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Abstract: In recent years, renewable portfolio standards (RPS), which require a certain percentage of electricity sold to consumers to come from renewable resources, have been established by many state governments to mitigate emissions of greenhouse gases and air pollutants in the United States. Nevada's RPS set a target of 50% of electricity to come from renewable sources by 2030. By coupling the U.S. Environmental Protection Agency's AVoided Emissions and geneRation Tool (AVERT) and CO–Benefits Risk Assessment (COBRA) model, this study assesses potential emission reductions from fossil fuels owing to this requirement and regional health benefits via improved air quality, as well as how these benefits vary spatially under high and low projected electricity demands in 2030. Successful implementation of the RPS could produce health benefits equivalent to USD 3–8 million per year for Nevada residents and up to USD 164 million per year for the entire U.S. Nevada is ranked only 6th among states benefiting from the policy, while California and Washington obtain the most health benefits. There is also inequity among Nevada counties, partly caused by the county population and proximity to major fossil fuel power plants. Lowering electricity demands by 5% in Nevada would lead to a ~10% increase in health benefits. These findings should empower public support of RPS policies and energy conservation to reduce air pollution and public health inequity for the region.

Keywords: RPS; $PM_{2.5}$; AVERT; COBRA; health inequity; health disparity

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1. Introduction

Burning fossil fuels such as coal, oil, and natural gas for energy is the leading cause of overloading the atmosphere with greenhouse gases and air pollutants, such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM). Extensive studies have associated exposure to these air pollutants with increased morbidity and mortality [1]. Electricity generation, transportation, and industry sectors are among the largest fossil fuel consumers in the U.S. and globally. International efforts to curb climate change since the Kyoto Protocol have focused on developing renewable resources, such as solar and wind energy, to substitute for fossil fuels in these sectors. These renewable resources generate little CO_2 while at the same time minimizing emission of co-pollutants into the air, which can produce immediate benefits to public health.

Nevada is a state in the western U.S. with ~3 million population, with three fourths of its population living in the southmost Clark County, which contains the Las Vegas metropolitan area. Nevada was among the first U.S. states that implemented renewable portfolio standards (RPS) to promote cleaner electricity production [2]. In general, an RPS requires electric utility companies to ensure that a certain percentage of electricity sold to customers comes from renewable resources [3]. Currently, twenty-nine states and the District of Columbia have adopted an RPS with varying timing, targets, and qualification requirements [4]. In 1997, the initial Nevada RPS was 0.2%, and target was subsequently increased to 5% by 2003, 15% by 2013, and 25% by 2025 [2]. Nevada Senate Bill 358 was adopted in 2019 to require the state public utility commission to gradually raise the RPS to 22% in 2020, 24% in 2021, 29% in 2022–2023, 34% in 2024–2026, 42% in 2027–2029, and eventually 50% in 2030 and beyond [5]. This requirement was incorporated into the Nevada constitution through direct votes in 2018 and 2020. While the state government conducted fiscal impact assessment for the RPS policies, the public health benefits due to air quality improvement over the region have not been quantitatively assessed.

The health burden due to air pollution is commonly assessed using fine particulate matter with aerodynamic diameter < 2.5 μm (i.e., $PM_{2.5}$) as a surrogate. $PM_{2.5}$ results from nearly all fossil fuel combustions. Besides being directly released into the air as a primary pollution, secondary $PM_{2.5}$ also forms in the atmosphere through chemical reactions involving its precursors such as ammonium (NH_3), SO_2, NO_x, and volatile organic compounds (VOCs) [6]. Inhaled $PM_{2.5}$ can reach the deeper part of the lung, enter the bloodstream, and cause cardiac and pulmonary diseases, including asthma, bronchitis, and ischemic heart disease [7,8]. The World Health Organization estimated 4.2 million premature deaths globally in 2016 from exposure to $PM_{2.5}$ [9], and there has not been a proven safety level for $PM_{2.5}$ that shows no adverse health effects [10].

This study aims to provide the first assessment on the health benefits of implementing a state RPS such as the one in Nevada through reducing emissions of $PM_{2.5}$ and precursors and subsequently exposures to outdoor $PM_{2.5}$ in- and out-side the state. Previous national-level analyses that linked state RPSs with air pollution [11–13] neither included the new Nevada RPS nor evaluated the regional impact of a single state. This assessment considers the interstate electricity trading and transmission as well as the transport/transformation of air pollutants from sources to receptors. Furthermore, since the reduction of fossil fuel electricity consumption also depends on future energy demands, two scenarios that bound the range of economic growth in Nevada were created for this assessment. A non-uniform distribution of the health benefits is expected even within Nevada, while lower energy demands should lead to more health benefits.

2. Approaches

A baseline year of 2019 was considered in this study, from which the emission changes due to the changes in demand and/or displacement of fossil fuels by renewable energy in electricity generation was estimated by the AVoided Emissions and geneRation Tool (AVERT). The AVERT emission reductions provided inputs into the CO-Benefits Risk Assessment (COBRA) model, which assessed air quality changes due to emission reduction, estimated the health impact associated with these changes, and calculated the economic value of the health impact. Both AVERT and COBRA were developed by the U.S. Environmental Protection Agency (U.S. EPA).

- AVERT

AVERT was used in previous health impact studies [14,15]. The web edition of AVERT v3.0 (https://www.epa.gov/avert (accessed on 15 August 2022)) calculates emissions of $PM_{2.5}$, NO_x, SO_2, CO_2, VOCs, and NH_3 released from individual electric power plants across the U.S. in 2019 as the baseline [16]. Based on the changes of electricity demand for fossil fuels within a region or a state, it analyzes changes of electricity generation and associated emissions at the plant level according to inter-state power transmission patterns on the existing grid. It assumes no emissions from added renewable electricity generation. AVERT v3.0 divides the continental U.S. into 14 independent electricity regions and Nevada is part of the Northwest region (Figure 1a). When Nevada's electricity demand is adjusted, AVERT calculates emission changes by state and by county in the entire Northwest region.

- COBRA

COBRA uses source-receptor (S-R) matrices to link emissions of $PM_{2.5}$, SO_2, NO_x, NH_3, and VOCs to annual $PM_{2.5}$ concentrations at the county level [17,18]. The S-R matrices were derived from the Climatological Regional Dispersion Model, which considers key physical and chemical processes of primary and secondary materials that make up $PM_{2.5}$. Emission changes can be inputted into COBRA by county and by sector to estimate changes in $PM_{2.5}$ concentrations and translate those to avoided health outcomes based on pre-established, region-specific exposure-outcome relationships. Finally, the monetary value (in 2017 dollar) of these health outcomes, with the high and low estimates, is determined using a 3% or 7% discount rate to address a lag phase of some health incidences (adult mortality, heart attack, etc.) after exposure to pollutants [19–21]. COBRA v4.0 (https://www.epa.gov/cobra (accessed on 15 August 2022)) was used in this study, which allows three evaluation years (2016, 2023, 2028). For specified emission reductions, the changes in $PM_{2.5}$ concentrations are insensitive to the evaluation year selected. To better estimate health benefits, however, the evaluation year 2028 with population and incidence data closest to year 2030 was selected for this analysis.

- Model Scenarios

Assuming the total electricity demand in Nevada and the renewable fraction of the supply in 2019 are denoted by *E2019* and F_N2019, respectively, the fossil fuel electricity demand would be: $E2019 \times (1 - F_N2019)$. Similarly, the fossil fuel electricity demand in a future year 20XX would be: $E20XX \times (1 - F_N20XX)$. The percentage of fossil fuel demand reduction (*FFDR*%) between 2019 and 20XX is thus:

$$FFDR\% = \left[1 - \frac{E20XX \times (1 - F_N20XX)}{E2019 \times (1 - F_N2019)}\right] \times 100\% \quad (1)$$

This study created two scenarios to bound electricity demands in 2030 (i.e., *E2030*) under high and low economic growth trajectories. The input to AVERT is the total electricity saving (in MWh per year) from energy programs/policies, and AVERT assumes that when the electricity demand is reduced, fossil fuel-fired power plants will be turned off or turned down, but no existing renewable facilities should reflect the changes [16]. Therefore, the percentage of effective demand reduction (*EDR*%) can be related to *FFDR*% by:

$$EDR\% = FFDR\% \times (1 - F_N2019) \quad (2)$$

In a situation where all electricity comes from fossil fuels in 2019, *EDR*% equals to *FFDR*%. *EDR*% was calculated for each scenario as the input to AVERT. The AVERT outputs then served as the inputs to COBRA to calculate health benefits, by county and by state, associated with each scenario.

3. Results and Discussion

- Scenario-specific Model Inputs

Table 1 lists the AVERT model parameters for the low and high economic growth scenarios in Nevada. The increase in electricity demand between 2019 and 2030 (*E2030/E2019*) was based on the Annual Energy Outlook (AEO) 2021 from the U.S. Energy Information Administration [22]. AEO associated economic growth with electricity demand using the National Energy Modeling System and predicted the electricity demand growth rate (2019–2030) to be bounded between 4.65% and 10.44% (see Supplemental Table S1). This is consistent with the Northwest Power and Conservation Council's estimate that the electricity demand growth rate for the Pacific Northwest area was 0.5 to 1.0% per year from 2015 to 2035 [23].

Table 1. AVERT model input parameters for the low and high electricity demand scenarios in Nevada for 2030.

AVERT Scenario	Low Economic Growth/Low Demand	High Economic Growth/High Demand
E2030/E2019	1.047	1.104
F_N2019	0.18	0.18
F_N2030	0.50	0.50
FFDR%	36.2%	32.7%
EDR%	29.7%	26.8%

E2019: Nevada electricity demand for 2019; *E2030*: Nevada electricity demand for 2030; F_N2019: Renewable electricity fraction in 2019; F_N2030: Renewable electricity fraction in 2030; *FFDR%*: Percentage of fossil fuel electricity demand reduction; *EDR%*: Effective electricity demand reduction.

NV Energy is the largest and almost sole electricity provider in Nevada, serving nearly 90% of Nevada customers. In 2019, NV Energy sold 34,132 GWh electricity to retail customers in Nevada through its two branches, the Nevada Power Company and Sierra Pacific Power Company [24]. While electricity generated by the companies nearly entirely resulted from fossil fuels, NV Energy purchased 6140.5 GWh from renewable resources, bring its renewable fraction to 18.0% (Table S2). This fraction is consistent with the 2020 Status of Energy Report by the Nevada Governor's Office of Energy [25], and is used to estimate F_N2019 in Equation (1). If the current RPS target will be met by 2030, F_N2030 should be 50% or higher, and this study adopts the conservative value of 0.5. *FFDR%* and *EDR%* were then derived from Equations (1) and (2) for each scenario.

- Fossil Fuel Demand and Emission Reductions

Based on *EDR%*, AVERT predicted fossil fuel-based electricity generation would decrease 5703–6312 GWh by 2030 with the demand gap filled by renewable electricity. A lower economic growth/electricity demand would lead to more reductions. Emissions from fossil fuel-fired electric power plants across the Northwest region would be reduced by 4.3–4.7 million tons CO_2, 4.0–4.4 million pounds SO_2, 6.1–6.7 million pounds NO_x, 0.49–0.54 million pounds $PM_{2.5}$, 0.19–0.22 million pounds VOCs, and 0.12–0.14 million pounds NH_3, accounting for 4.1–5.8% of the baseline-year emissions (Table S3). By state, the most reductions in SO_2, NO_x, $PM_{2.5}$, VOCs, and NH_3 would occur in Wyoming, Utah, Oregon, Washington, and Nevada, respectively (Table 2). Washington would also lead in CO_2 reduction, reaching 0.90–1.0 million tons, compared to 0.69–0.76 million tons in Nevada.

A previous study by the National Resource Defense Council (NRDC) on the effect of Nevada's RPS by 2030 demonstrated decreased in-state emissions of SO_2, NO_x, and CO_2 by 2.9 million pounds (74%), 3.5 million pounds (55%), and 2.0 million tons (13%), respectively, from the baseline year 2017 [26]. These emission reduction estimates appear to be substantially higher than those for Nevada alone from this study but closer to the estimates for the entire AVERT Northwest region. The discrepancy may be attributed to different models for fossil fuel displacement, as NRDC predicted fossil fuel displacement mainly occurring inside Nevada while AVERT assumes that fossil fuel electric generation units (EGUs) across the Northwest region would be affected, to various degrees, by the RPS policy depending on their capacity and historical behavior. EGUs with a higher capacity and higher cost to generate electricity would be first turned off [16]. These EGUs could be inside or outside Nevada.

Table 2. Annual state emission changes from the 2019 baseline in the Northwest region, upon RPS 50% in Nevada and under the low- or high-demand scenario by 2030.

State	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	$PM_{2.5}$ (lbs)	VOCs (lbs)	NH_3 (lbs)
Idaho						
Low demand	−198,030	−128,660	−1590	−12,370	−3740	−18,120
High demand	−179,590	−117,350	−1440	−11,170	−3370	−16,480
Montana						
Low demand	−536,670	−1,177,910	−900,990	−100,500	−21,480	−1100
High demand	−482,140	−1,057,280	−809,500	−90,460	−19,330	−1000
Nevada						
Low demand	−755,710	−614,010	−591,890	−89,870	−49,390	−49,960
High demand	−688,170	−560,300	−539,380	−81,890	−45,090	−42,850
Oregon						
Low demand	−633,880	−726,560	−933,240	−115,350	−20,960	−31,530
High demand	−569,860	−653,830	−839,870	−103,790	−18,870	−28,350
Utah						
Low demand	−929,380	−1,753,900	−649,360	−69,050	−25,660	−17,630
High demand	−838,320	−1,580,030	−584,310	−62,350	−23,190	−16,020
Washington						
Low demand	−1,001,140	−1,144,610	−308, 790	−104,090	−73,090	−20,370
High demand	−903,120	−1,030,550	−277,740	−93,880	−65,810	−18,440
Wyoming						
Low demand	−687,890	−1,184,920	−1,027,900	−53,630	−21,260	−320
High demand	−621,290	−1,071,760	−927,810	−48,420	−19,200	−290

The emission reductions are also unequal at the county level in the Northwest region (Figure 1b). In principle, RPS policies would not impact emissions from counties without fossil fuel EGUs. For Nevada, there are only five counties showing emission reductions (Table 3). Humboldt County where Valmy Power Plant, a 522 MW coal-fired EGU, is located would see the most reductions of NO_x and SO_2 emissions (354–388 and 521–572 thousand pounds, respectively). $PM_{2.5}$, VOCs, and NH_3 emission reductions are considerably higher in Clark County, which contains a few natural gas-powered EGUs.

Table 3. County-level emission changes in Nevada from the 2019 baseline, upon RPS 50% and under the low- or high-demand scenario by 2030.

County	CO_2 (tons)	NO_x (lbs)	SO_2 (lbs)	$PM_{2.5}$ (lbs)	VOCs (lbs)	NH_3 (lbs)
Clark						
Low demand	−454,009	−83,846	−3094	−63,298	−23,920	−34,846
High demand	−413,433	−76,954	−2820	−57,714	−21,840	−31,804
Eureka						
Low demand	−43,500	−20,346	−16,116	−3476	−296	−532
High demand	−39,612	−18,322	−14,866	−3134	−268	−480
Humboldt						
Low demand	−124,662	−388,308	−571,872	−7806	0	−1526
High demand	−113,521	−354,090	−520,960	−7102	0	−1388
Lyon						
Low demand	−30,253	−55,892	−438	−3652	−16,680	−1564
High demand	−27,549	−50,954	−398	−3332	−15,216	−1428
Storey						
Low demand	−103,286	−65,622	−374	−11,634	−8504	−8496
High demand	−94,056	−59,984	−342	−10,608	−7762	−7750

- Regional Health Benefits

Figure 1c,d show the county-level $PM_{2.5}$ reduction and health benefits, respectively, as predicted by COBRA. Every county in the U.S. would experience lower $PM_{2.5}$ concentrations when the Nevada RPS target is met in 2030. The total health benefits over the entire U.S. range from USD 72 to USD 164 million for the low-demand scenario and USD 65 to USD 148 million for the high-demand scenario. Most of the benefits are attributed to avoided 6.5–14.8 (low demand) or 5.9–13.4 (high demand) adult mortality and 0.62–5.7 (low demand) or 0.56–5.2 (high demand) non-fatal heart attacks per year (Table S4). Among the top ten states that benefit, Nevada is ranked only sixth (Figure 2). California benefits the most due to its large population and proximity to Nevada, as emission reductions around Nevada substantially reduce California's population exposure to air pollution. Washington benefits the second most partly due to major emission reductions as a result of lower electricity demands in Nevada (Table 2).

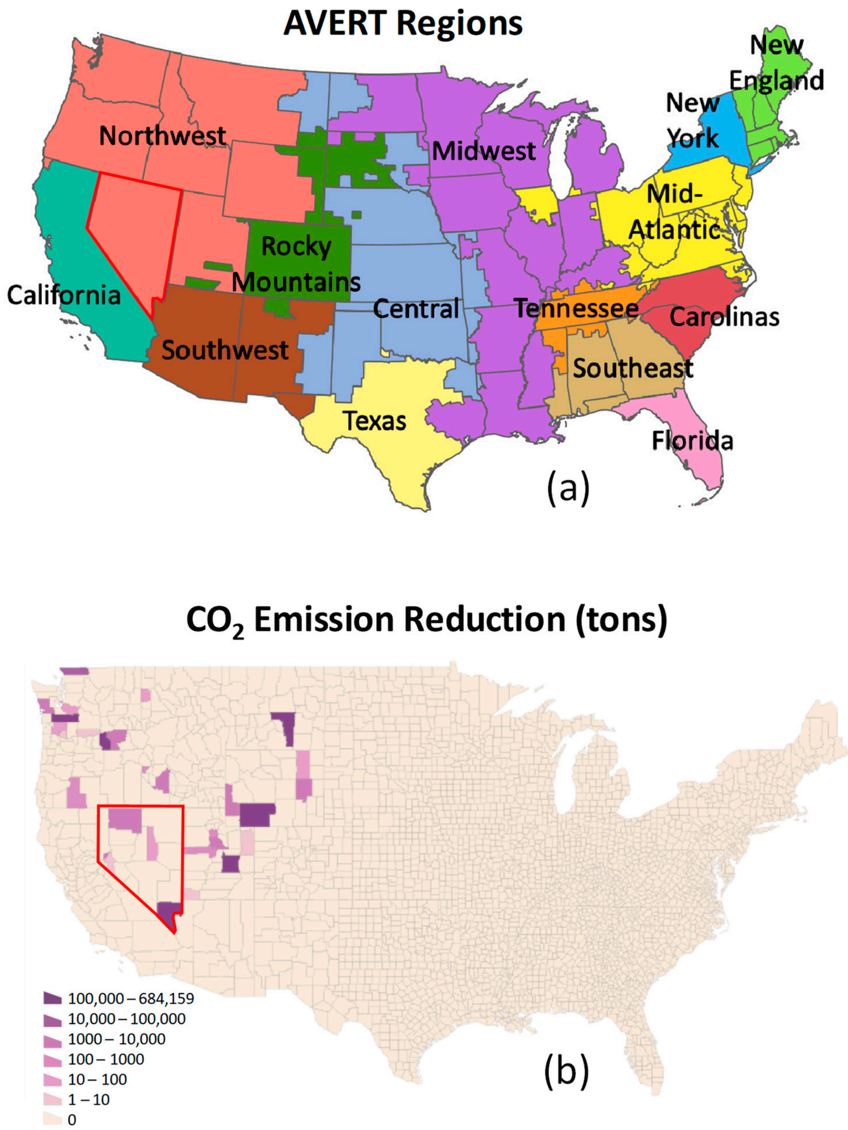

Figure 1. *Cont.*

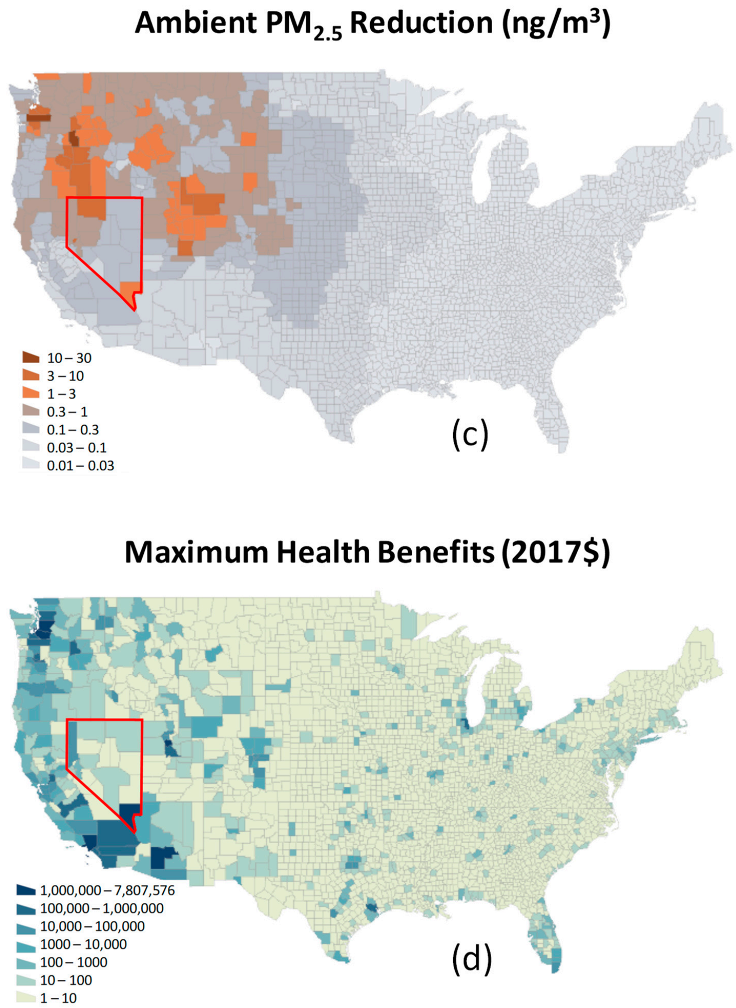

Figure 1. Distribution of (**a**) AVERT regions [16] and (**b**) CO_2 emission reductions, (**c**) ambient $PM_{2.5}$ reductions, and (**d**) maximum health benefits at the county level, attributed to the Nevada 50% RPS policy by 2030. The State of Nevada is highlighted.

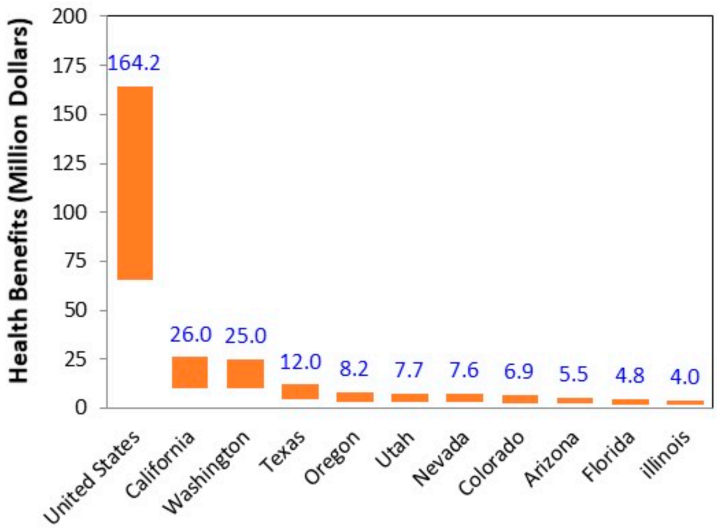

Figure 2. Range of estimated annual health benefits for the top ten state beneficiaries from the Nevada 50% RPS policy across the high- and low-demand scenarios by 2030. The maximum health benefits are indicated in blue.

- Distribution of Benefits Among Nevada Counties

The monetary health benefits for Nevada residents are between 3.1 and 7.6 million dollars, with lower demands leading to more health benefits. These benefits stem from 0.27–0.69 avoided adult mortality, 0.025–0.252 nonfatal heart attack, 208–229 minor restricted activity days, 35–39 work loss days, 0.053–0.058 hospital admits due to cardiovascular disease, and 0.048–0.064 hospital admits due to respiratory disease per year (Table S5).

There is inequity among Nevada counties with respect to monetary health benefits (Table 2). Clark and Washoe Counties, which have the largest populations in the state, also obtain the most benefits (USD 2.4–USD 6.0 million for Clark and USD 0.39–USD 0.97 million for Washoe County). Counties with the smallest populations, i.e., Eureka County (2091 people), obtain the least health benefits (USD 1300–USD 3200). A distinct distribution is found for the per capita benefits (Figure 3, Table S6). Storey and Humboldt Counties receive more per capita benefits (USD 3.6–USD 8.9 for Storey County and USD 2.4–USD 6.1 for Humboldt County) than other counties. Meeting the RPS target by 2030 would lead to substantial emission reductions from EGUs in these two rural counties (Table 3), including the 885 MW natural gas-fired Frank A. Tracy Generating Station in Storey County and the 522 MW coal-fired Valmy Power Plant in Humboldt County. The emission reductions translate to health benefits for residents living close to the EGUs. As rural residents generally use less electricity than the state average while suffering from disproportionate air pollution, Nevada's RPS policy could help reduce environmental injustice among Nevada counties.

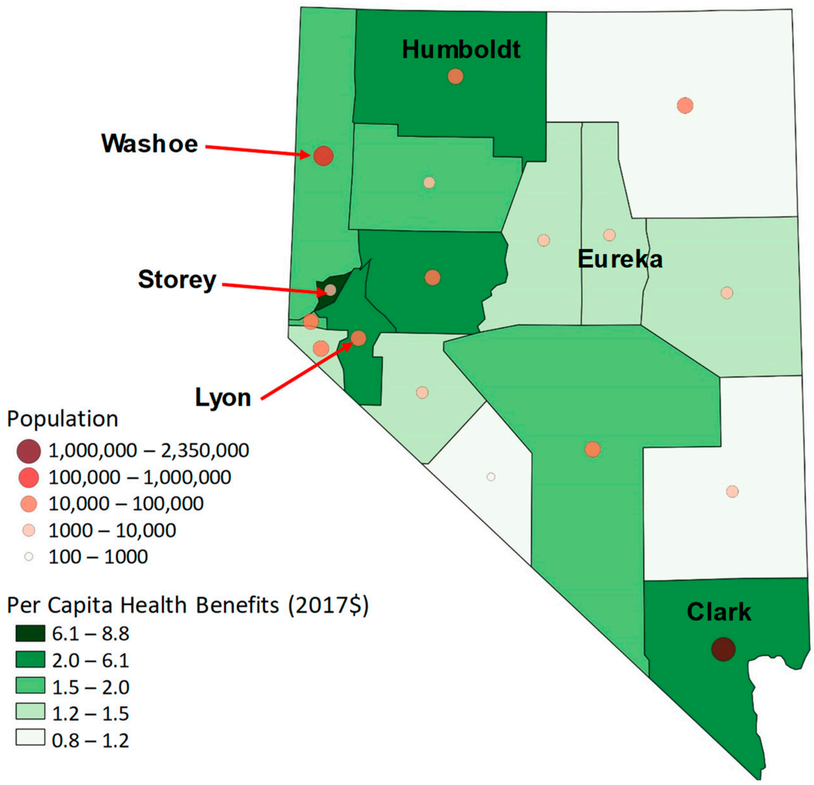

Figure 3. Distribution of population and per capita health benefits across Nevada counties. Clark, Eureka, Humboldt, Lyon, Storey, and Washoe counties are noted.

- Effect of Electricity Demand

Assuming full compliance with Nevada's RPS, the 4.7% and 10.4% increases in electricity demand from 2019 to 2030 due to different economic perspectives could lead to USD 3.3–USD 7.6 million and USD 3.0–USD 6.9 million health benefits, respectively, in Nevada.

A higher demand would need to use more fossil fuel electricity and therefore weaken the emission reductions and RPS health benefits. Roughly a 5% increase in electricity demand in Nevada would decrease health benefits by 10% for Nevada as well as the entire U.S. The lower electricity demand does not necessarily imply a slower economic growth; it could be achieved through energy efficiency and/or conservation. The RPS policy would work best when continuing to incentivize consumers to upgrade their non-efficient appliances and adopt low-carbon lifestyles.

It should also be noted that health benefits can go beyond better air quality. They may include mitigating regional climate change, reducing water consumption, and creating renewable energy jobs. Sullivan [26] predicted that implementation of Nevada SB 385 could urge Nevada to build 470 MW of new battery storage, bring in USD 6.2 billion of investment, and create 9800 new jobs by 2030.

- Limitations

All assumptions in this study are based on existing renewable policies, which may be amended before 2030. For example, the U.S. Inflation Reduction Act [27] aims to reduce greenhouse gas emissions nationwide by 40% below 2005 levels by the year 2030, possibly leading to a review of the Nevada RPS in future state legislative sessions. There is uncertainty in predicting future economic growth and electricity consumption. AVERT's estimation of emission changes is based on existing fossil fuel EGUs in 2019, and does not factor into added or withdrawn units between 2019 and 2030. There are also uncertainties in COBRA parameters, such as economic values and exposure-outcome relationships. COBRA did consider demographic differences across the counties and provide the upper and lower values to bound the health benefits. Furthermore, AVERT and COBRA cannot consider electricity market changes due to implementing a RPS policy. For example, the policy may decrease electricity generation in one place and increase electricity generation in other areas within the Northwest region [16,18]. Air quality may also be influenced by other pollution sources, such as the increasing trend of wildfires in the western U.S. [28].

4. Conclusions

Implementing a RPS is considered a powerful policy tool to reduce greenhouse gases and air pollutants by substituting fossil fuels with renewable resources to generate electricity. This study investigated the spatially non-uniform health benefits of Nevada's RPS, an ambitious initiative to require 50% of the electricity sold by providers in Nevada to come from renewable sources by 2030. This study used two new models: AVERT v3.0 and COBRA v4.0 and considered low and high electricity demand scenarios due to different economic growth projections. By reducing ambient air pollution, Nevada's RPS policy could produce annual health benefits valued USD 65–USD 164 million for the U.S. and USD 3.0–USD 7.6 million for Nevada residents. Most of these health benefits are attributed to the reduction of adult mortality. Five states, led by California and Washington, can obtain more benefits than Nevada, as a result of their large populations, emission reductions, or both. Nevada counties would also benefit unequally, with higher overall and per-capita benefits occurring in counties that have larger populations and that generate more fossil fuel electricity, respectively. Due to the high connectivity of modern power grid and cross-boundary transport of air pollutants, state RPS policies should evaluate their impact on the greater region and on environmental justice. Moreover, as lower electricity demands will lead to additional health benefits, RPS policies should be coupled with energy efficiency and conservation programs to achieve the best outcome.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos13091387/s1, Table S1: Annual electricity demand growth rate based on economic projection 2019–2030 in the United States; Table S2: Breakdown of NV Energy's electricity supplies for 2017–2019; Table S3: Annual fossil fuel-based electricity and total emission displacement in the Northwest region upon RPS 50% in Nevada, under the low- and high-demand scenarios; Table S4: Annual incidence changes of health endpoints and related monetary values for the entire U.S. upon RPS 50% in Nevada under the low- and high-demand scenarios; Table S5: Annual incidence changes of health endpoints and related monetary values for Nevada upon RPS 50% under the low- and high-demand scenarios; Table S6: Total and per-capita health benefits by county in Nevada upon RPS 50% in 2030, under the low- and high-demand scenarios.

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