Impacts of Future Energy Transition on the U.S. Air Quality: Projections of Emissions and Air Quality in 2050

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Background and Objectives

- Modeling impacts of future energy transition on regional air quality and human health is very challenging
- Linking national scale energy models and regional air quality models via downscaling process is a very important step
- Emission change factors (ECFs) of major species for energy related sectors downscaled from the National Energy Modeling system (NEMS) ar
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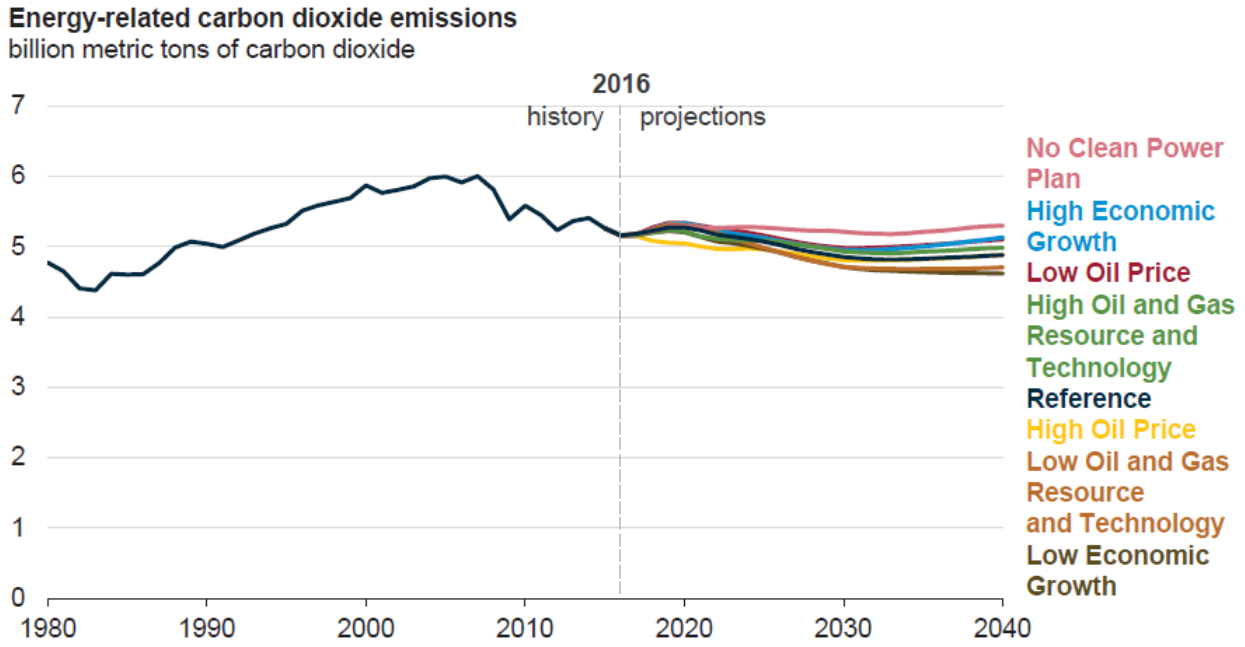


Source: Annual Energy Outlook (2017)

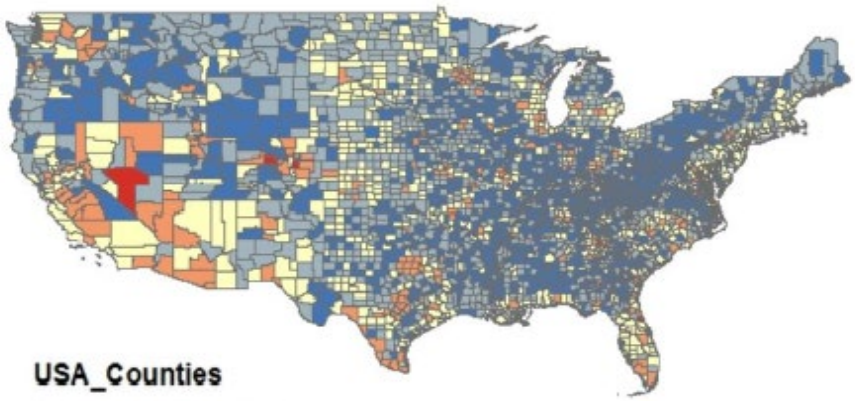
Selected Scenarios

(Gillingham and Huang, 2019, 2020; Gillingham et al., 2021)

- **Reference without clean power plan (Refnocpp)**
  - Projection assumes trend improvement in known technologies and current regulations without considering any potential impacts from regulations and others
- **HighNG***
  - Projection assumes higher natural gas and oil resources and technology
- **HighEV***
  - Projection assumes higher electric vehicles penetration
- **Port***
  - Fossil fuels for maneuvering and generating onboard are replaced by on-shore electricity by 2025. After 2025, energy consumption by marine ships is electricity
- **HighEE***
  - Innovations in building energy efficiency

*These scenarios are all side cases of Refnocpp

Methodology



Example ECFs downscaled from NEMS

National Emission Inventory (NEI)
Energy sectors: electricity, industrial, commercial, residential, marine, and oil/gas production
Transportation sector: on-road

SMOKE model (emissions projection)

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Air Quality Model (WRF/Chem)

Predicted concentrations:
CO, SO_2, NO_x, VOCs, O_3, $PM_{2.5}$, PM_{10}, and PM components

Model Configuration & Simulation Setup

Domain and Period

• Model	WRF/Chem v3.7.1
• Period & Domain	2008-2012 over CONUS
• Horiz. & Vert. Resolution	36 km (148×112) & 34 layers (up to 100 hPa)

Physics and Chemistry Options

• Radiation	RRTMG
• PBL & Land Surface	YSU & NOAH
• Cumulus	Multi-Scale Kain Fritsch
• Microphysics	Morrison 2-moment
• Gas-Phase Chemistry	CB05 with updated chlorine chemistry
• Aerosol Module	MADE/VBS
• Photolysis	F-TUV

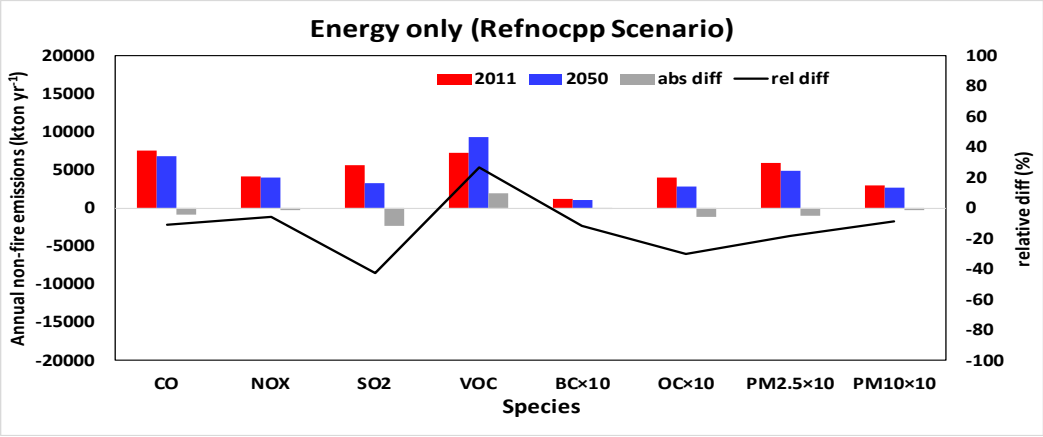
Input

• Chemical & Met. IC/BC	CESM/CAM5 v1.2.2 (He et al., 2015; Glotfelty et al., 2017) & NCEP/FNL
• Anthropogenic Emission	NEI 2011 for current years and projected 2050 for future year

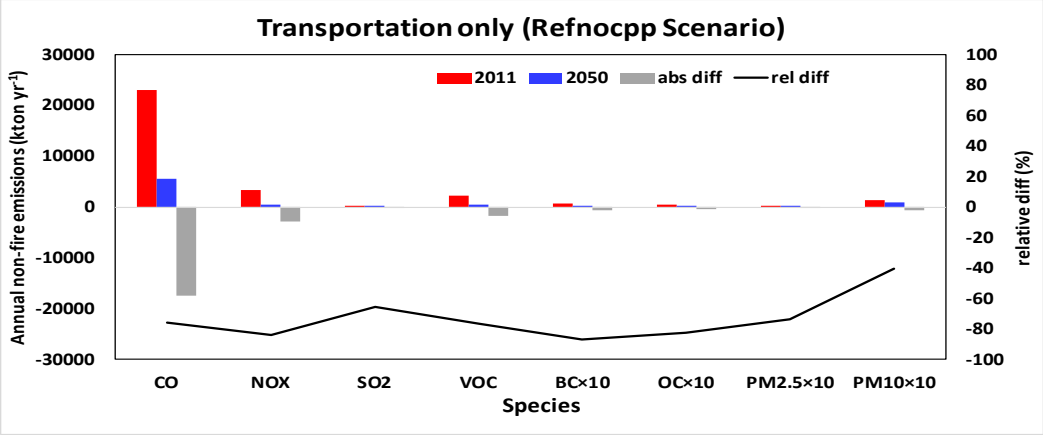
Run Index	Description
Base	Baseline simulation using the 2008-2012 climate and NEI 2011
E_refnocpp	Same as Base but with 2050 projected emis for major energy sectors under refnocpp scenario
T_refnocpp	Same as Base but with 2050 projected emis for onroad mobile sector under refnocpp scenario
TandE_ref	Same as Base but with 2050 projected emis for combined sectors under refnocpp scenario
TandE_highEV	Same as Base but with 2050 projected emis for HighEV scenario
TandE_highNG	Same as Base but with 2050 projected emis for HighNG scenario
TandE_port	Same as Base but with 2050 projected emis for Port scenario
TandE_highEE	Same as Base but with 2050 projected emis for HighEE scenario

Emission Projections-Refnocpp Scenario

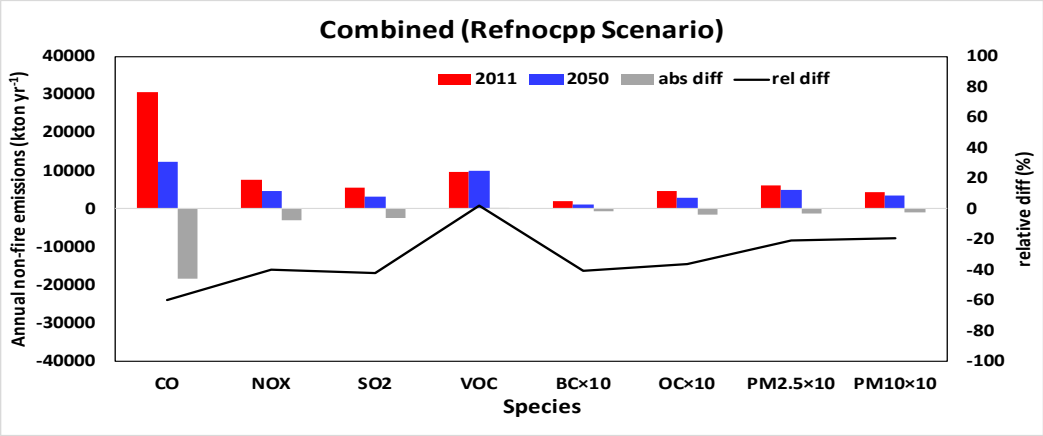
Energy



Transportation

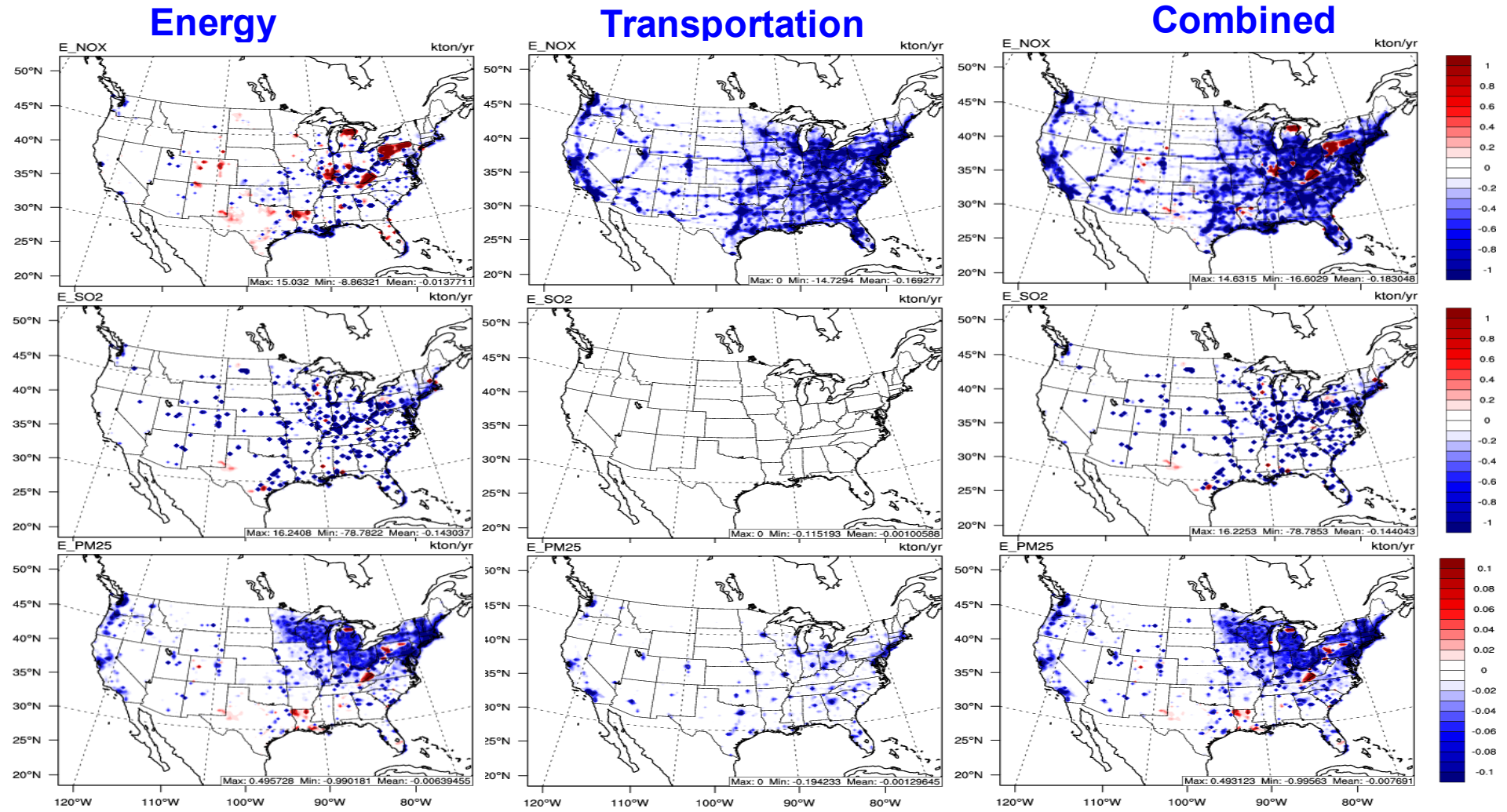


Combined



- Much larger reduction of SO_2 and PM for energy sectors
- Reduction of CO, NO_x, and VOCs more dominant by transportation sector
- Large reduction of VOCs emissions from mobile sources offset by increases in oil/gas production

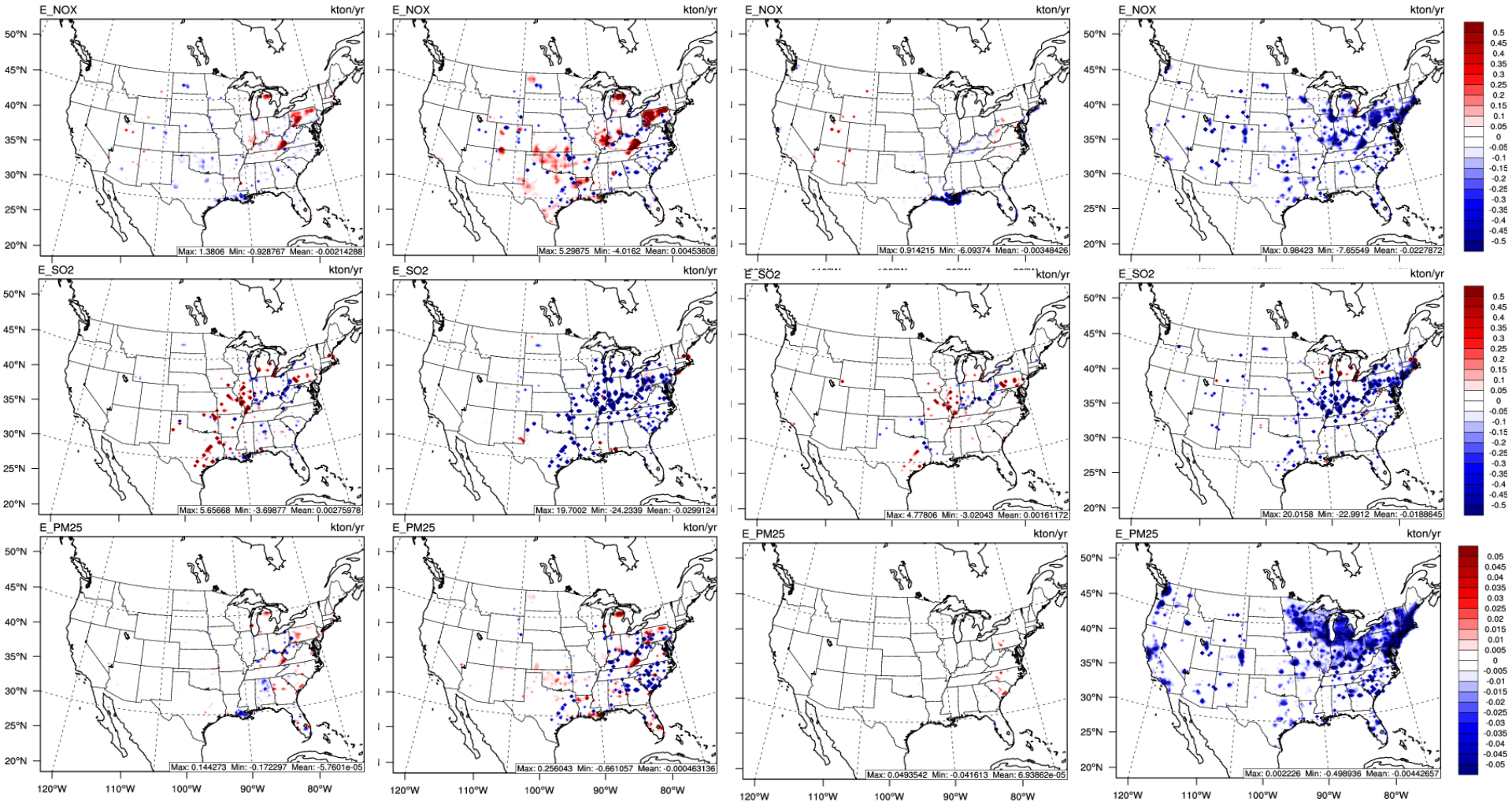
Emission Projections-Refnocpp Scenario



- **Transportation emissions projected to decrease over CONUS for all species, those in energy sectors show more heterogeneity with increases especially for NO_x, VOCs , and $PM_{2.5}$ in some regions due to more oil & gas production**
- **Overall emission changes for NO_x are dominated by on-road mobile sources while those for SO_2 and $PM_{2.5}$ are dominated by power/industrial sectors**

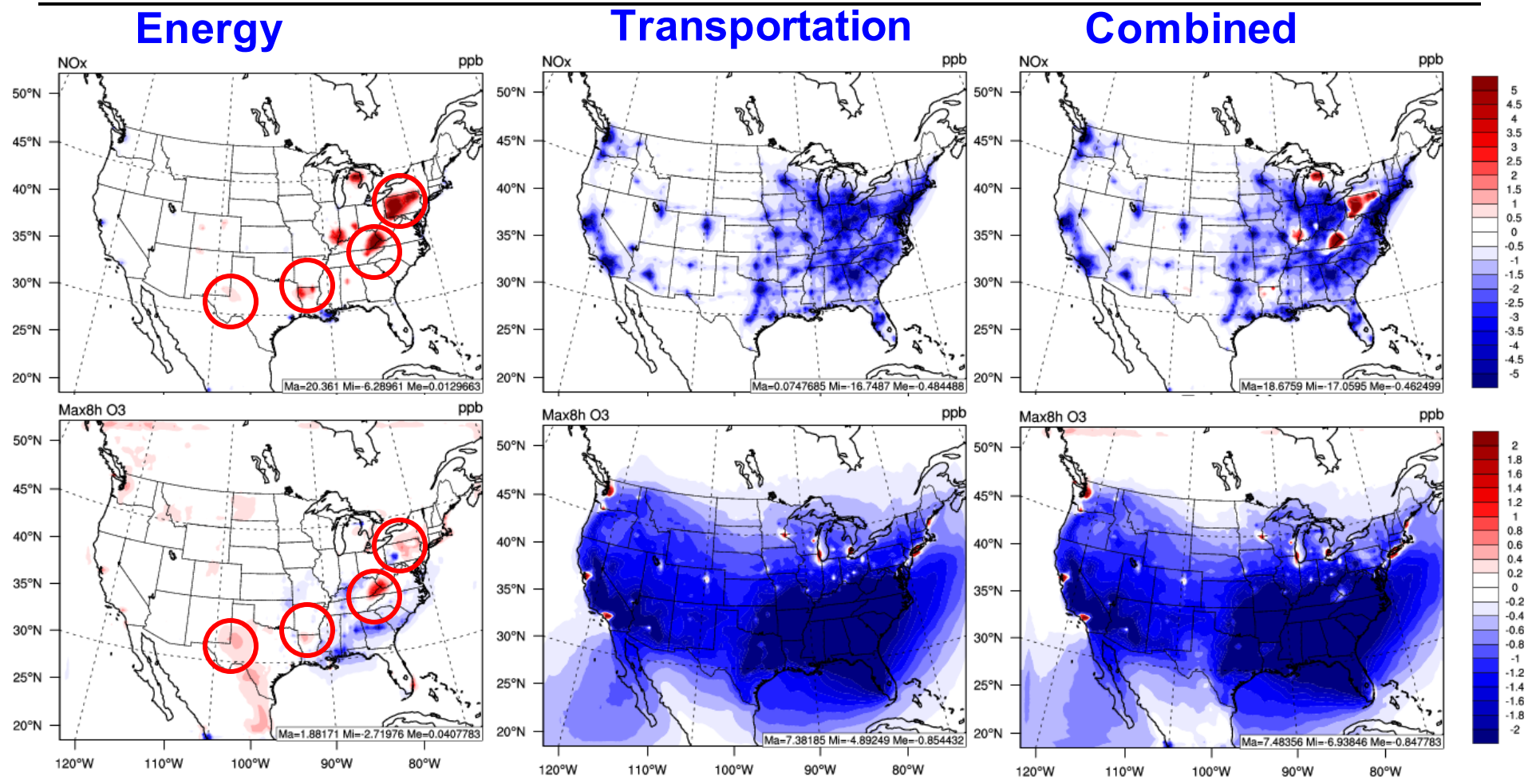
Emission Projections-Other Scenarios

HighEV-Refnocpp HighNG-Refnocpp Port-Refnocpp HighEE-Refnocpp



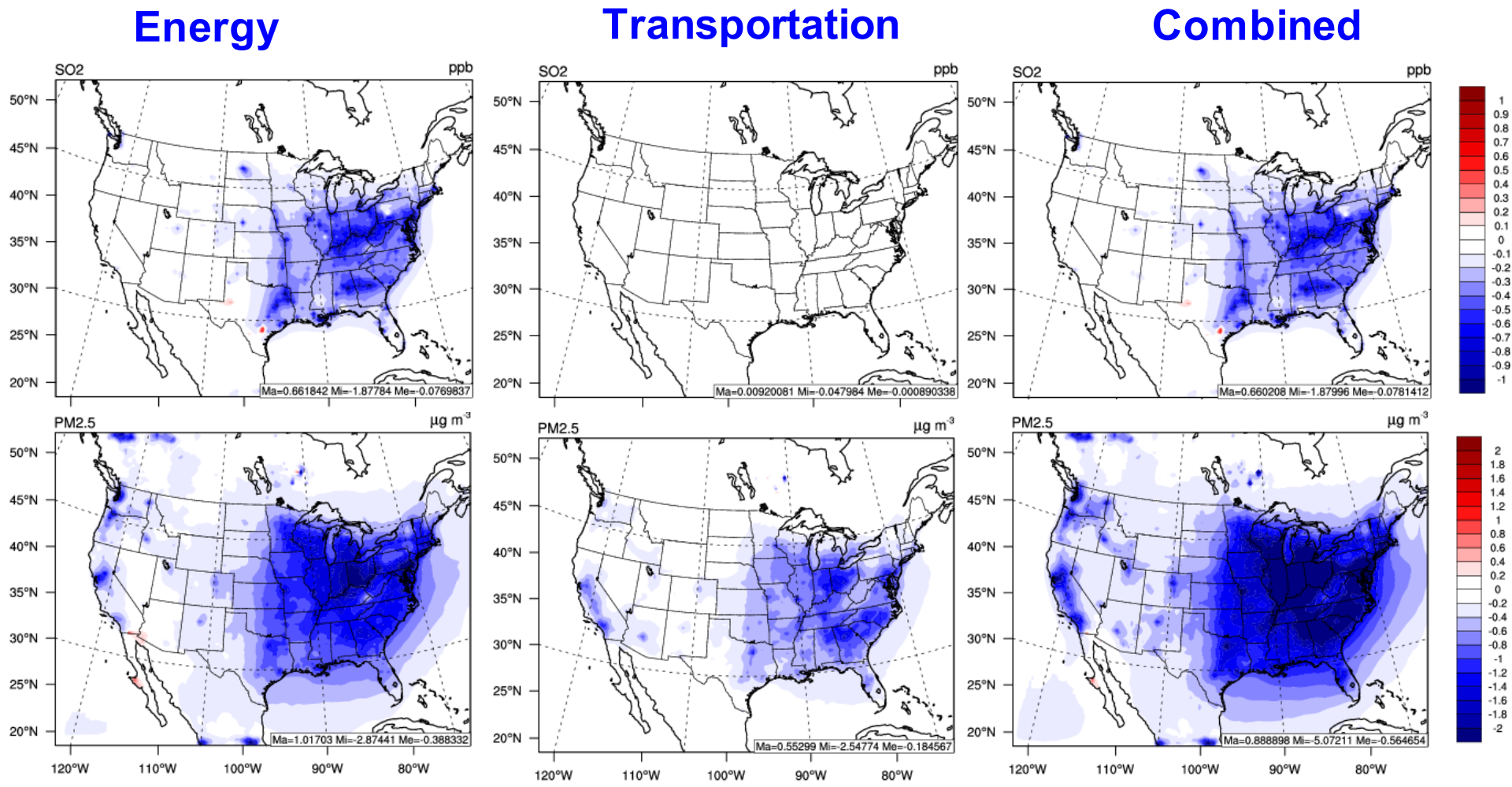
- **Compared to refnocpp, other scenarios show noticeable differences for emission changes due to different energy transition assumptions**
- **highEE shows the largest reductions**

Air Quality Projections-Refnocpp Scenario



- **Wide-spread domain-mean and maximum reductions of max 8hr O_3 by ~1.5 ppb (~4.0%) and up to 6.9 ppb (~15%), respectively in combined case**
- **Dominant impacts from transportation on O_3 reduction**
- **Noticeable increases (hot spots) for NO_x and O_3 over TX, LA, KY, and PA etc., due to the increased precursor emissions caused by oil & gas production**

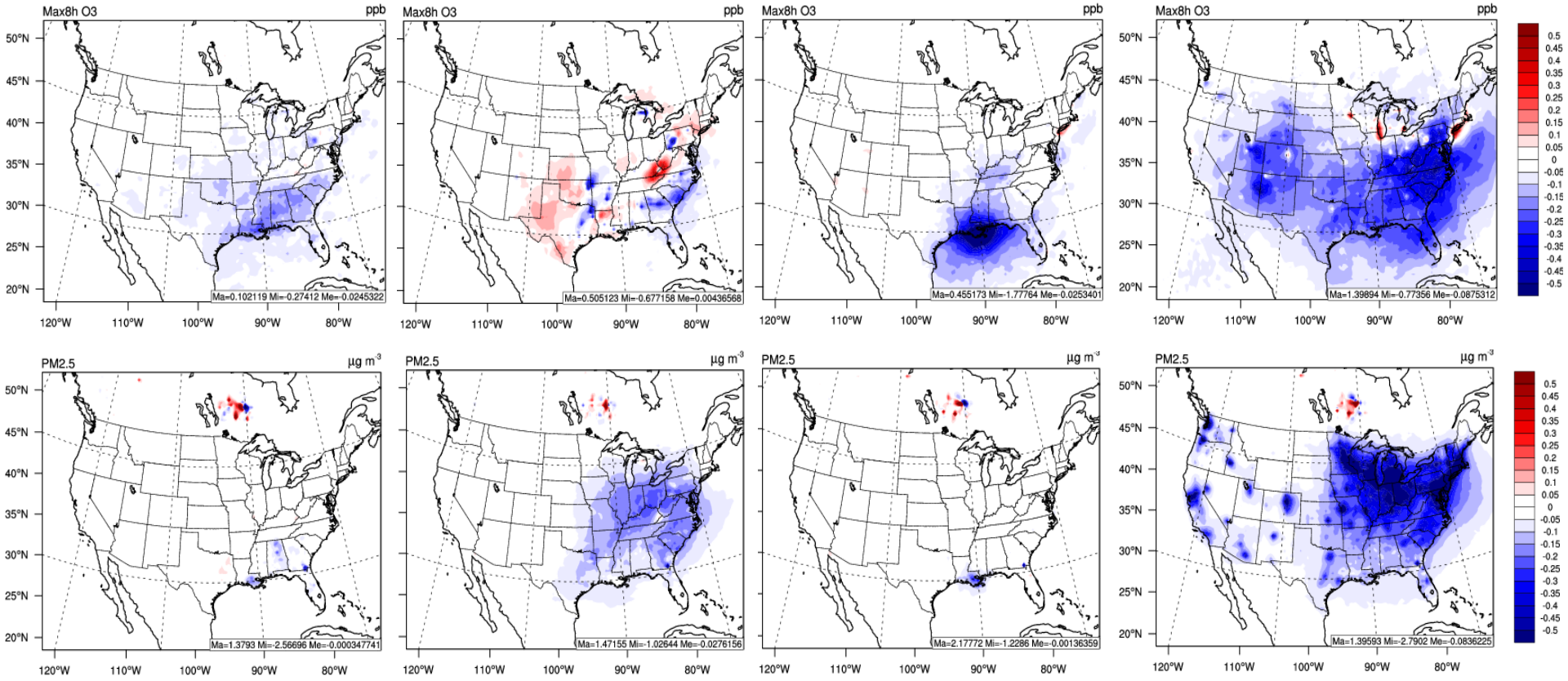
Air Quality Projections-Refnocpp Scenario



- **Wide-spread domain-mean and maximum reductions of $PM_{2.5}$ are by ~1.0 µg m^{-3} (~16.3%) and up to 4.1 µg m^{-3} (~39.1%), respectively in combined case**
- **Dominant impacts from energy sectors on both SO_2 and $PM_{2.5}$ reduction**

Air Quality Projections-Other Scenarios

HighEV-Refnocpp HighNG-Refnocpp Port-Refnocpp HighEE-Refnocpp



- **WRF/Chem simulations show noticeable changes of max 8h O_3 and $PM_{2.5}$ over specific regions between scenarios due to different assumptions**
- **Overall highEE scenario shows the largest reduction over CONUS due to large decreases in building demand for energy**

Major Findings and Future Work

- Projected emission changes in 2050 under all future scenarios show large reduction for CO, NO_x, and SO_2 due to the retirement of coal power plants and gasoline vehicles, but small increase for VOCs and moderate reduction for $PM_{2.5}$ due to offset of increased natural gas/oil production in states such as TX, PA, OH, and KY
- Emission trends for CO, NO_x, and VOCs are dominated by on-road mobile sources while those for SO_2 and $PM_{2.5}$ are mainly affected by energy sectors such as power plants and industry
- WRF/Chem simulations using projected emissions show domain-mean small increase for VOCs (1.4 to 5.7%); small to moderate reductions for max 8hr O_3 (-3.9 to -4.3%), CO (-10.1 to -11.1%), and $PM_{2.5}$ (-12.0 to -13.7%); and relatively large reduction for NO_x (-31.6 to -38.8%) and SO_2 (-34.6 to -41.8%), indicating the important roles of future energy transition in air quality
- **Future work:** completing multi-decadal projection (e.g., 2020, 2030, and 2040) and examining the impacts of changes in climate, land use/cover, and lateral boundary conditions on future air quality

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