# Princeton's Net-Zero America study
# Annex N: Fossil Fuels Transitions

Erin Mayfield and Chris Greig

Andlinger Center for Energy and the Environment, Princeton University

21 December 2020

Table of Contents

# 1 Introduction

Fossil fuel supplies rapidly decline throughout Net-Zero America (NZA) transitions, while energy supply is increasingly comprised of wind and solar, bioenergy, and/or nuclear power. Figure 1 depicts the transition of primary energy across the NZA scenarios based on RIO modelling as described in Annex A. This Annex explores the implications of NZA transitions for fossil fuels upstream and midstream operations and assets.

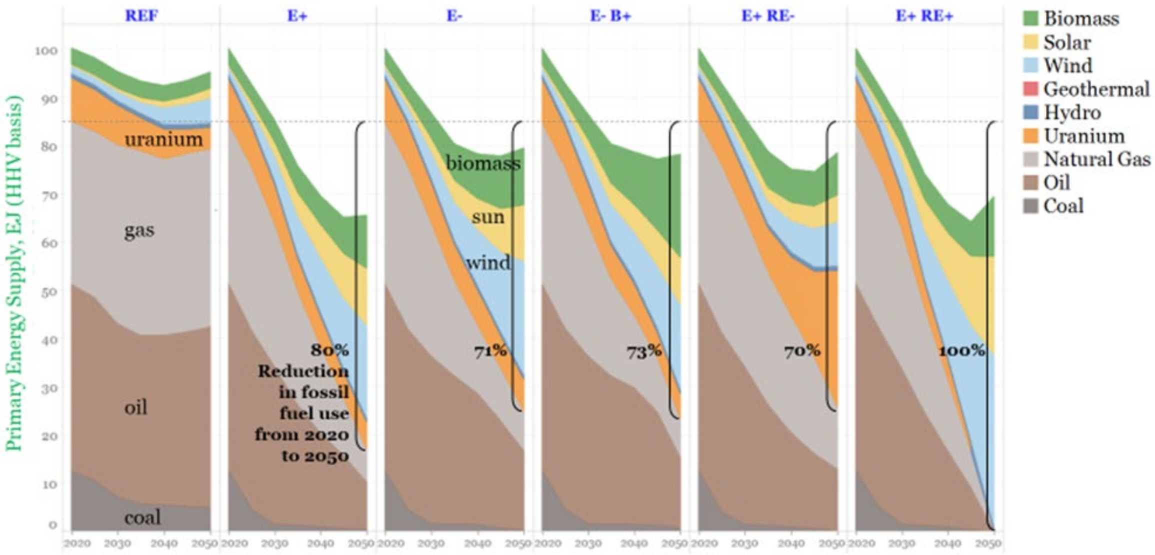



**Figure 1. Graphical presentation of primary energy mix transition over the period in each of NZA scenarios. Fossil fuels decline by 70 % to 100% in NZA scenarios relative to the Reference case.**

## 2 Coal production and consumption

All coal-fired power plants retire by 2030 in the net-zero (NZ) scenarios, as described in Annex E. As a result, coal consumption and production for thermal electric power ceases by 2030. However, we assume that the United States (U.S.) continues to produce coal post-2030 to meet continuing domestic industrial and coking demand. In addition, we further assume that exports either cease or continue to meet projected exports consistent with the U.S. Energy Information Administration Annual Energy Outlook Reference case projections.[1] The resultant decline in U.S. coal production in the E+ (which is representative of all NZ scenarios) and Reference (REF) scenarios is depicted in Figure 2. We find that the production decline rate in the NZ scenarios (54-56 Mt/yr) is approximately double the historical rate of decline from 2005 to 2019 (27 Mt/yr).

We estimate the state-level distribution of production over time, assuming that spatial production patterns are consistent with those observed for 2019. Specifically, we assume that coal production to meet future domestic demand is spatially distributed based on historical state-level production, and production to meet future export demand is spatially distributed in those states that have historically produced coal for export.[2,3] As shown in Figure 3, production declines in every state, with the closure of nearly all 700 mines by 2030 in the NZ scenarios. If the U.S. continues to export coal, remaining coal mines in 2030 are concentrated in the Appalachian basin where metallurgical coal production is more predominant.

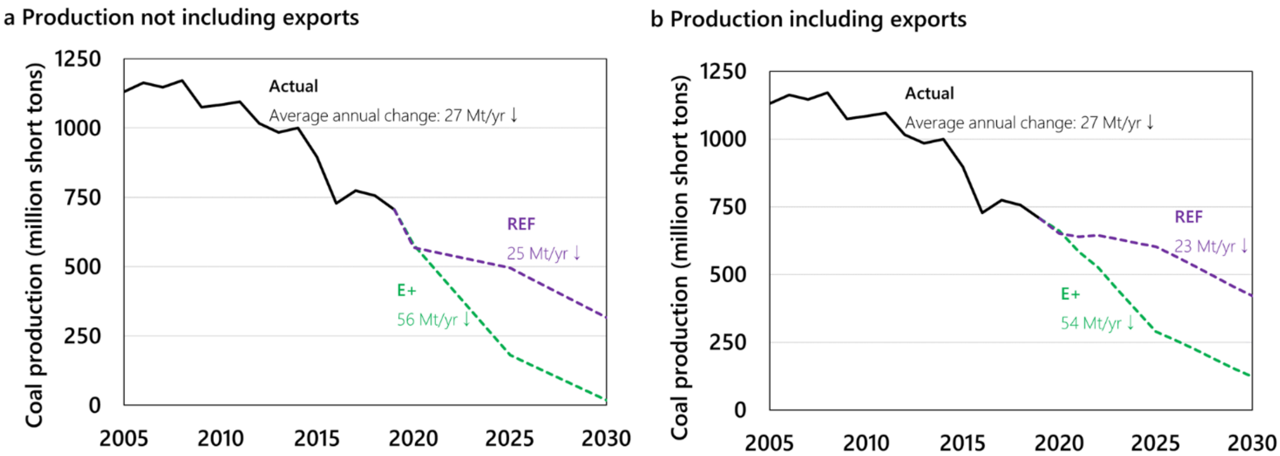



**Figure 2. Decline in coal production in the REF and E+ scenarios with and without exports.**

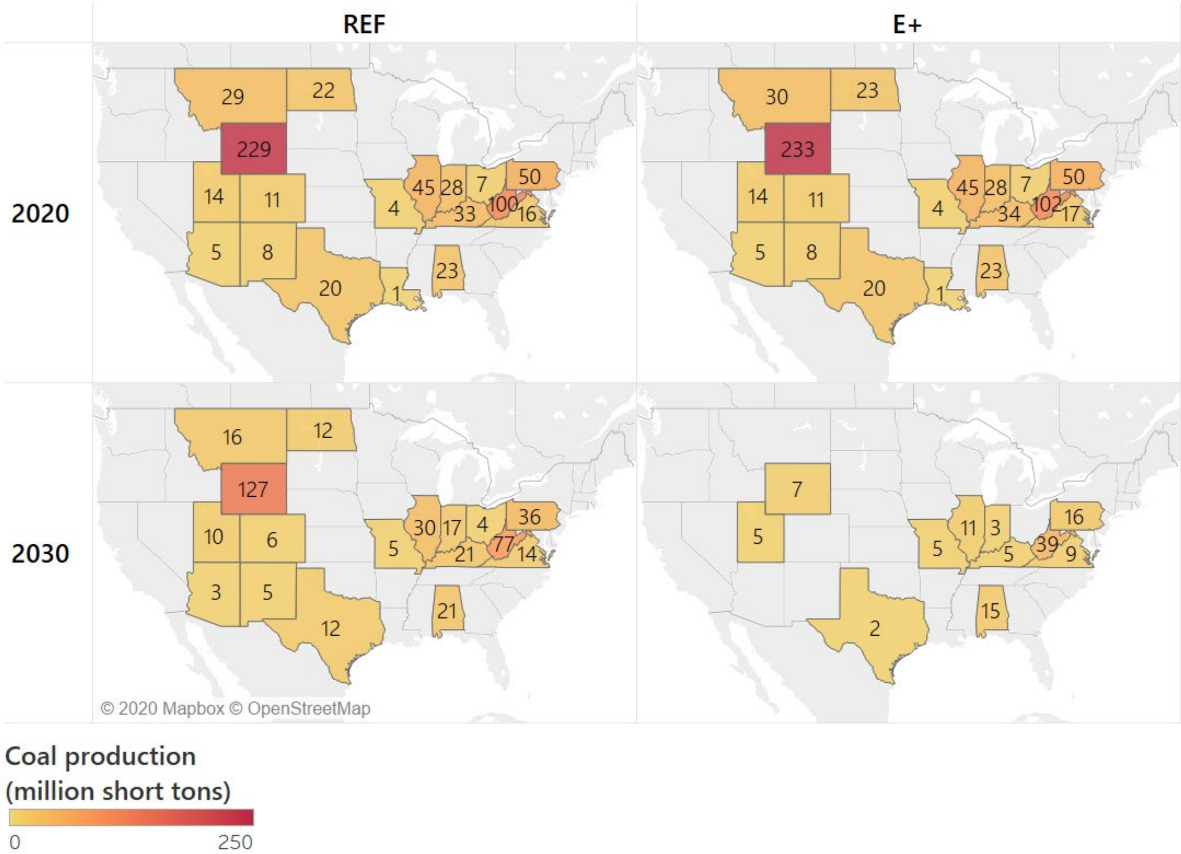



**Figure 3. Mine production capacity by state in 2020 and 2030 for the REF and E+ scenarios. The estimates depicted assume that mines continue to meet domestic coal demand for industrial uses and export demand.**

## 3 Oil production and consumption

Oil consumption declines across all NZ scenarios as a result of electrification of transportation (as described in Annex C) as well as the substitution of crude oil and refined derivatives with synthetic liquid fuels and feedstocks. The top panel in Figure 4 illustrates the decline in consumption, ranging from 55% in E+RE- and E- scenarios to 100% in the E+RE+ scenario by mid-Century; in the E+RE+ scenario, fossil fuels use by 2050 is explicitly precluded in the scenario definition.

The bottom panel in Figure 4 depicts the decline in domestic oil production, which ranges from 25% in the E+RE- and E- scenarios to 85% in the E+RE+ scenario by mid-Century. To project future production, it is assumed that oil exports are consistent with the U.S. EIA AEO reference case projections, and that as domestic consumption declines, an increasing share of domestic demand is met through domestic production relative to imports. By the 2030s, the decline in domestic demand reaches a level such that oil imports are no longer required and demand can be met solely through domestic production.

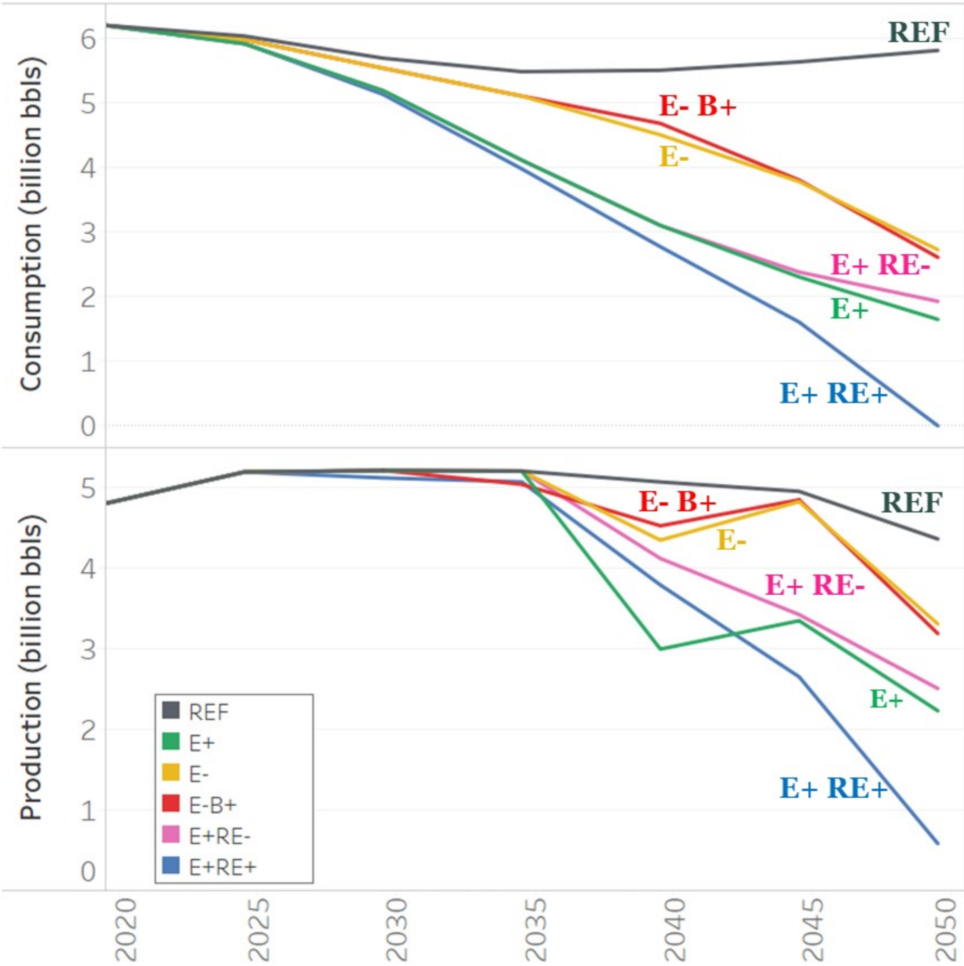
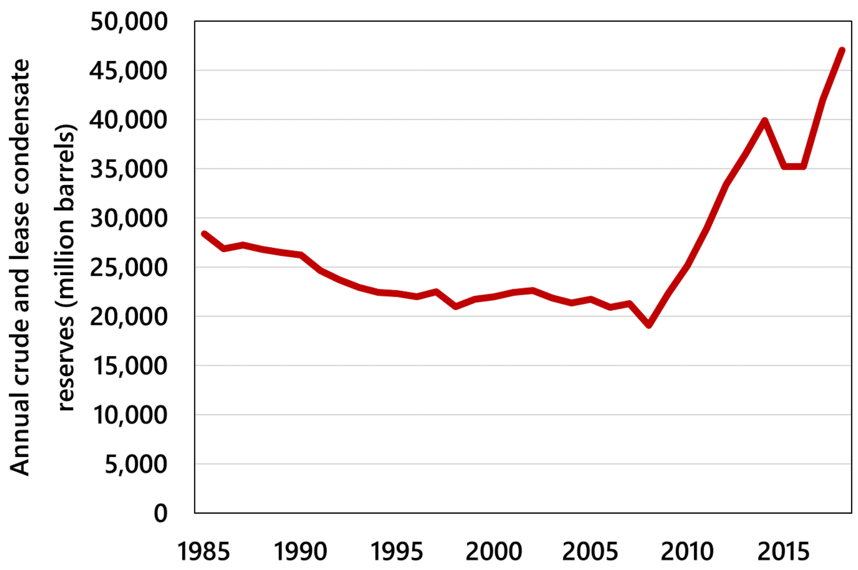



**Figure 4. U.S. oil consumption trends (top panel) and production trends (bottom panel) in NZ and REF scenarios.**

U.S. domestic oil reserves have risen rapidly over the past decade, more than doubling since the Global Financial Crisis, as illustrated in Figure 5. Declining oil production will command the attention of producers managing reserves, especially in light of the uncertainty in future demand, associated with differences across REF and NZ scenarios, the role of imports in meeting domestic demand, and interactions with domestic natural gas production. Figure 6 indicates that while current proved reserves are insufficient to meet the projected near- and long-term production, technically recoverable resources are on the order of 2.5 times expected cumulative production by mid-Century.  The decline domestic consumption and production will also have implications for a range of upstream and downstream businesses and assets, which have not been studied in the work to date.

a Historical crude oil reserves




b Historical crude oil reserve change

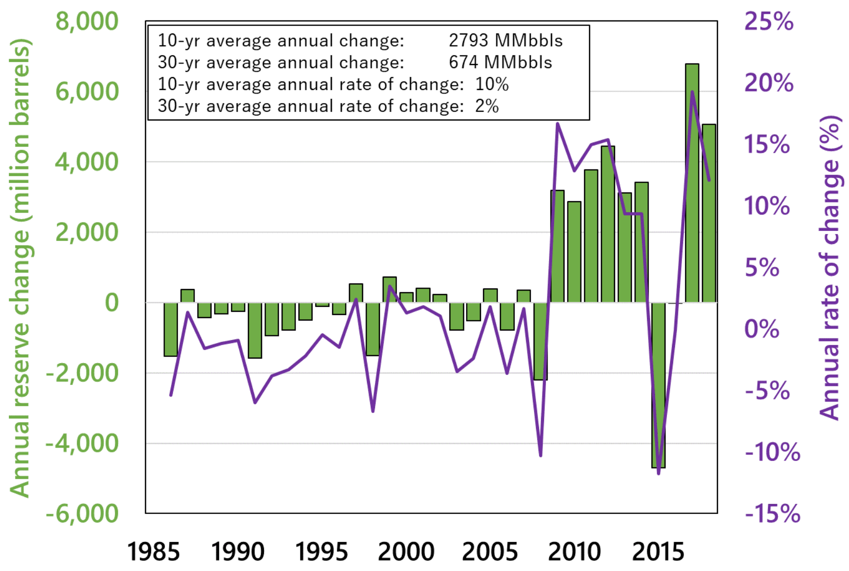



**Figure 5. Historical U.S. oil reserves growth since 1985, illustrating the volatility in reserve additions as well as the significant increase in reserves over the past decade.**

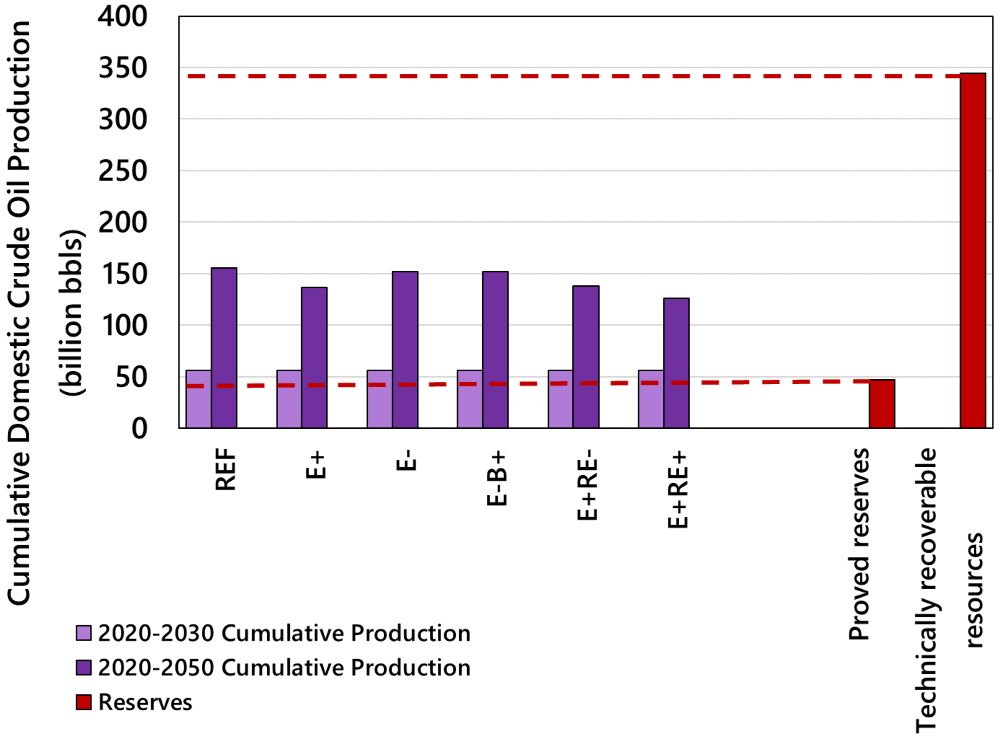



**Figure 6. Projected cumulative oil production under each scenario for the periods 2020 to 2030 and 2020 to 2050 (purple bars to the left) compared with current levels of reserves and technically recoverable resources (red bars to the right).**

# 4 Natural gas production, transmission, and distribution

## 4.1 Production

Over the past two decades, U.S. natural gas production increased with the commercialization of shale gas resources. Over the next three decades, natural gas production is projected to decline in all NZ scenarios as a result of the increasing use of wind, solar, and biomass for power generation, renewable hydrogen and synthetic gas production for use in power generation and industry, and the electrification of heating.

Based on RIO modelling described in Annex A, we find that natural gas consumption declines by between 50% (E+RE-) and 100% (E+RE+) across the suite of NZ scenarios, while consumption stays relatively flat in the REF scenario. To project future natural gas production, we assume that domestic production meets domestic demand. In addition, as with oil and coal production, we alternatively assume that natural gas exports either cease or follow the same trajectory as the U.S. EIA AEO reference case projection.[1] Figure 7 shows natural gas production declines between 40% (E+RE-) and 75% (E+RE-), assuming that natural gas exports persist.

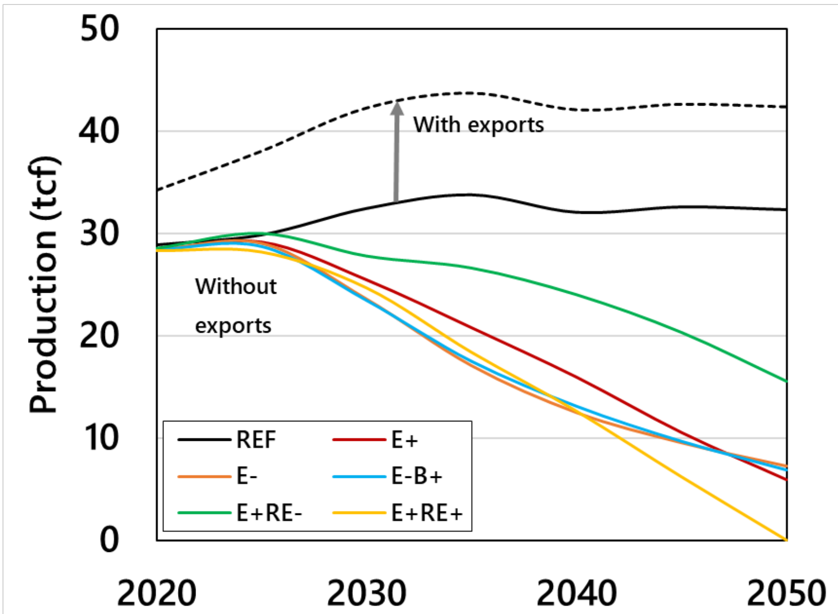



**Figure 7. The declining consumption of natural gas in NZ scenarios relative to the REF scenario. Production without exports are indicated by the solid lines, and production with exports for the REF scenarios is indicated by the dotted line.**

U.S. domestic natural gas reserves have risen rapidly over the past 15 years, as illustrated in Figure 8. Declining natural gas production will, like oil, command the attention of producers managing reserves, in light of the uncertainty in future demand. Figure 9a indicates that current reserves are at least sufficient to meet the projected cumulative production to 2030 across both the NZ and REF scenarios. The decline in natural gas during the first decade will potentially require the earlier than planned closure of an estimated 0.5 million gas wells during the first decade of the transition, requiring on the order of $25 billion for plugging and abandoning well in addition to other remediation costs.

As shown in Figure 9b, cumulative production estimates through 2050 exceed current reserves by 10% (E+RE+ with discontinued exports) to over 100% (E+RE- with continuing exports) but are well short of the projected reserves based on recent historical rates of reserves growth.

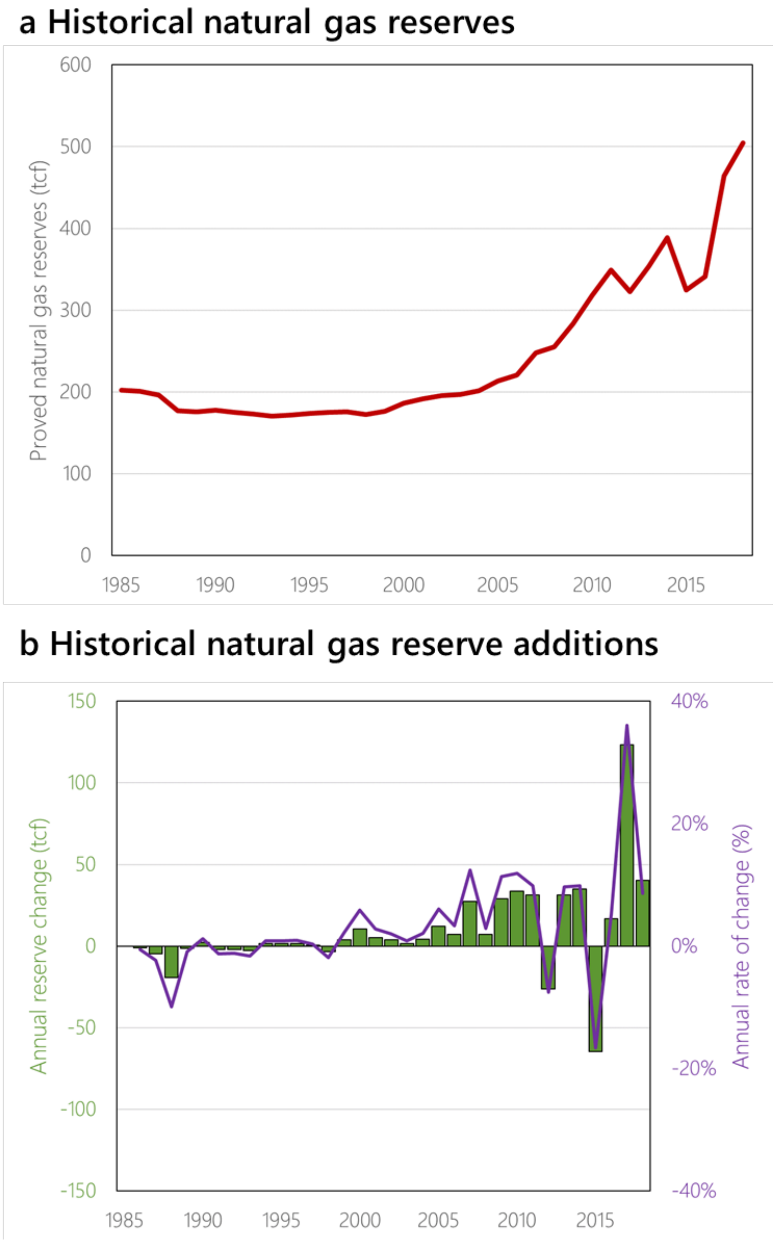



**Figure 8. Historical U.S. natural gas reserves growth since 1985, illustrating the volatility in reserve additions as well as the significant increase in reserves over the past 15 years.**

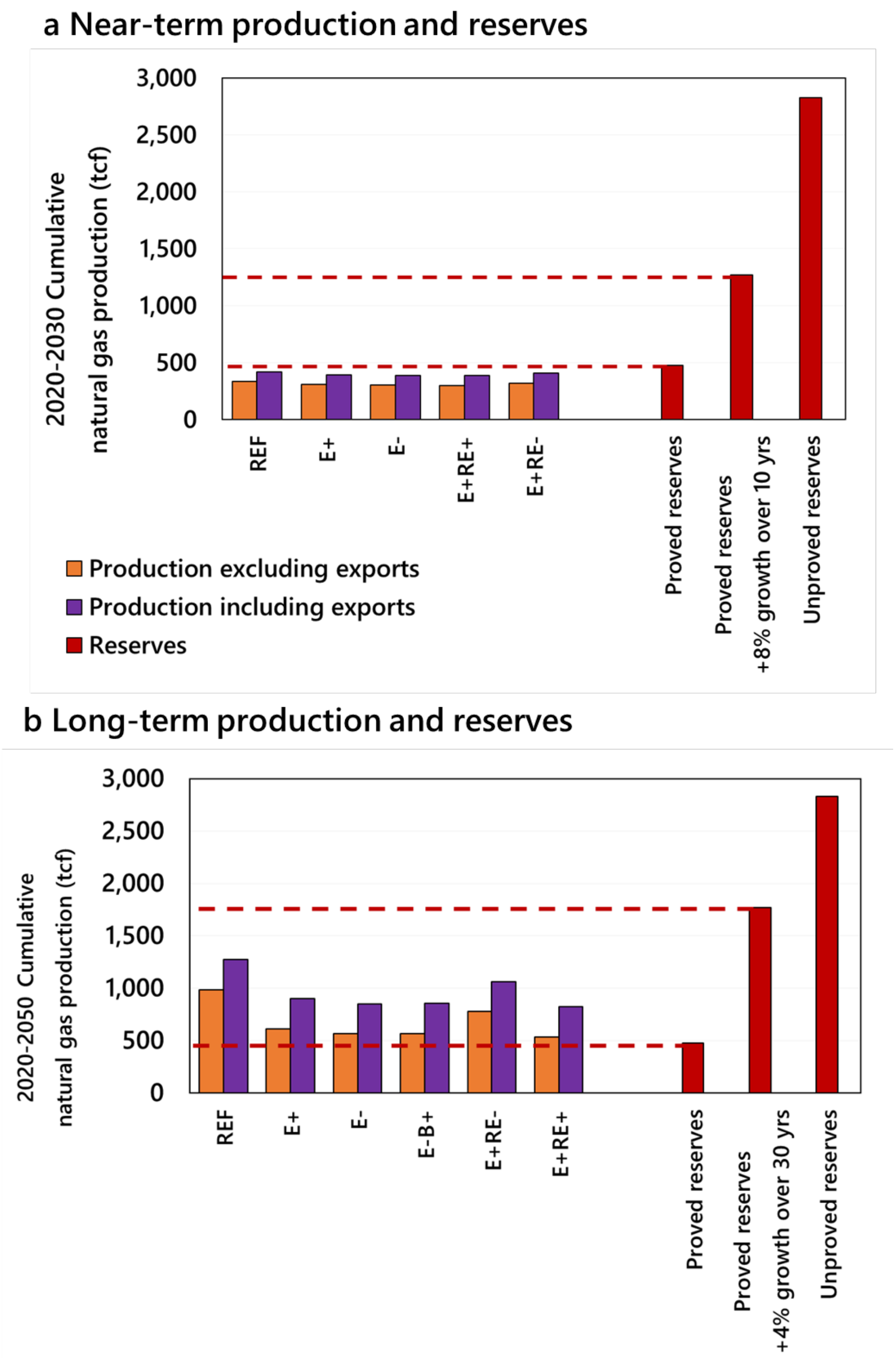



**Figure 9. Projected cumulative production of natural gas under each NZ scenario (with and without exports) for the periods 2020 to 2030 (Panel a) and 2020 to 2050 (Panel b), compared with: current levels of proven reserves; projected reserves at the rate at which new reserves are currently being appraised; and technically recoverable resources (red bars to the right).**

### 4.2 Transmission

As shown in Figure 10, the U.S. natural gas transmission system is vast, comprised of over 300,000 miles of interstate and intrastate transmission lines and 20,000 miles of gathering lines.[4,5] However, transmission infrastructure assets are aging, with over 70% of pipelines and over 50% of gathering lines greater than 30 years old, as shown in Figure 11.

As natural gas production and consumption declines across all of the NZ scenarios, transmission volume gradually declines from 2020 to 2050 by 22-60%, as shown in Figure 12. This assumes that the U.S. continues to export natural gas, and synthetic gas and blended hydrogen use existing natural gas transmission infrastructure. Transmission capacity utilization will progressively decline, resulting in potential asset revaluations (write-downs), and/or a requirement to reassess the structure and consumer rates. Declining utilization of midstream gas assets will therefore require careful management to minimize unwanted fiscal disruption or any equity issues in the communities affected. Based on the demand projections in the NZ scenarios these impacts will vary across states through the first decade but are likely to be universal across the nation by 2050, as illustrated for the E+ scenario in Figure 13.

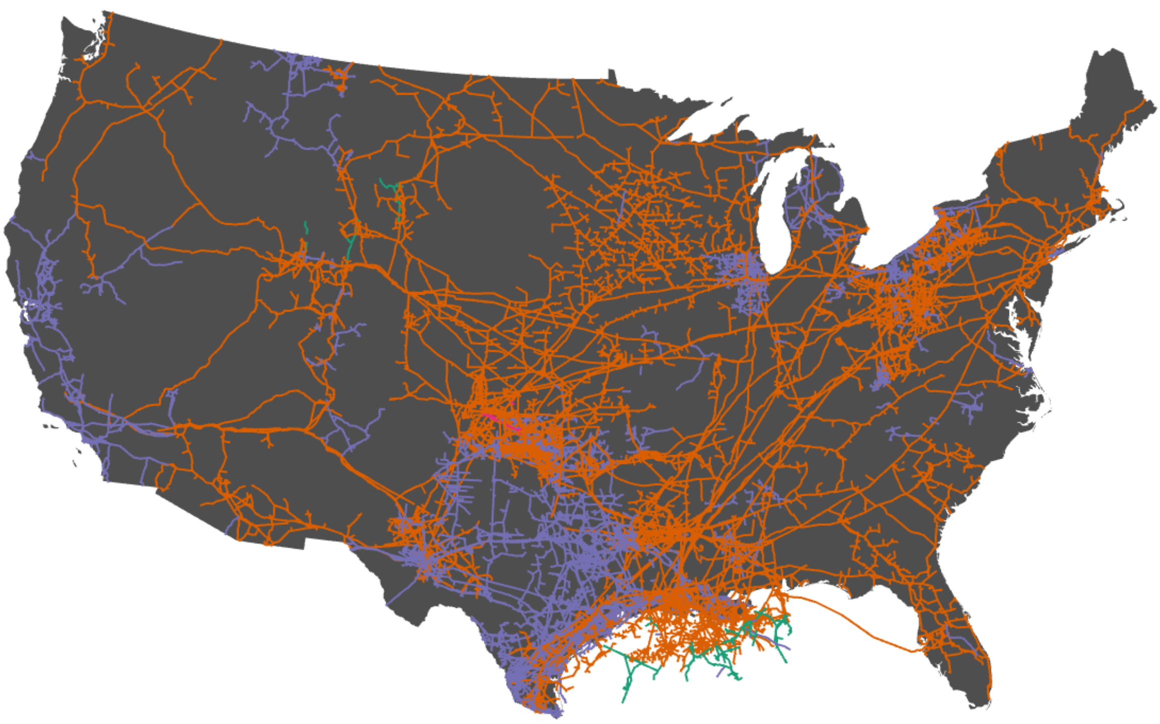


**Figure 10. Map of the existing network of natural gas pipeline infrastructure. Interstate pipelines, intrastate pipelines, and gathering lines are depicted orange, purple, and green, respectively.**

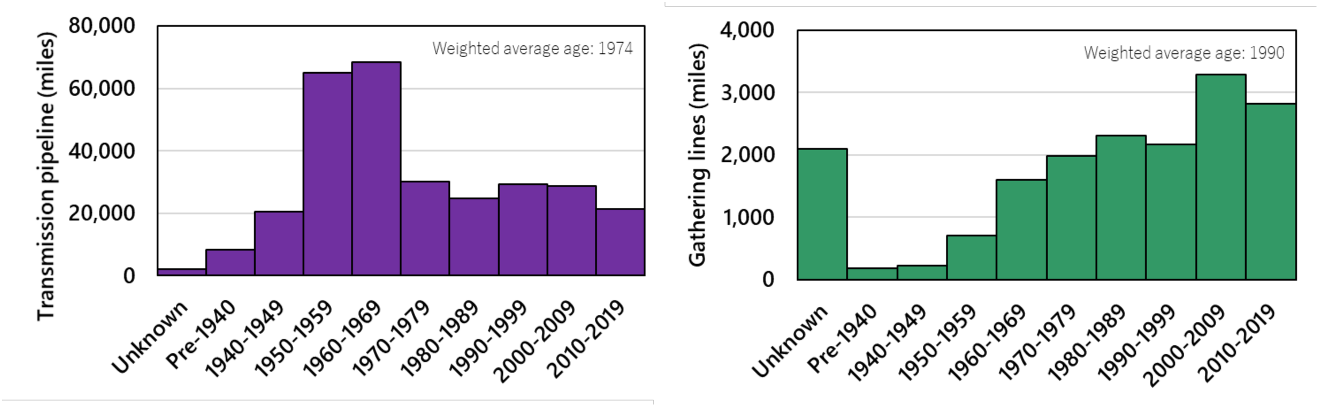



**Figure 11. Age distribution of existing natural gas transmission pipelines and gathering lines, as of 2019.**

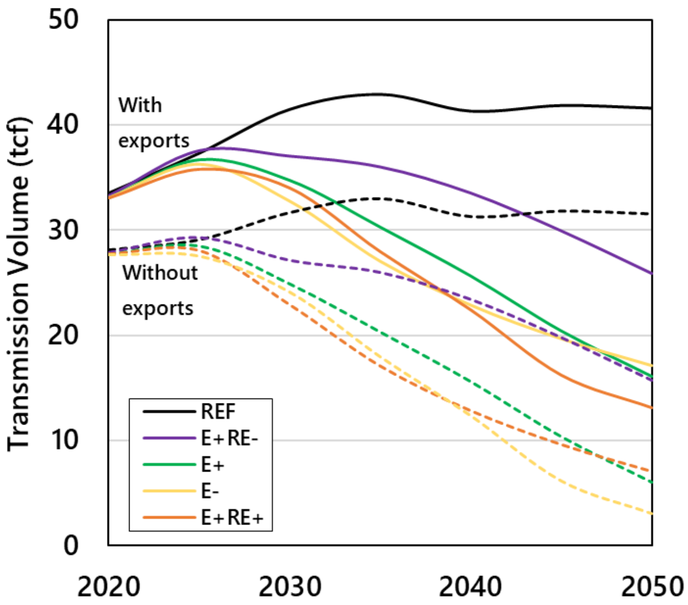



**Figure 12. Annual natural gas transmission volume by scenario, including exports (solid lines) and excluding exports (dashed lines).**

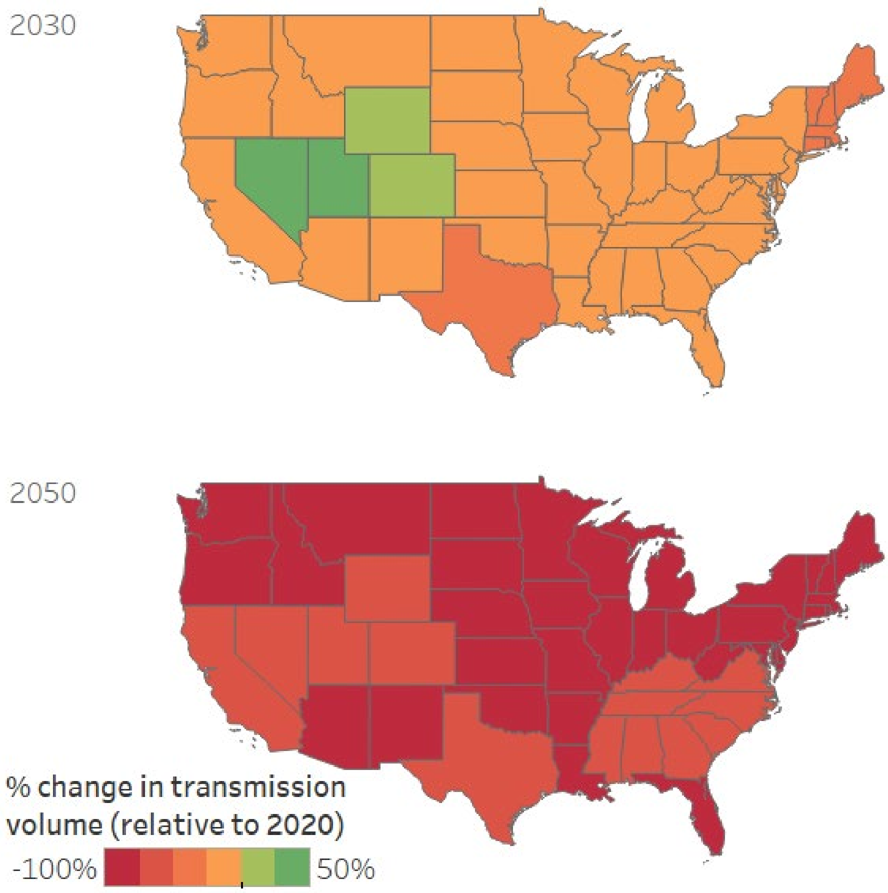



**Figure 13. Percent change in natural gas transmission volume relative to 2020 for the E+ scenario.**

## 4.3 Distribution

The existing U.S. natural gas distribution network is vast, with over 1.3 million miles of mains and 70 million service lines.[4,6] Within recent years, there have been several pipeline replacement and expansion projects, spurred in part by the shale gas boom. As shown in Figure 14 and Figure 15, about two-thirds of the mains are less than 50 years old, the typical life of distribution assets, and in some states a majority of the distribution infrastructure is relatively new.

Natural gas consumption and heat pump adoption serve as proxies for declines in the use of natural gas distribution assets. Based on the EnergyPATHWAYS modelling described in Annex A, residential, commercial, and industrial natural gas consumption declines in both NZ demand scenarios (E+ and E-) and stays relatively flat in the REF scenario, as depicted in Figure 16. In the E+ scenario, residential and commercial gas consumption declines moderately over the first decade (27% and 13%, respectively), with more rapid declines over the subsequent two decades (94% and 85%, respectively in 2050). Whereas, industrial consumption declines moderately over the 30-year period (15%). In aggregate, consumption declines by 35% in E- to 55% in E+ by 2050, and correspondingly, the consumer base begins to diminish. Demand reductions in the NZ scenarios vary across states through the first decade but are likely to be universal across the nation by 2050, given that there is a high degree of electrification with heat pumps substituting most natural gas- and oil- fired furnaces, as shown in Figure 17.

The decline in production will progressively reduce the capacity utilization of these assets, resulting in potential asset revaluations (write-downs), and/or a requirement to reassess the structure and consumer rates. Rate recovery periods for capital expenditures on recent pipeline replacements can span several decades. Cost recovery may become problematic, especially in states with a relatively new distribution system and large declines in gas consumption during the first decade of the transition, such as Vermont and North Carolina. Declining utilization of distribution gas assets will therefore require careful management to minimize unwanted fiscal disruption or any equity issues in the communities affected.

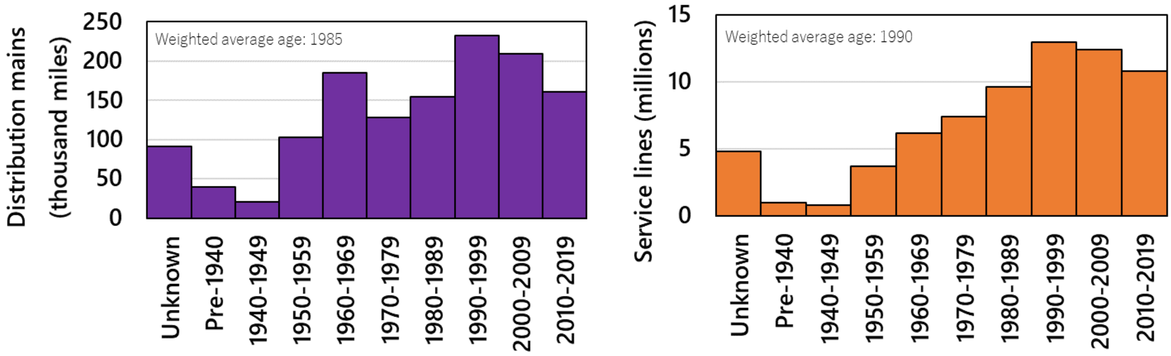



**Figure 14. Age distribution of natural gas distribution mains and service lines, as of 2019.**

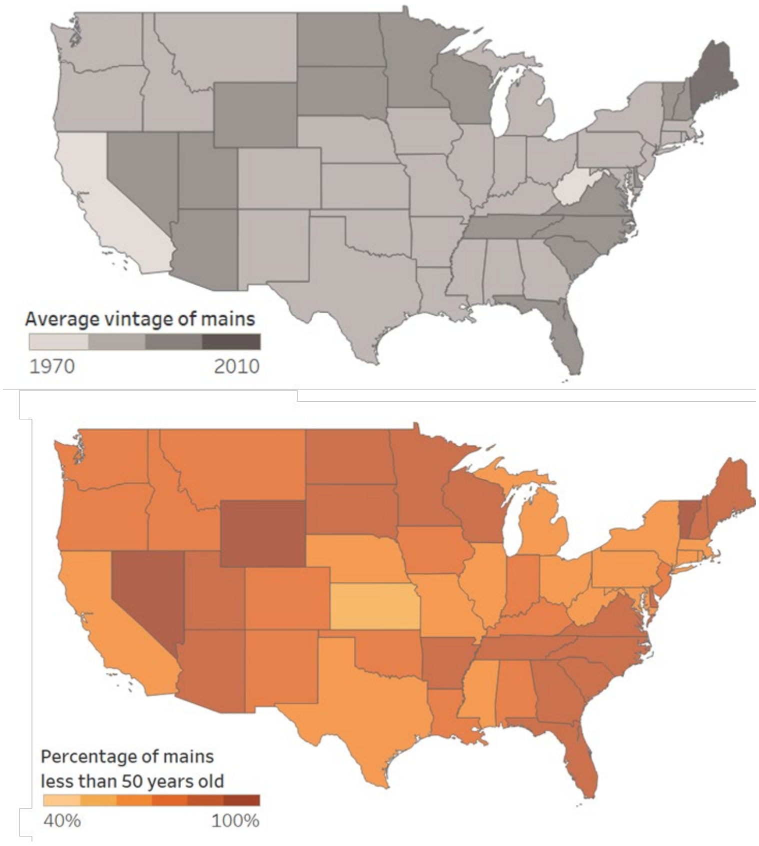



**Figure 15. Maps of the average age of distribution mains and the percentage of mains that are less than 50 years old.**

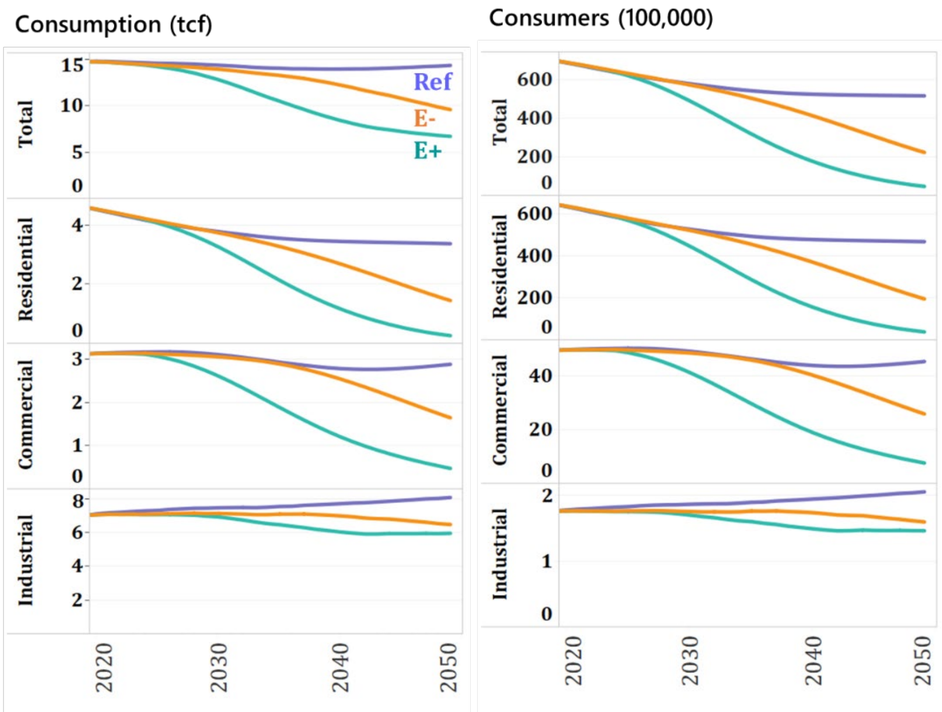



**Figure 16. Change in natural gas consumption and number of consumers by demand scenario.**

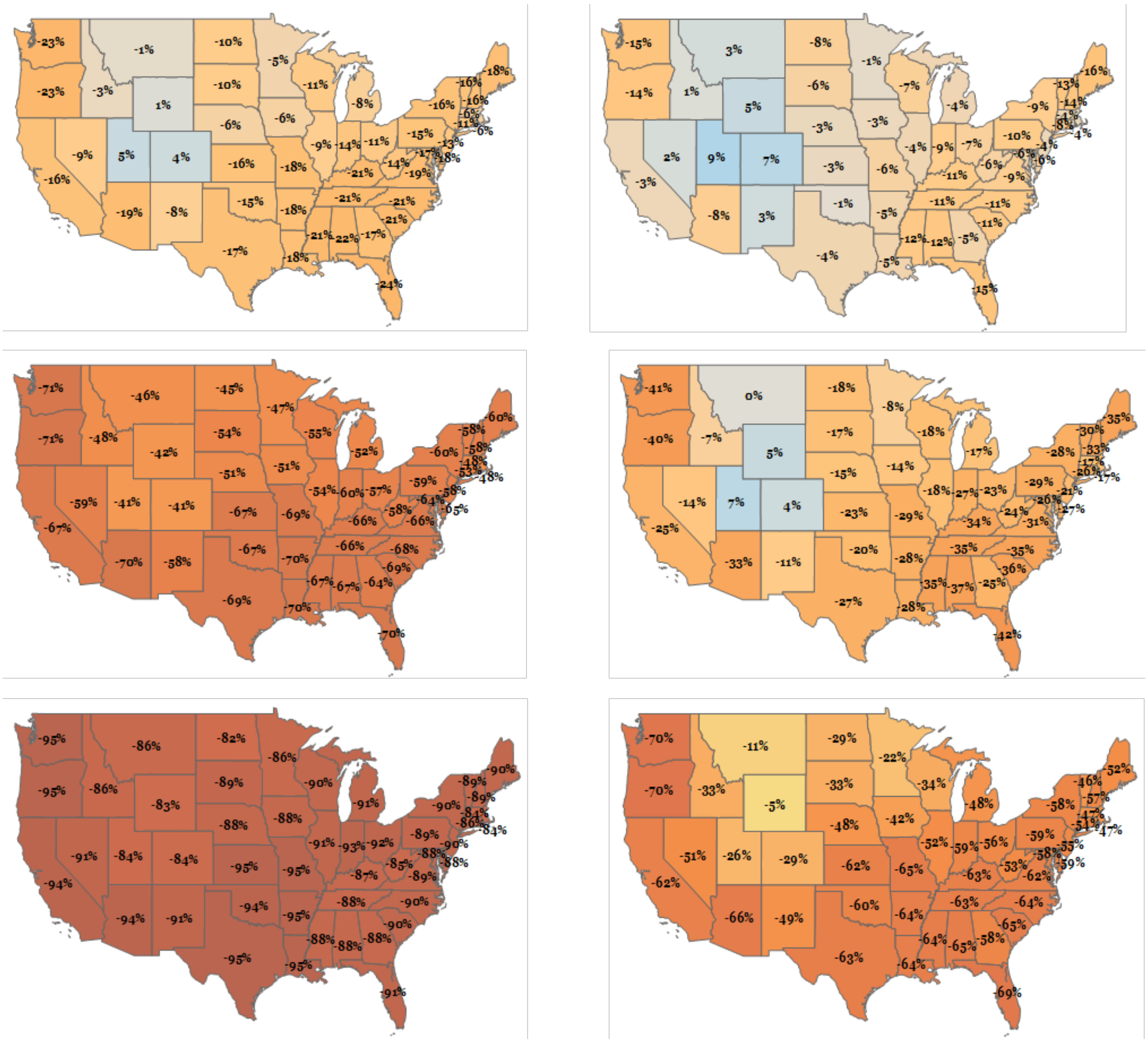


**Figure 17. Percentage reduction in number of residential gas-fired heaters by state for the E+ scenario.**

# 5 References


1. U.S. Energy Information Administration. Annual Energy Outlook 2020. (2020). doi:10.1128/AAC.03728-14
2. U.S. Energy Information Adminstration. State Energy Data System. (2020). Available at: https://www.eia.gov/state/seds/. (Accessed: 12th May 2020)
3. Energy Information Administration. *Annual coal distribution report*. (2019).
4. U.S. Energy Information Administration. Layer Information for Interactive State Maps. (2020). Available at: https://www.eia.gov/maps/layer_info-m.php. (Accessed: 12th August 2020)
5. U.S. Department of Transportation & Pipeline and Hazardous Materials Safety Administration. Gas Transmission & Gathering Annual Data. (2020). Available at: https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.
6. U.S. Department of Transportation & Pipeline and Hazardous Materials Safety Administration. Gas Distribution Annual Data. (2020). Available at: https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.