Development of Fine-Grained Spatial Resolution for an Integrated Health Impacts Assessment Tool for the Sacramento Region

October 2018

A Research Report from the National Center for Sustainable Transportation

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Disclaimer

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EXECUTIVE SUMMARY

Plans crafted by metropolitan planning organizations (MPOs) lay out how billions of dollars in transportation investments will be made over a 20 to 30-year time horizon. Federal transportation authorizations require MPOs to identify and track key indicators of system performance (e.g. collision rates, emissions, congestion) to ensure that they are stewarding public funds wisely to meet specific goals related to safety, environmental performance, and congestion mitigation, among other areas.

At the same time, there is a growing desire among transportation planning agencies to develop transportation and land use plans that shift travel behavior away from driving and towards more active travel modes. Research has shown that living in areas where walking and bicycling are convenient leads to greater use of those modes, which can lead to improved health outcomes due to increases in physical activity. But increasing non-motorized travel can also increase active travelers' risk of traffic injury and exposure to air pollution. Analytical tools that assess the tradeoffs between transportation plan alternatives are needed to inform public debate and ensure that gains in some health outcomes are not being undermined by losses elsewhere. To fill this need, researchers have developed the Integrated Transport and Health Impact Model (ITHIM), which predicts the public health impacts of transportation and land use scenarios from expected changes in air quality, traffic safety, and physical activity (*14*, *15*).

However, current transportation health impact assessment models (including ITHIM) that operate at coarse geographic scales (e.g. region or county) to quantify health changes are unable to illuminate questions about who will benefit from plans that promote increases in active travel.

The aim of this project is to build on previous work using a Sacramento calibration of ITHIM to generate demographically explicit health outcomes (*16*) to provide neighborhood-level estimates of public health changes predicted from transportation plan scenarios. The project is demonstrated by investigating the spatial distribution of public health impacts resulting from a regional transportation plan in the six-county Sacramento Area Council of Governments (SACOG) region. This report summarizes findings related to our two key goals:

1. **Employ a refined version of the Integrated Transportation Health Impacts Model (ITHIM) to quantify health impacts resulting from the 2016 SACOG Metropolitan**

Transportation Plan/Sustainable Communities Strategy. We adapt ITHIM to produce estimated changes in death and disease burden at a fine grained spatial resolution. Results are presented as totals (to indicate the magnitude of impacts) as well as standardized by age and population (to facilitate comparisons of risks faced by different geographic areas and populations.)

2. **Report on the development of a user-friendly web interface for summarizing ITHIM results**. In response to the requests of various health and sustainability stakeholders in the SACOG Region, we created a web version of our tool that can be used to visualize existing model results. This web interface allows a user to tailor the results shown by scenario.

Our results demonstrate the utility of analyzing and representing the public health impacts of transportation plans in a user-friendly way for planners, policy makers, and advocates. The methodology used in this project can serve as a model for those working on active transportation, public health, and regional equity in other locations across the US.

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Introduction

An important product of the regional transportation planning process is a long-range plan and a short-term spending program. Plans crafted by metropolitan planning organizations (MPOs) lay out how billions of dollars in transportation investments will be made over the subsequent 20 to 30 years. They identify the challenges that a region faces and describe how the plan will help to alleviate those challenges via transportation infrastructure investments and policy strategies. Historically, a single preferred plan was identified through a process of regional consensus-seeking and put forward to the residents of a region before being adopted by an MPO's board. That practice began to change in California, first in Sacramento, and then elsewhere, as agencies and the public increasingly sought to understand how alternative transportation and land use scenarios would affect the performance of the entire transportation system (*1*, *2*). This work was prompted by state policies such as SB 375, California's Sustainable Communities and Climate Protection Act of 2008.

The idea of performance assessment has since become embodied in federal transportation policy (*3*). Moving Ahead for Progress in the 21st Century (MAP-21) Act and its follow-up transportation authorization, the Fixing America's Surface Transportation (FAST) Act both require MPOs to conduct performance-based transportation planning. In other words, they must identify and track key indicators of system performance (e.g. collision rates, emissions, congestion) to ensure that they are stewarding public funds wisely to meet specific goals related to safety, environmental performance, and congestion mitigation, among other areas.

One topic that is increasingly gaining attention is the public health impacts of transportation planning and programming activities (*4*–*8*). In the US, these impacts first became apparent with early air pollution crises during the 1950s in Los Angeles. Since that time, the automobile's contribution to air pollution, and the importance of air quality issues generally in the US, has been declining in importance due to improvements in automotive and fuel technology (e.g., *9*). Risks of death and injury from collisions are another area that have historically been important but have been declining in importance over time as safety technology, seatbelt laws, and driver behavior undergo substantial changes (*10*). Automobile dependence looms large in both types of impacts, but our reliance on the car also influences the level of physical activity that we experience. Research has shown that living in areas where walking and bicycling are convenient leads to greater use of those modes (*11*). But increasing non-motorized travel can also increase injury risk and exposure to air pollution (*12*). Analytical tools that assess the tradeoffs between alternatives are needed to inform public debate and ensure that gains in some health outcomes are not being undermined by losses elsewhere.

The need for such tools is also motivated by an increasing desire among transportation planning agencies to develop transportation and land use plans that shift travel behavior away from driving and towards more active modes (*13*). However, questions remain about who truly benefits from such shifts. Current transportation-health impact assessment models (including ITHIM) generally operate at very coarse geographic scales (e.g. the metropolitan region or a single county) to quantify average health changes across population groups. This scale limits the ability of the tool to provide information about health changes in sub-region or sub-county areas.

The work presented here enhances earlier versions of ITHIM-Sacramento by providing *highly spatially disaggregate* estimates of the public health changes expected to result from plan implementation. This disaggregation increases the utility of the existing ITHIM-Sacramento tool for understanding spatial variations in public health changes. Disaggregation is especially important from both transportation sustainability and transportation equity perspectives to determine the *locations where* the physical activity benefits of non-motorized transportation are outweighed by increased exposure to the risk of air pollution and injury or death.

The aim of this work is to investigate the spatial distribution of public health impacts resulting from a regional transportation plan in the six-county Sacramento Area Council of Governments (SACOG) region. This report summarizes findings related to our two key goals:

1. **Employ a refined version of the Integrated Transportation Health Impacts Model (ITHIM) to quantify health impacts resulting from the 2016 SACOG Metropolitan Transportation Plan/Sustainable Communities Strategy.** We adapt ITHIM to produce results at a fine-grained spatial resolution.
2. **Report on the development of a user-friendly web interface for summarizing ITHIM results**. In response to the requests of various health and sustainability stakeholders in the SACOG Region, we created a web version of our tool that can be used to visualize existing model results.

Our results demonstrate the utility of summarizing the public health impacts of transportation plans and can serve as a model for those working in other locations across the US.

Sacramento Application

Overview

The primary purpose of this work is to enhance previous versions of the Sacramento-region implementation of ITHIM to facilitate spatially detailed analyses of transportation plans. We synthesize data from a range of sources. The ITHIM-Sacramento spatial analysis tool estimates health outcomes from changes in physical activity and traffic injury in the six SACOG counties (El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba), disaggregating results by zip code. We demonstrate the ITHIM-Sacramento spatial analysis tool by evaluating expected health outcomes due to changes in physical activity and traffic injury that are expected under SACOG's 2016 Metropolitan Transportation Plan / Sustainable Communities Strategy (MTP/SCS) scenarios and the adopted plan. Modeled results can be viewed with a user-friendly web tool.

Methods and Data

The fundamental methodological approach employed by ITHIM is known as comparative risk assessment (CRA). In the ITHIM CRA, the relationships between changes in travel behavior and expected health outcomes are obtained from scientific research studies. These general relationships are applied to region and scenario-specific population and travel data to estimate health outcomes that are expected to occur under different transportation plans. Data for the Sacramento ITHIM implementation are compiled from a number of sources describing demographics, transportation behavior, physical activity, traffic injury, and health. Below we provide an overview of the modeling methods. A more detailed discussion of ITHIM-Sacramento methods and results can be found in the "Modeling Health Equity in Active Transportation Planning" working paper posted at https://github.com/aakarner/ITHIM-Sacramento. These estimation methods are similar except that the disaggregation is spatial rather than demographic, as described below.

Scope

To demonstrate the tool, we evaluate health outcomes of the adopted 2016 MTP/SCS for three future years (2020, 2027, 2036) and evaluate outcomes of three alternative scenarios (S1, S2, S3) in 2036. The three scenarios vary in terms of the housing and transportation provisions planned (Table 1). S2 is the "preferred scenario" and is similar to the adopted 2016 MTP/SCS except that the adopted plan has more transit service and slightly more new or expanded roads. S1 includes lower density housing and more emphasis on auto travel than S2. S3 includes higher density housing and a greater emphasis on multimodal travel than S2. All scenario and future year results are presented as a change in outcome relative to 2012, which is modeled as the baseline year.

Table 1: Description of the 2016 MTP/SCS Scenarios. (SACOG 2016)

Transportation inputs	S1	S2	S3	Adopted 2016 plan
New or expanded roads (lane miles, percent increase from 2008)	34%	31%	25%	32%
Transit service (vehicle service hours, percent increase from 2008)	54%	88%	127%	98%
Funding for maintaining and operating the road and highway ($ in billions)	$10.9	$11.5	$11.0	$11.5
Funding for maintaining and operating the transit system ($ in billions)	$7.5	$7.9	$9.6	$7.9
Funding for bike and pedestrian routes, trails and paths ($ in billions)	$2.8	$2.8	$3.0	$2.8
Funding for new or expanded bus and light rail lines ($ in billions)	$3.2	$3.4	$4.1	$3.4

Physical Activity

In the physical activity module, we combine baseline health data, baseline non-transport physical activity data, and baseline and scenario transport-related physical activity to estimate the health benefits of increases in walking and biking that are expected to occur under each plan scenario.

Baseline health data include the overall disease burden for the US (from the 2010 Global Burden of Disease, or GBD, database) and all-cause mortality rates for the Sacramento region (from 2008-2010 California Department of Public Health, or CDPH, vital statistics). We use disability-adjusted life years (DALYs) as a measure of disease burden. Baseline non-transport physical activity data are from the 2005 California Health Interview Survey. Baseline and scenario-specific transport related physical activity are estimated from outputs of SACSIM15, SACOG's activity-based travel demand model. Expected changes in deaths and DALYs due to changes in transport-related physical activity are estimated based on these data and health relationships established in scientific literature.

Traffic Injury

In the injury module, we combine baseline transport injuries and collision rates with baseline and scenario travel distances by mode to estimate the change in collision risks due to changes in walking, biking, and driving. US baseline transport injury rates are from the 2010 GBD database. Sacramento region baseline 2006 – 2016 collision rates are from the Statewide Integrated Traffic Records System (SWITRS) and the Transportation Injury Mapping System (TIMS). Baseline and scenario travel distances by mode are estimated from outputs of SACSIM15. Expected changes in deaths and DALYs due to changes in traffic collisions are estimated based on these data and relationships established in scientific literature.

Disaggregating Estimates by Zip Code

To conduct the fine-grained spatial analysis, we require data for each zip code. We first obtain US 2010 Census population data by age and gender at the zip code tabulation area (ZCTA) for the 151 ZCTAs that are completely within the SACOG region.[1]

Baseline mortality rates are estimated at the ZCTA level by multiplying the population distribution of each ZCTA by Sacramento region-wide rates (as deaths per capita in each age-sex category), where region-wide rates are estimated from the CDPH 2008 to 2010 vital statistics.[2]

Scenario-specific transport-related physical activity for a synthetic population is available at the traffic analysis zone (TAZ) level from SACSIM15 outputs. ZCTAs are larger than TAZs, and most TAZs fall completely within a single ZCTA. Where TAZs straddle more than one ZCTA, residents are allocated to each ZCTA in proportion to the area of overlap.

Non-transport physical activity is estimated at the ZCTA level by multiplying the population distribution of each ZCTA by Sacramento region-wide activity (as non-transport physical activity in each age-sex category), where region-wide activity is estimated from the 2005 California Health Interview Survey.

Baseline injury data from the 2006 – 2016 SWITRS data are stratified by striking and victim modes, severity, and road type. Region-wide injury rates[3] for each combination are applied at the zip-code level in proportion to miles traveled for each mode, where the miles traveled for

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[1] Note that ZCTAs approximate zip code locations but are not exactly the same.

[2] Although we have zip-code level mortality data, when disaggregating by age and gender, which are important factors related to mortality risks, we encounter a small numbers limitation (where observed mortality data are noisy because the population examined is too small). We attempted to estimate zip code-level mortality risks at the ZCTA level using statistical regression accounting for a number of socioeconomic factors but were unable to resolve the model. A request for additional mortality data (spatially detailed and for a longer time period) from CDPH which might be used to improve the statistical regression could not be fulfilled on this project timeline. Future work might explore improving the baseline mortality estimates using regression and/or additional mortality data.

[3] Although injury data are available at specific locations, when they are summarized at the ZCTA level, we observe a small numbers limitation: injury rates equal zero in many areas although we infer that there is a nonzero risk. For example, areas with a risk of 0.05 injuries per year for some combination of striking mode, victim mode, severity, and road type would be expected to have observations of zero in most years.

each mode is obtained at the TAZ level from SACSIM15 outputs and applied to the zip code level using the area-weighting method described above for transport-related physical activity.[4]

Results and Discussion

Below we present maps of estimated health outcomes for each scenario evaluated. We evaluate health outcomes of the adopted 2016 MTP/SCS for three future years (2020, 2027, 2036) and for the three alternative scenarios (S1, S2, S3) in 2036. All results are presented as a change in outcome relative to 2012, which is modeled as the baseline year. Health outcomes are presented as deaths and disability-adjusted life years (DALYs). DALYs are a measure of disease burden that considers both life years lost due to premature mortality and the reduction in quality of life caused by life years spent living with illness-related disability. Both total death and DALY values and death and DALY values standardized by age and population are presented. Total death and DALY values provide insight into the magnitude of the impacts to a particular geographic area or population. Standardized death and DALY values are age-standardized per capita values that account for differences in a population's size and age-gender distribution to facilitate comparisons of the risks faced by individuals in different geographic areas. These standardized values show the risk of death or DALYs assuming identical population and age-gender distributions.

Figures 1 , 2, and 3 show the expected reductions in death for zip codes across the region for changes in physical activity, traffic injury, and both combined, respectively. Note that positive (green) values represent health benefits while negative (red) values indicate health burdens. These maps demonstrate the variation in total death reductions (from physical activity, traffic injury, and combined) in zip codes across the region; variation is driven by spatial differences in population and changes in travel behavior relative to the 2012 baseline. The larger health burdens of traffic injuries under the adopted plan in 2020 (Figure 2) are explained by greater VMT in that year, where more auto travel increases the expected fatalities. Detailed results for total deaths can also be viewed at https://aakarner.shinyapps.io/ITHIM-Sacramento-Spatial/.

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[4] Because the baseline injury is related to both striking mode VMT and victim mode VMT, we consider both ratios in the scaling process as follows:

$$Injury_{ZCTA} = Injury_{RegionWide} \times \left[\left(\frac{VMT_{striking,ZCTA}}{VMT_{striking,RegionWide}}\right)^{m} \times \left(\frac{VMT_{victim,ZCTA}}{VMT_{victim,RegionWide}}\right)^{n}\right]$$

where m and n are set equal to 0.5 representing a safety in numbers relationship. This formulation may be imperfect as it applies the safety-in-numbers concept to a subset of the region (vs. applying it to different scenarios). In this study this formula approximately conserves the total number of fatalities in the region (with a difference of less than 2% when aggregating all zip codes and comparing to region-wide totals). Improvements to the spatial allocation of injury rates could be further explored in future work.

This web interface allows users to view interactive maps of estimated total deaths, while tailoring the results by scenario.

Figures 4, 5, and 6 show the expected reductions in disability-adjusted life years (DALYs) for zip codes across the region for changes in physical activity, traffic injury, and both combined, respectively. As above, positive (green) values represent health benefits while negative (red) values indicate health burdens. These maps reflect similar variation as are shown in the total death Figures (1, 2, and 3).

Figures 7, 8, and 9 show the expected reductions in death *risks* (presented as age-standardized deaths per 100,000 people) for zip codes across the region for changes in physical activity, traffic injury, and both combined, respectively. As above, positive (green) values represent health benefits while negative (red) values indicate health burdens. Figures 10, 11, and 12 show the expected reductions in DALYs *risks* (presented as age-standardized DALYs per 100,000 people) for zip codes across the region for changes in physical activity, traffic injury, and both combined, respectively. As above, positive (green) values represent health benefits while negative (red) values indicate health burdens.

The results standardized by age and population shown in Figures 7 through 12 **Error! Reference source not found.**are an indication of the changes in the risk of death faced by the average resident of each community whereas the total results shown in**Error! Reference source not found.** reflect the changes in impact to each community as a whole (which depends on the average risk to each resident and the total population and its distribution by age and gender). For example, suppose that community A's residents are all in their twenties and community B's residents are all in their sixties and both communities have the same baseline travel behavior and then experience identical changes in travel behavior. The change in total deaths (corresponding to community-level impacts) will be greater in community B while the change in standardized deaths (corresponding to individual-level risks) will be the same in both communities. Similarly, if community C has a population of 10 and community D has a population of 100,000 (and they have the same baseline and change in travel behavior) then the change in total deaths will be greater in community D while the change in deaths standardized by age and population will be the same in both communities. In other words, the community-level impacts will be greater in community D although the change in individual-level risks will be the same in both communities. Thus, standardized estimates facilitate comparisons of the change in risk across communities holding their population size and age-gender distributions constant.

As with the total death reductions and DALYs, the death and DALY *risk* reductions demonstrate variation in zip codes across the region, although the specific patterns of variation differ. This variation is attributable to different changes in travel behavior relative to the 2012 baseline. Traffic injuries again stand out as causing an increased burden under the adopted plan in 2020.

Note that data for one zip code (95966 in Oroville) is excluded from all maps because the Scenario 1 physical activity health burdens are outlying and skew the map legend enough to obscure the rest of the results. This zip code exhibits very large increases total in deaths and DALYs in Scenario 1, which can be traced to a very large increase in walking by elderly female residents.[5]

[5] A large change in physical activity for this group results in very large changes in deaths and DALYs because this group has a very high baseline mortality rate. The large change in physical activity reflected in the data (over 2 hours per person per day in Scenario 1) may be due to a computational error or due to noise in the travel model itself but seems unlikely to reflect actual travel outcomes.

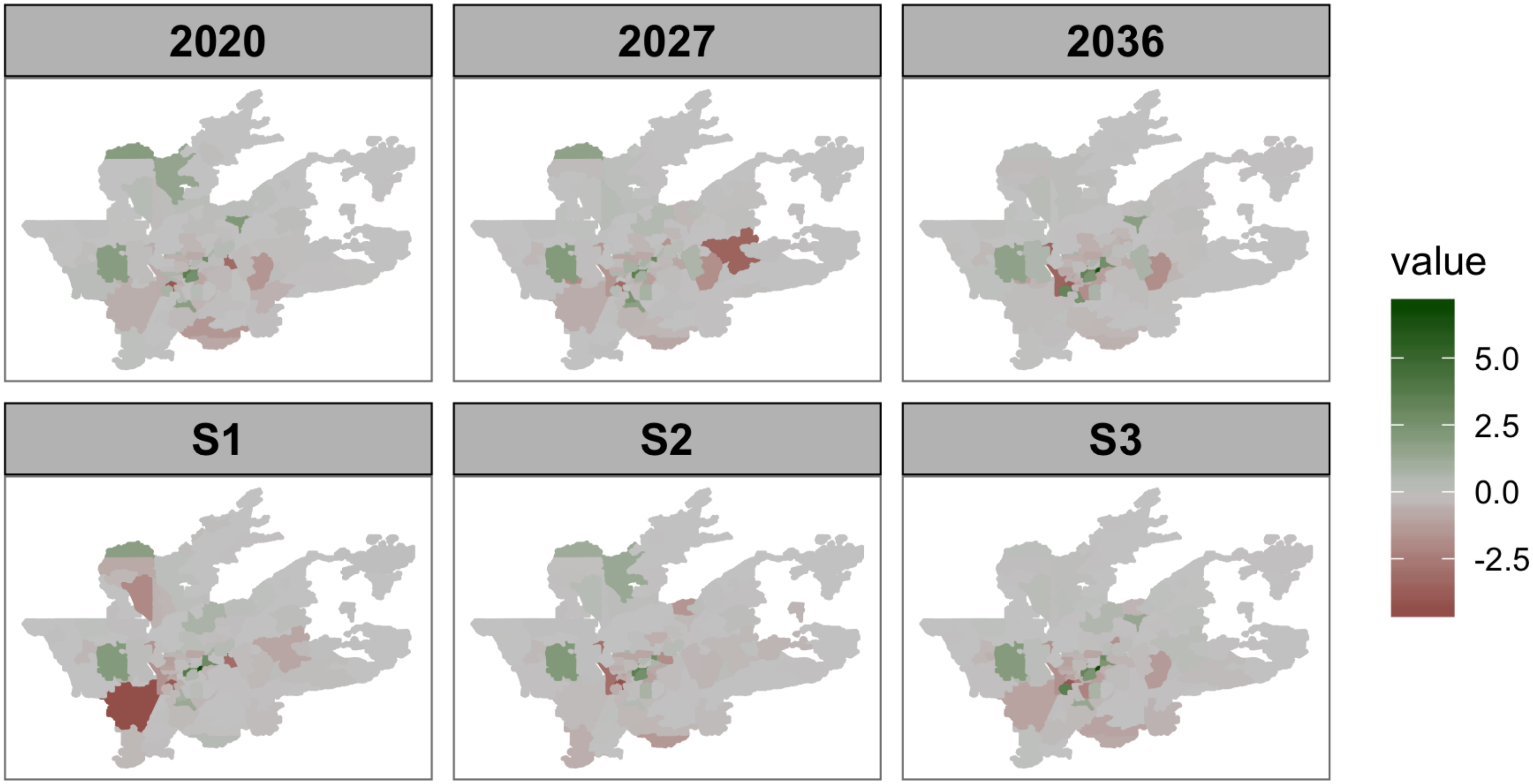

Figure 1: Total Expected Reduction in Deaths from Changes in Physical Activity. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

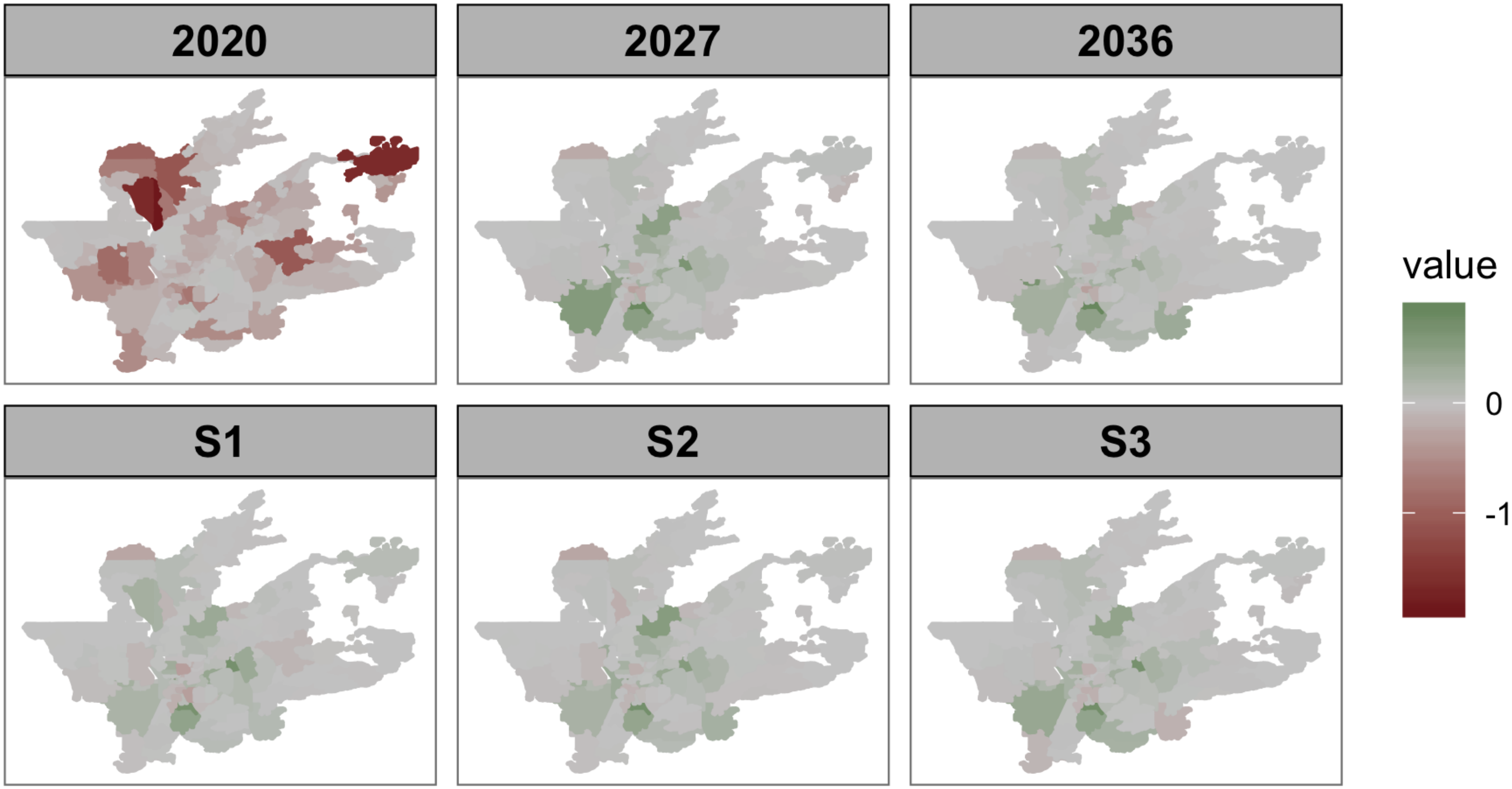

Figure 2: Total Expected Reduction in Deaths from Traffic Injury. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

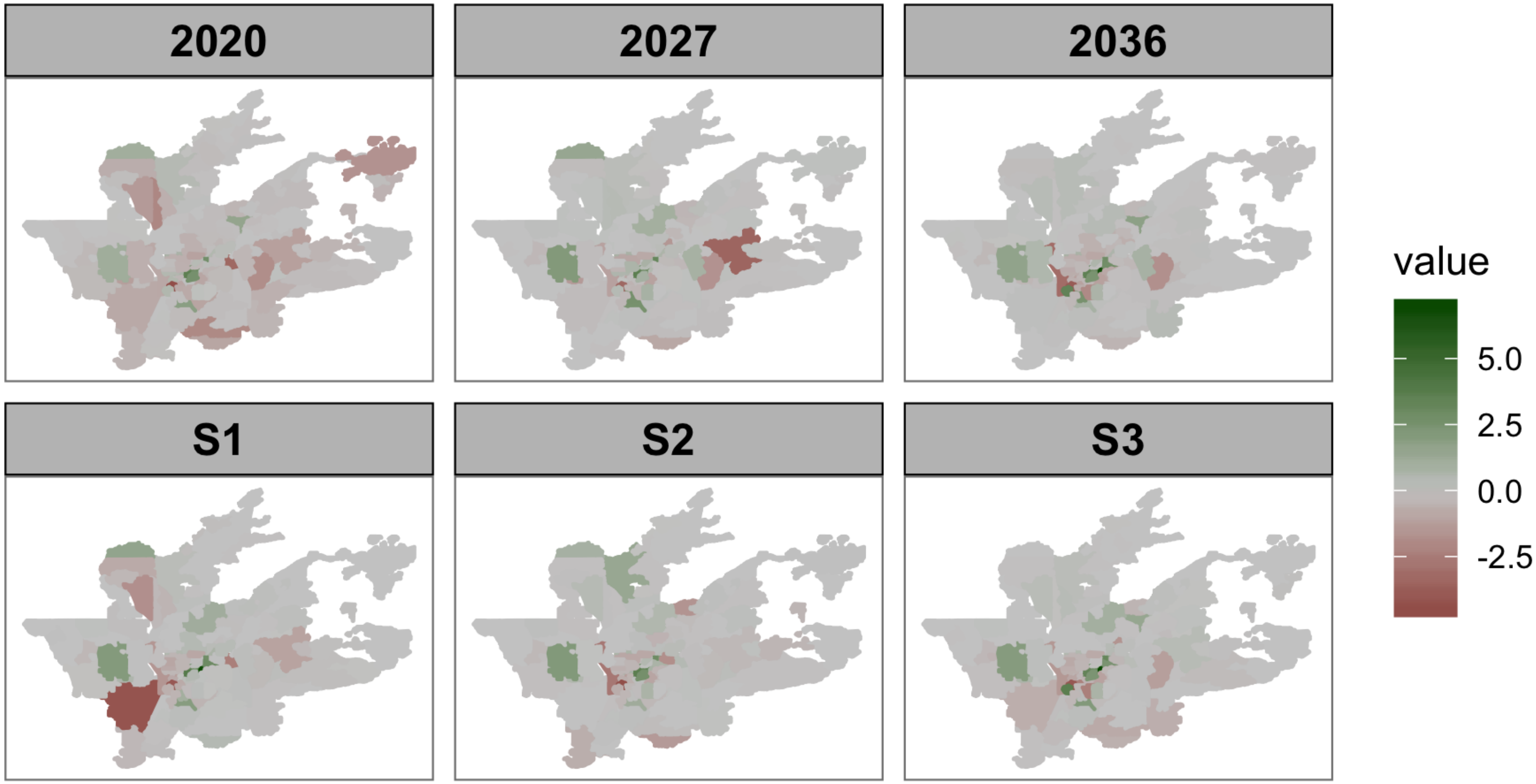

Figure 3: Total Expected Reduction in Death from Physical Activity and Traffic Injury Combined. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

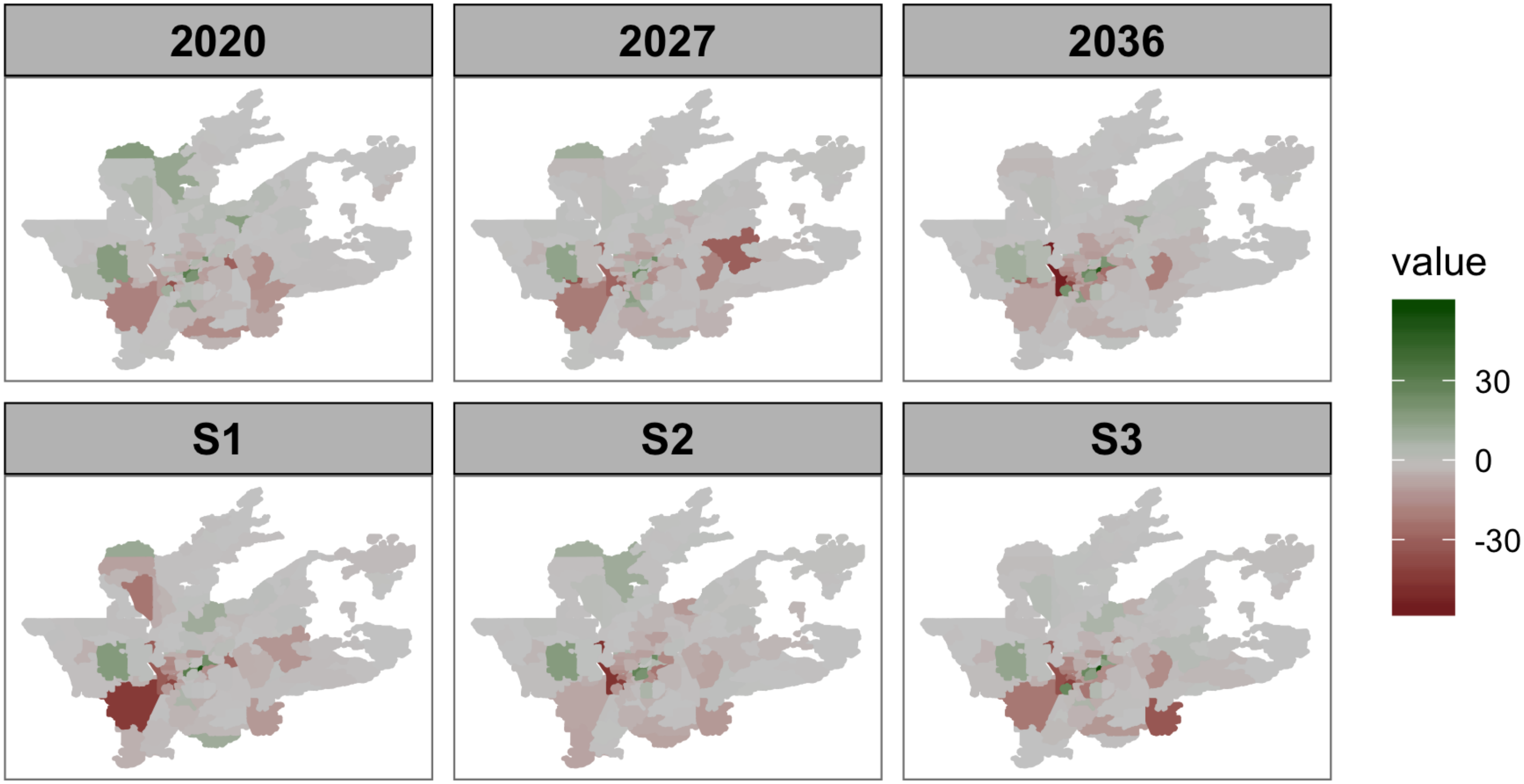

Figure 4: Total Expected Reduction in DALYs from Changes in Physical Activity. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

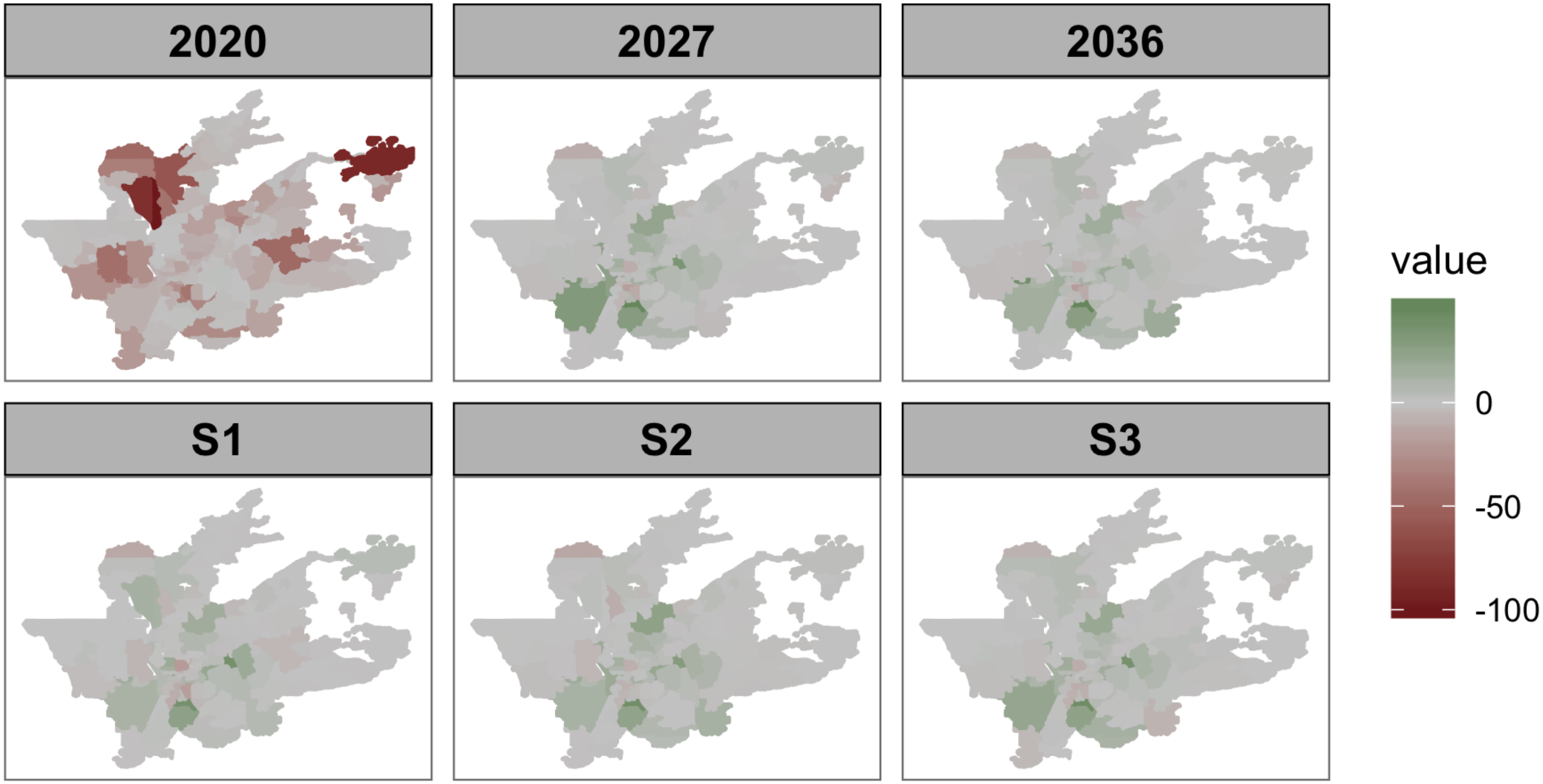

Figure 5: Total Expected Reduction in DALYs from Traffic Injury. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

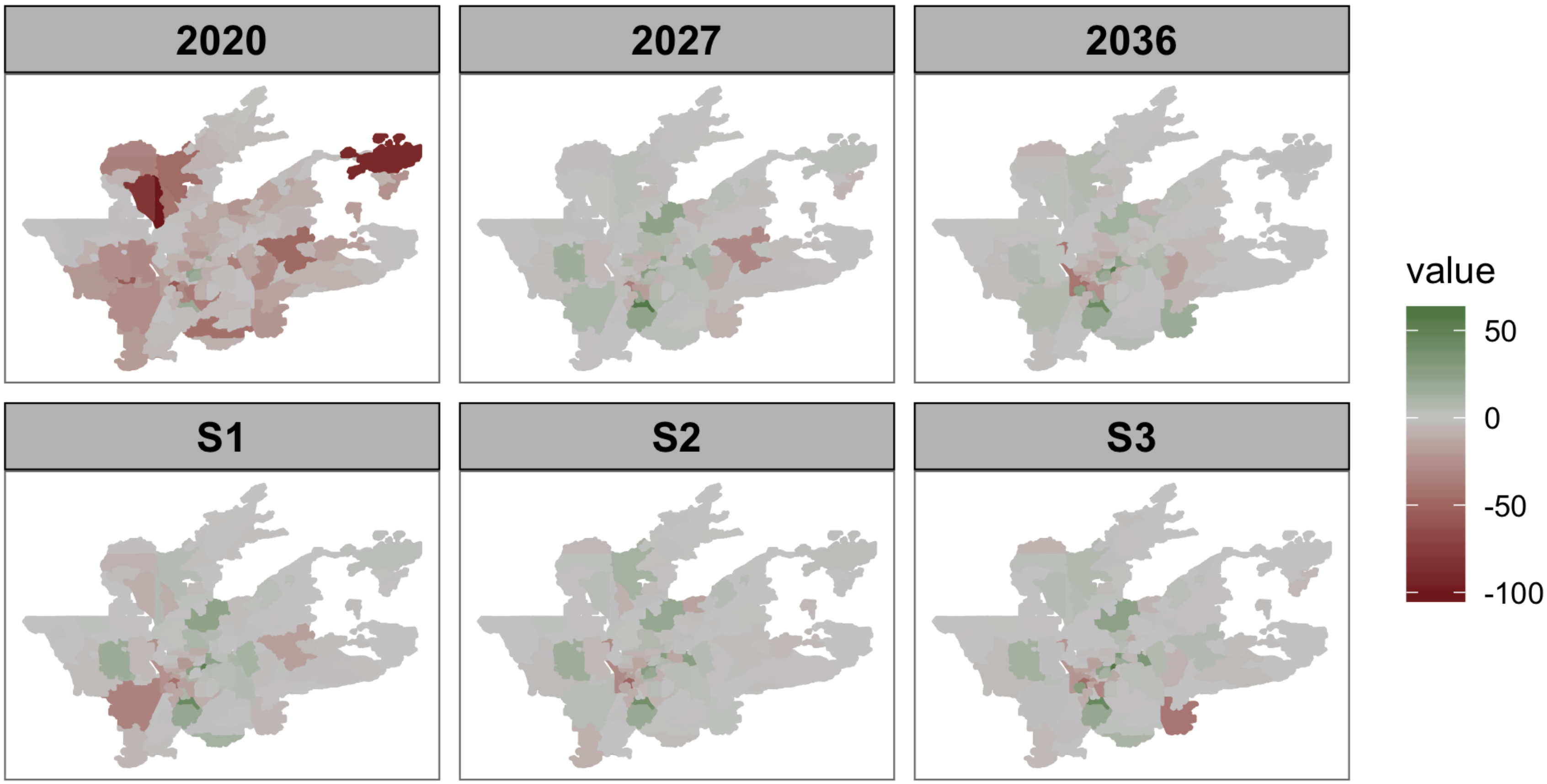

Figure 6: Total Expected Reduction in DALYs from Changes in Physical Activity and Traffic Injury Combined. Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

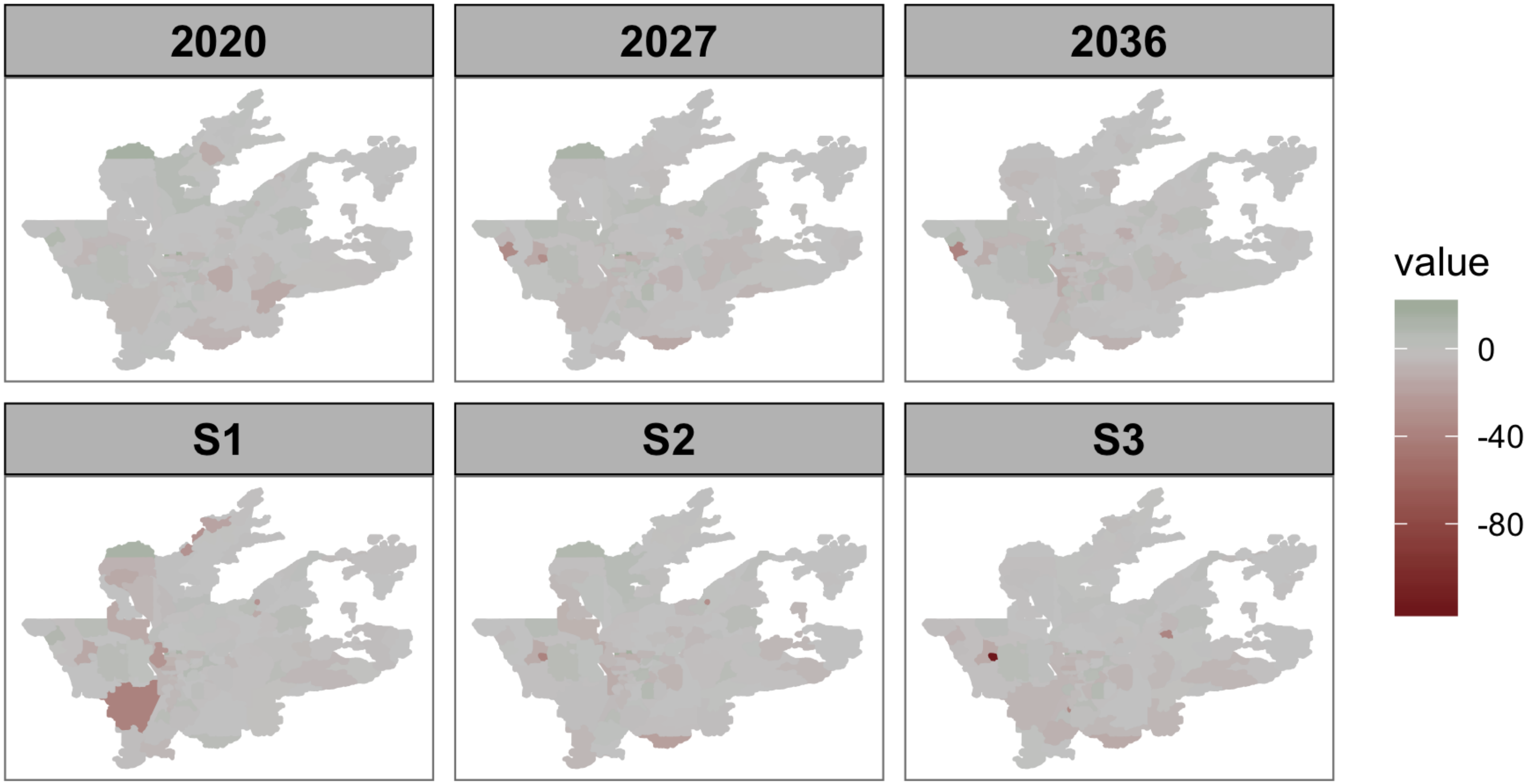

Figure 7: Expected Reduction in Death Risk from Changes in Physical Activity (shown as age-standardized reduction in deaths per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

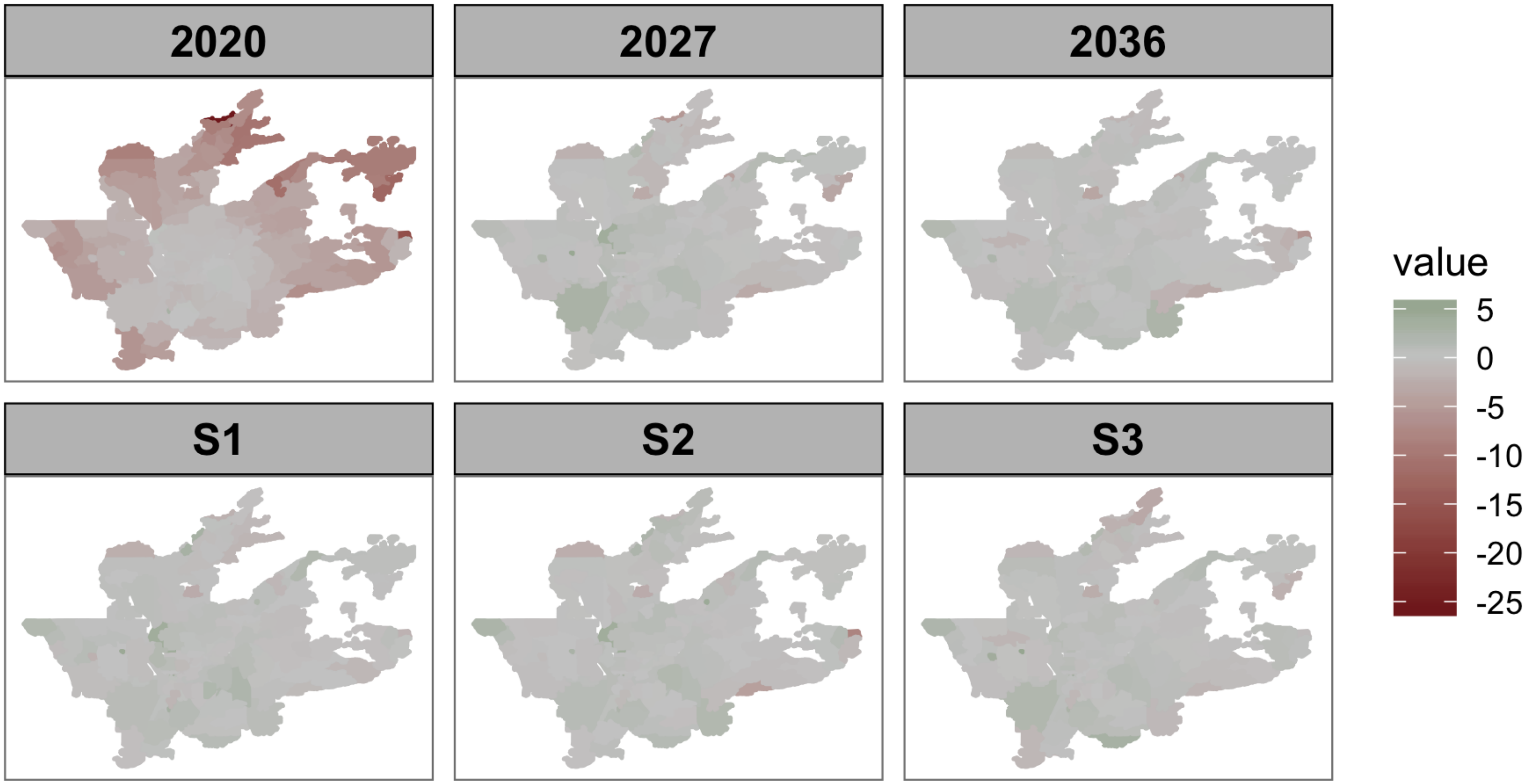

Figure 8: Expected Reduction in Death Risk from Traffic Injury (shown as age-standardized reduction in deaths per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

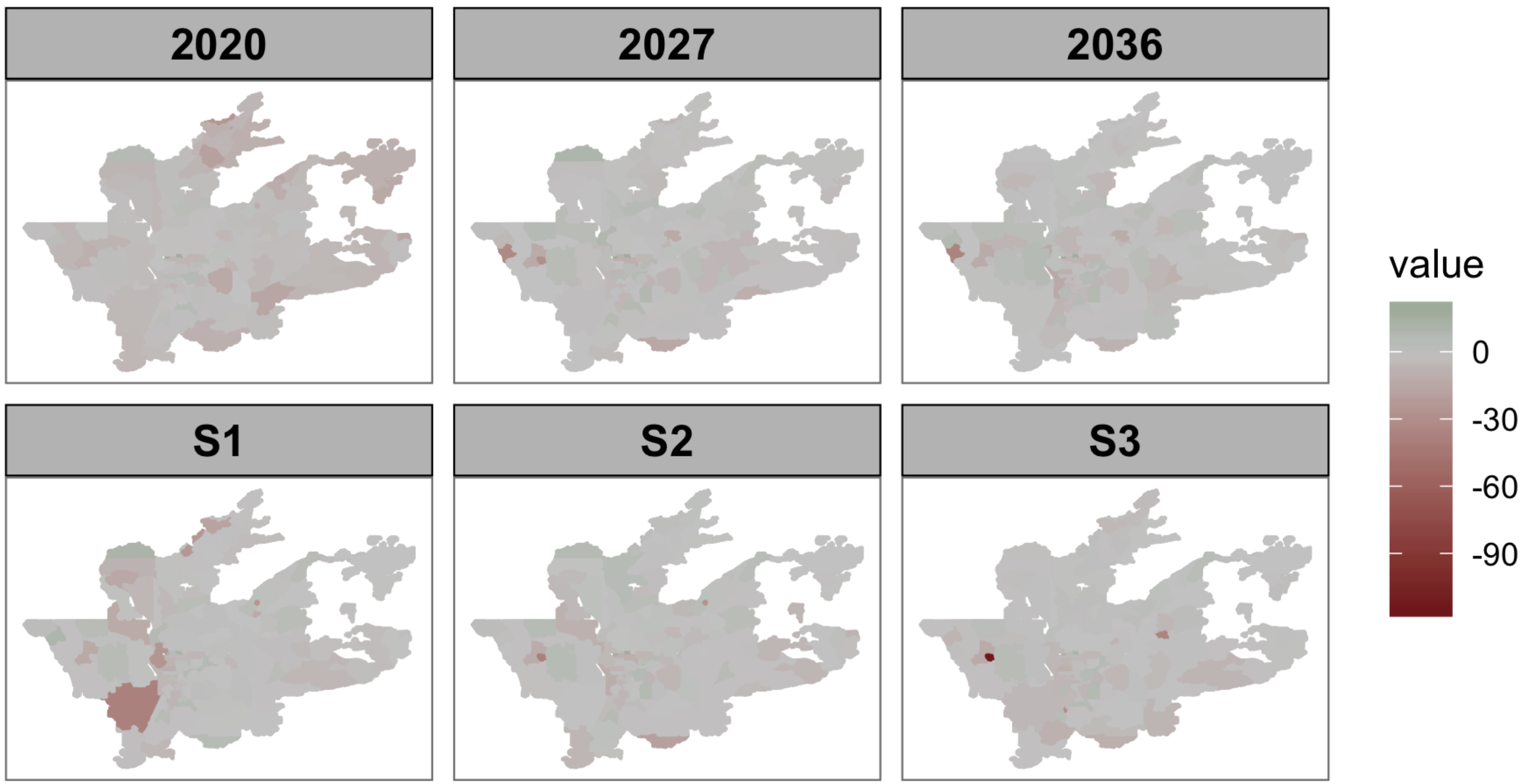

Figure 9: Expected Reduction in Death Risk from Changes in Physical Activity and Traffic Injury (shown as age-standardized reduction in deaths per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

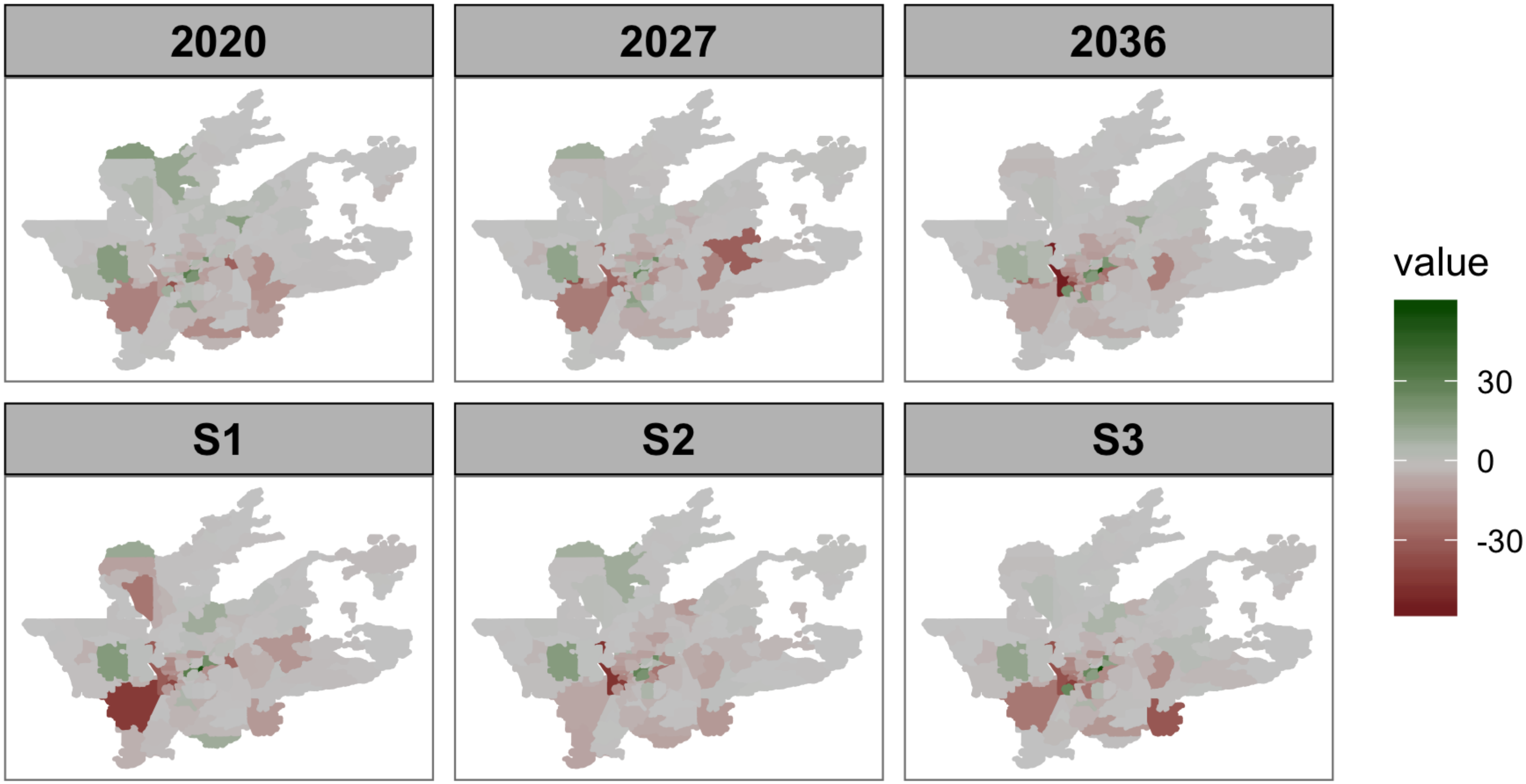

Figure 10: Expected Reduction in DALYs Risk from Changes in Physical Activity (shown as age-standardized reduction in DALYs per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

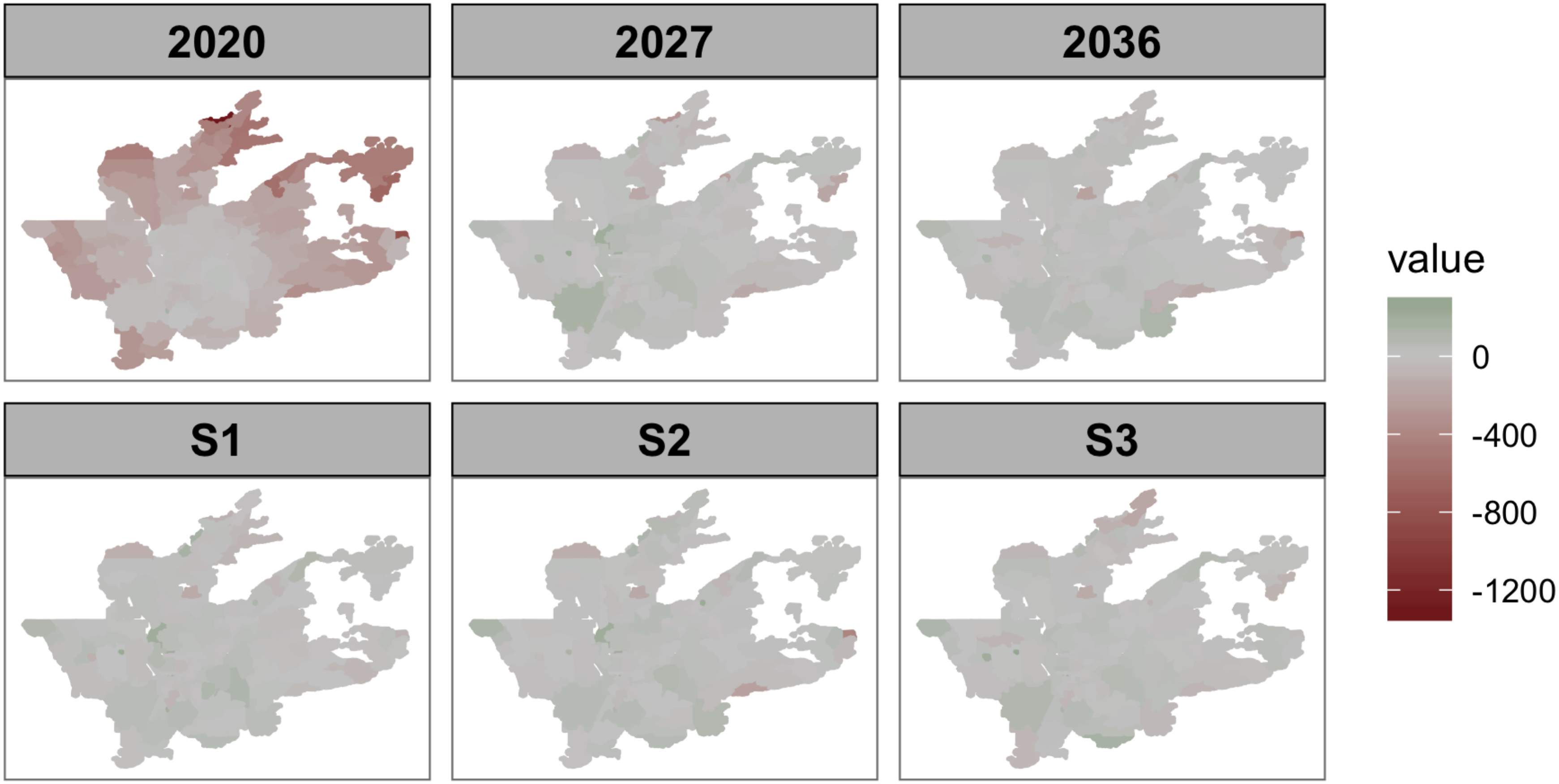

Figure 11: Expected Reduction in DALYs Risk from Traffic Injury (shown as age-standardized reduction in DALYs per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

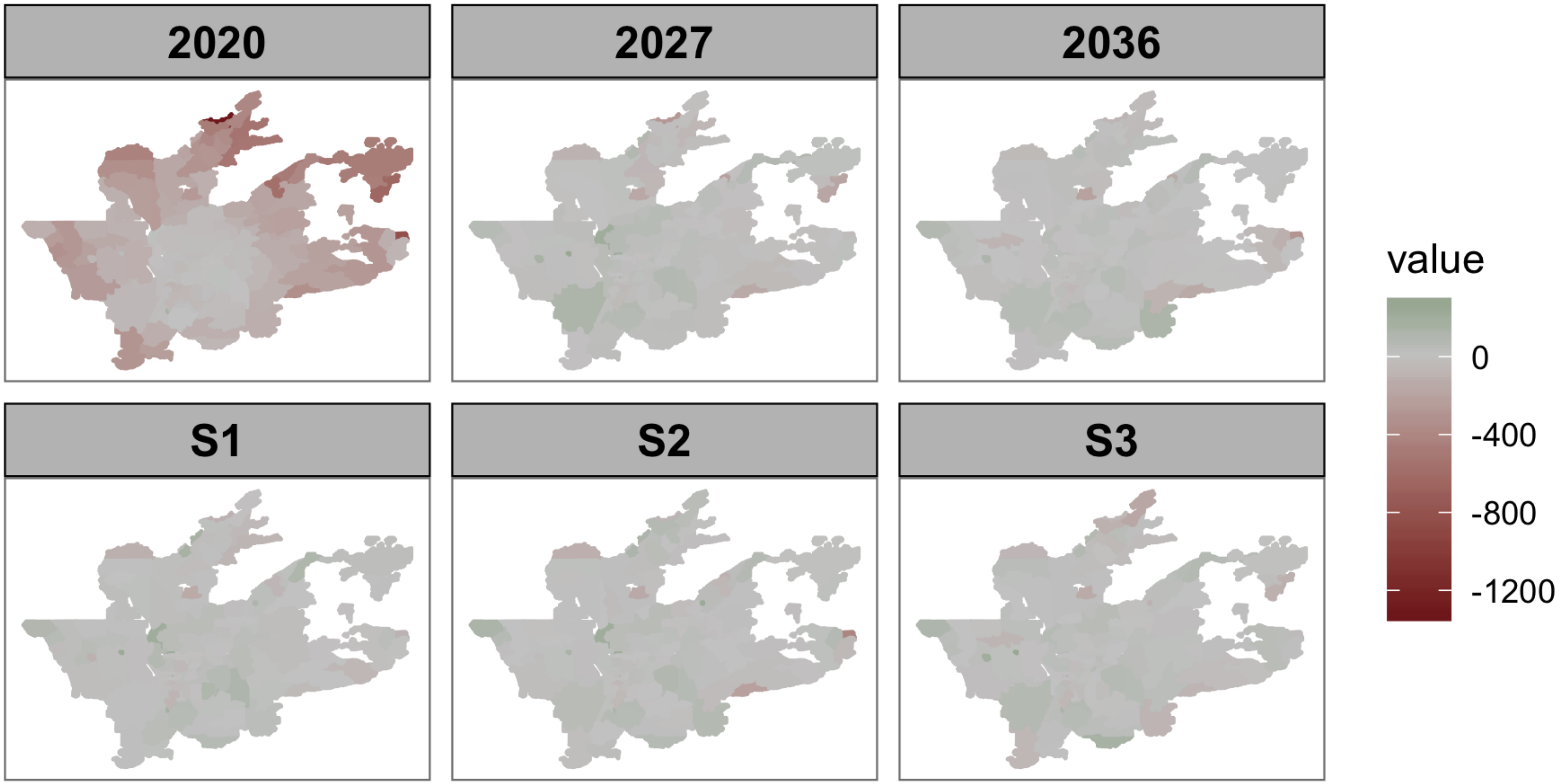

Figure 12: Expected Reduction in DALYs Risk from Changes in Physical Activity and Traffic Injury Combined (shown as age-standardized reduction in DALYs per 100,000 people). Positive (green) values indicate health benefits while negative (red) values indicate worsening health outcomes.

Applications

By helping to visualize the health impacts of different planning scenarios, the ITHIM-Sacramento equity analysis tool can be used by policy makers, planners, and community advocates to develop a shared information base to inform crucial decisions about the region's future. With limited resources, such regional planning often entails trade-offs between different values (e.g., expansion of suburban development vs. densification of urban cores or investments in bicycle and pedestrian infrastructure vs roadway construction). In many cases, the public health impacts of these decisions are either not addressed or addressed too generally to guide decision-making. Furthermore, neighborhood-level impacts are often given limited attention. The ITHIM-Sacramento equity analysis tool can elevate the quality of the civic dialogue about how to build healthy communities and regions and the specific strategies needed to achieve this. It is recommended that leaders in the policy, planning, advocacy, business and philanthropic sectors familiarize themselves with the ITHIM methodology and explore how it can support their work. Ideally, this will occur in collaborative forums hosted by regional entities such as SACOG, the Sacramento Air Quality Management District, or area universities such as UC Davis.

Limitations

The ITHIM-Sacramento spatial analysis tool is limited by the limited availability of fine-grained health and non-transport travel data and the assumptions made in the analysis to overcome those limitations. A sensitivity analysis would shed light on the extent to which these decisions affect modeled outcomes but is beyond the scope of this effort.

Web Interface

Detailed model results can be viewed at https://aakarner.shinyapps.io/ITHIM-Sacramento-Spatial/. The website provides a spatial summary of the changes in health outcomes associated with SACOG's adopted plan in future years and alternative planning scenarios in 2036. Webinar materials describing the project and web tool will be made available and posted at https://github.com/aakarner/ITHIM-Sacramento-Spatial.

Source Code and Model Documentation

All source code and model documentation are available at https://github.com/aakarner/ITHIM-Sacramento-Spatial. This source code can be used to replicate this approach in other regions or to update the built-in values for the Sacramento region.

Conclusions

The ITHIM-Sacramento spatial analysis tool combines the region's health, injury, and physical activity information with research-based relationships about the health outcomes of changes in travel behavior to estimate the health effects of future regional transportation planning scenarios. We demonstrate the ITHIM-Sacramento spatial analysis tool by evaluating expected health outcomes that are expected under SACOG's 2016 Metropolitan Transportation Plan / Sustainable Communities Strategy (MTP/SCS) scenarios and the adopted plan. The estimated health impacts for several communities in the region (broken out by zip code of residence) are presented in this report. Changes in death and disease burden (represented as DALYs) are shown as totals to understand the overall magnitude of the effects. They are also shown as age and population standardized values to facilitate comparisons across geographic areas. Total deaths can also be viewed in a user-friendly web interface that allows a user to specify the scenario shown.

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