013) and the second which pools studies based on nationwide data (Wu et al. 2020, Pope et al. 2019). The two California studies have RRs of 1.03 and 1.01, respectively, and the two National study estimates have RRs of 1.07 and 1.13, respectively. The two sets of C-R functions consider studies conducted at progressively larger geographic scales, generally with larger sample sizes.

Table 9 shows the results of the sensitivity analysis for health impacts using the two different sets of C-R functions, and monetized benefits based on the midpoint VSL and income elasticity in the year 2030. The quantified public health benefits are lower under both alternative sets of C-R functions, ranging from about 61 percent of the main scenario for the national estimates to 19 percent for the California estimates. The key difference between the main estimates and the sensitivity analysis stems from the estimated magnitude of how mortality risk responds to a change in PM2.5 concentration, which is lower in the national and California-wide studies used.

### TABLE 9: SENSITIVITY ANALYSIS OF PREMATURE DEATHS AVOIDED AND MONETIZED BENEFITS ASSOCIATED WITH REDUCED LONG-TERM EXPOSURE TO PM2.5

| Scenarios | Health Impacts (premature deaths avoided in 2030) | Monetized Benefit (Billions of 2023 Dollars) |
|---|---|---|
| Main Scenario<br>(Los Angeles Studies) | 665 | $8.8 |
| California Studies | 123 | $1.6 |
| National Studies | 406 | $5.4 |