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Comparing estimates of SO_2 and NOx emissions inventories for the U.S. and China: exploring the reasons for discrepancies between EDGAR and ECLIPSE

Mingyuhui (Jane) Liu, Clementine (Clemi) Sraha, Kaifeng Xu
Advisor: Dalia Patino-Echeverri
Client and co-advisor: Karl Seltzer

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Question

- What are emission inventories
- What are EDGAR and ECLIPSE
- Why do they matter

1

Background

Background

Emission Inventory

- An estimation of current air emissions
- A projection of those emissions
- Simulated with computer models based on assumptions
- Data can be used as guidance for policy making process

Data Sets

- EDGAR (Emissions Database for Global Atmospheric Research)
- ECLIPSE (Evaluating the Climate and Air Quality Impacts of Short-lived Emissions)

Background - ECLIPSE

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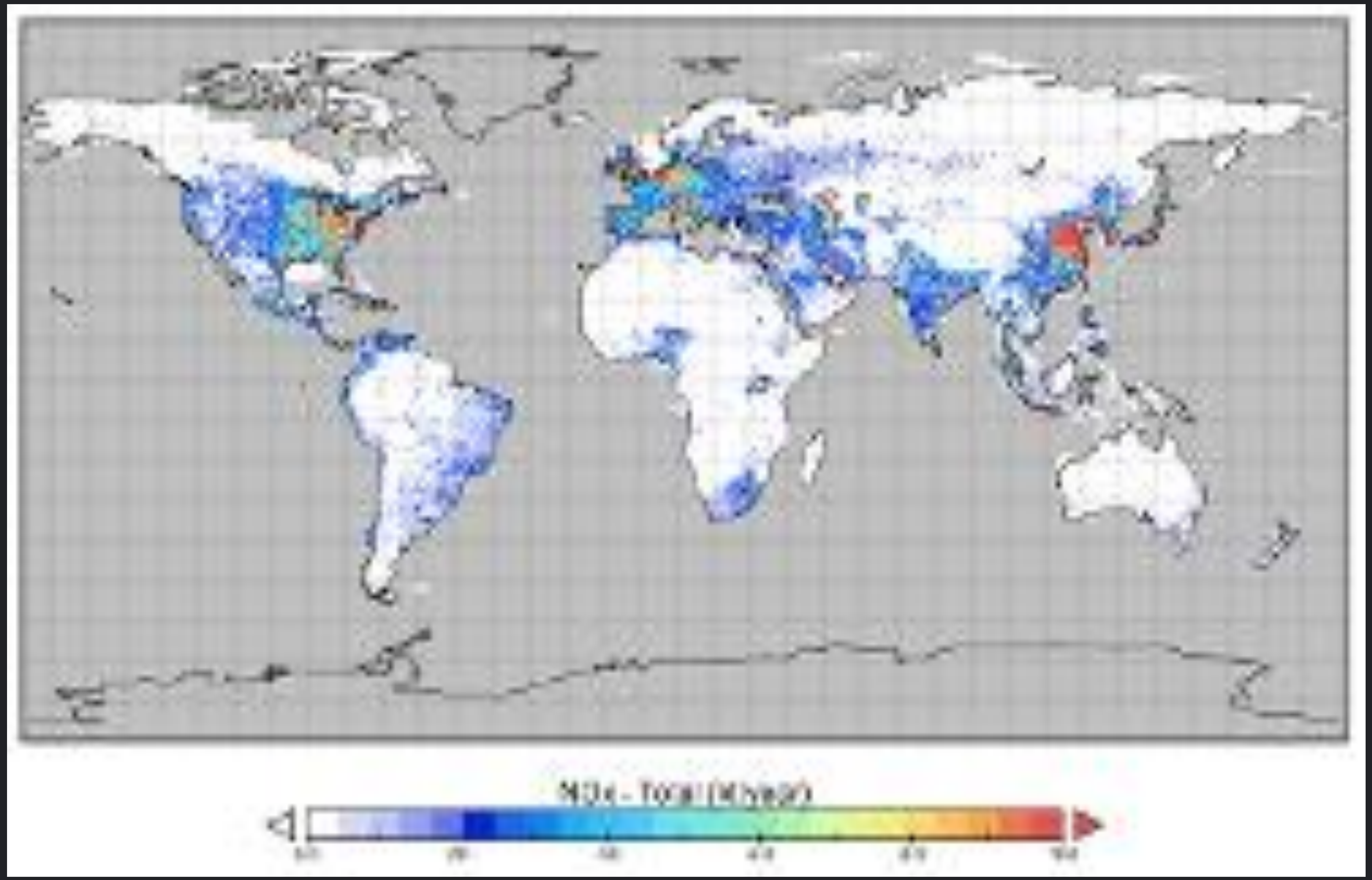
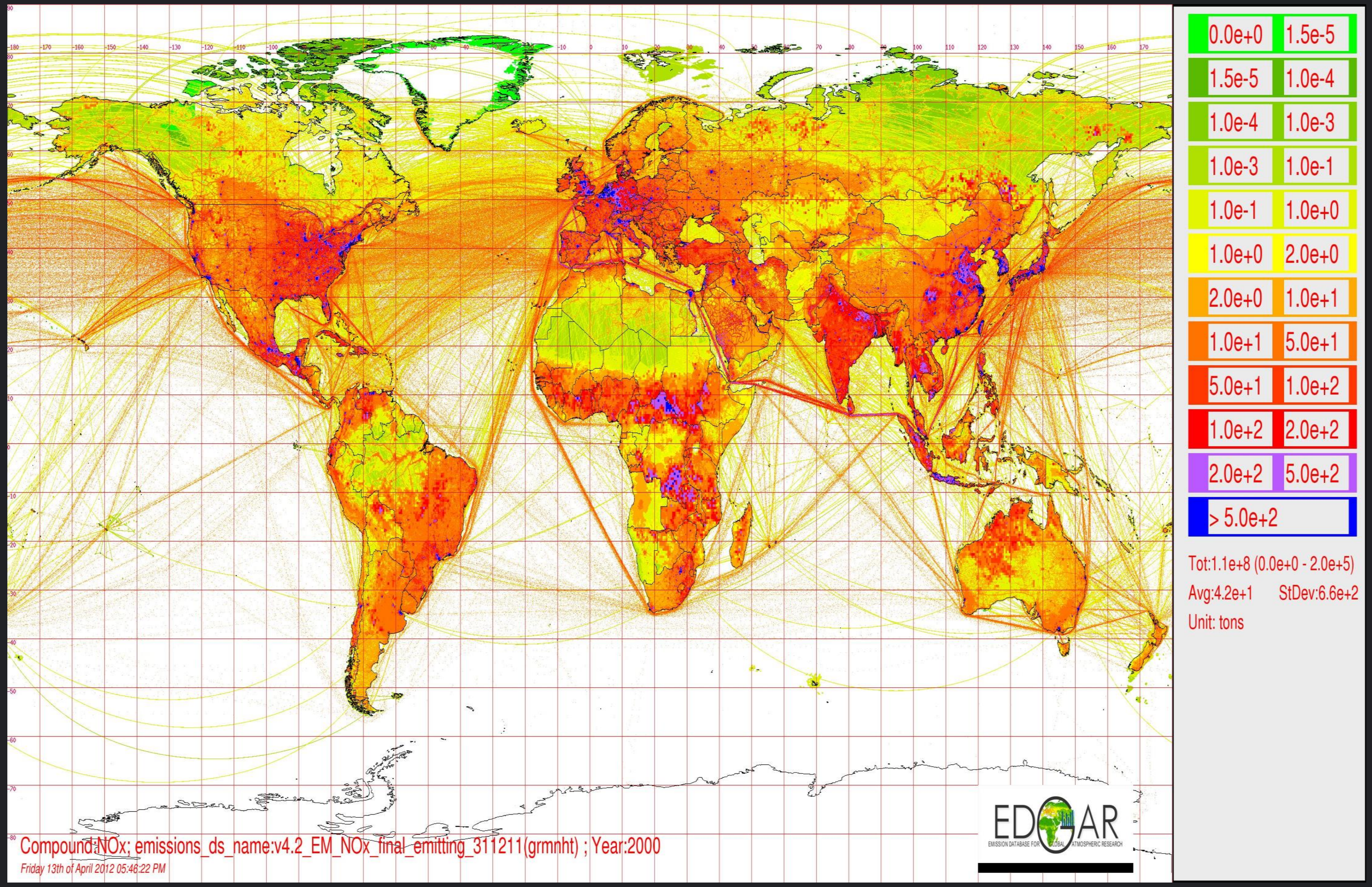


ECLIPSE V5a (July 2015),International Institute for Applied Systems Analysis (IIASA), http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html

Uses the GAINS model to get global air pollutant and GHGs emission

- 0.5^ox0.5^o longitude-latitude as spatial distribution by sector
- Output in ktons of pollutant per year/grid
- SO2, NO2,NH3,CO,CH4,BC,OC,PM2.5,PM10
- Several of scenarios provided depending on assumptions
- The V5 version dataset with period covered: 1990-2030,2040,2050

Background - EDGAR

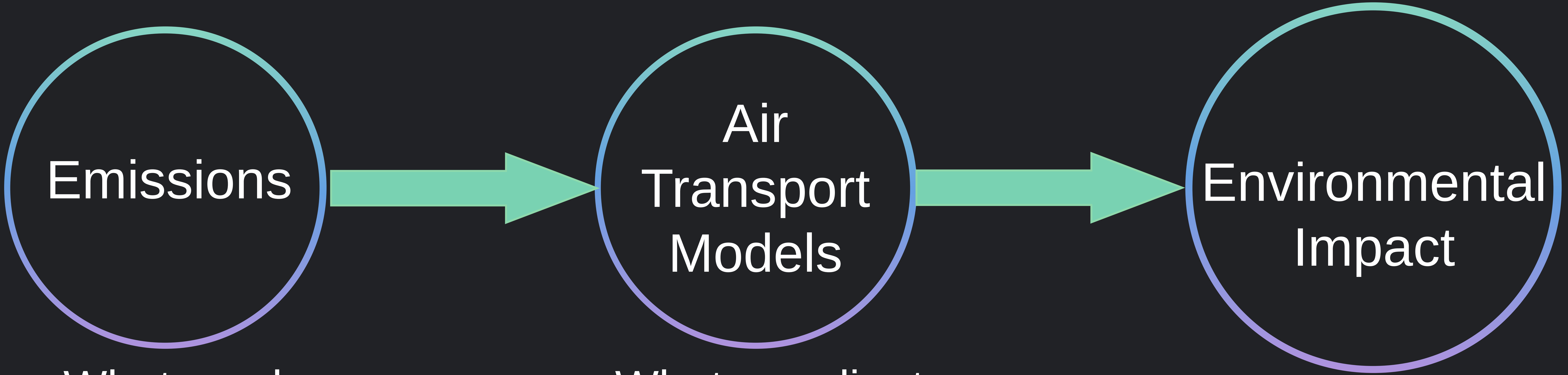


EDGAR 4.2 NOX (2000), Emission Database for Global Atmospheric Research
http://edgar.jrc.ec.europa.eu/overview.php?v=431#

Developed by the European Commission and the Netherlands Environmental Assessment Agency to simulate global air pollutant and GHGs emissions

- 0.1ºx0.1º longitude-latitude as spatial distribution by sector
- Output in kg S or kg N of pollutant per s/m^2
- SO2, NO2,NH3,CO,CH4,OC,,PM10
- The V4. 2 version dataset with period covered:1970-2008

[redacted]



What we do

What our client does

To compare datasets

To use dataset to build models

2

Objectives

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EDGAR and ECLIPSE emissions are not the same

They are not readily comparable

- Overlapped periods for these two datasets: 2000,2005, and the close period 2008,2010
- Lack of systematic comparison of the assumptions and model design underlying these two datasets

1. To compare assumptions reflected in the EDGAR and ECLIPSE
2. To determine what variable can be adjusted in the systems models that are used to develop emission inventories
3. To implement in depth studies on emissions from four main sectors for both datasets on both global and national levels

3

Method

Method

Sector Selection

ECLIPSE Sector Name	ECLIPSE Code	EDGAR Code	EDGAR Sector Name
Energy/Power	ENE	ENE + PRO + OTH	Power industry + Fuel Exploitation + Fossil Fuel Fires
Domestic	DOM	RCO	Energy for Building
Industry	IND	IND+PPA	Combustion for Manufacturing + Production Emission
Transportation	TRA	TRO	Road Transportation

1

Selecting Four sectors to investigate the differences of NOx and SO2 emissions

Method

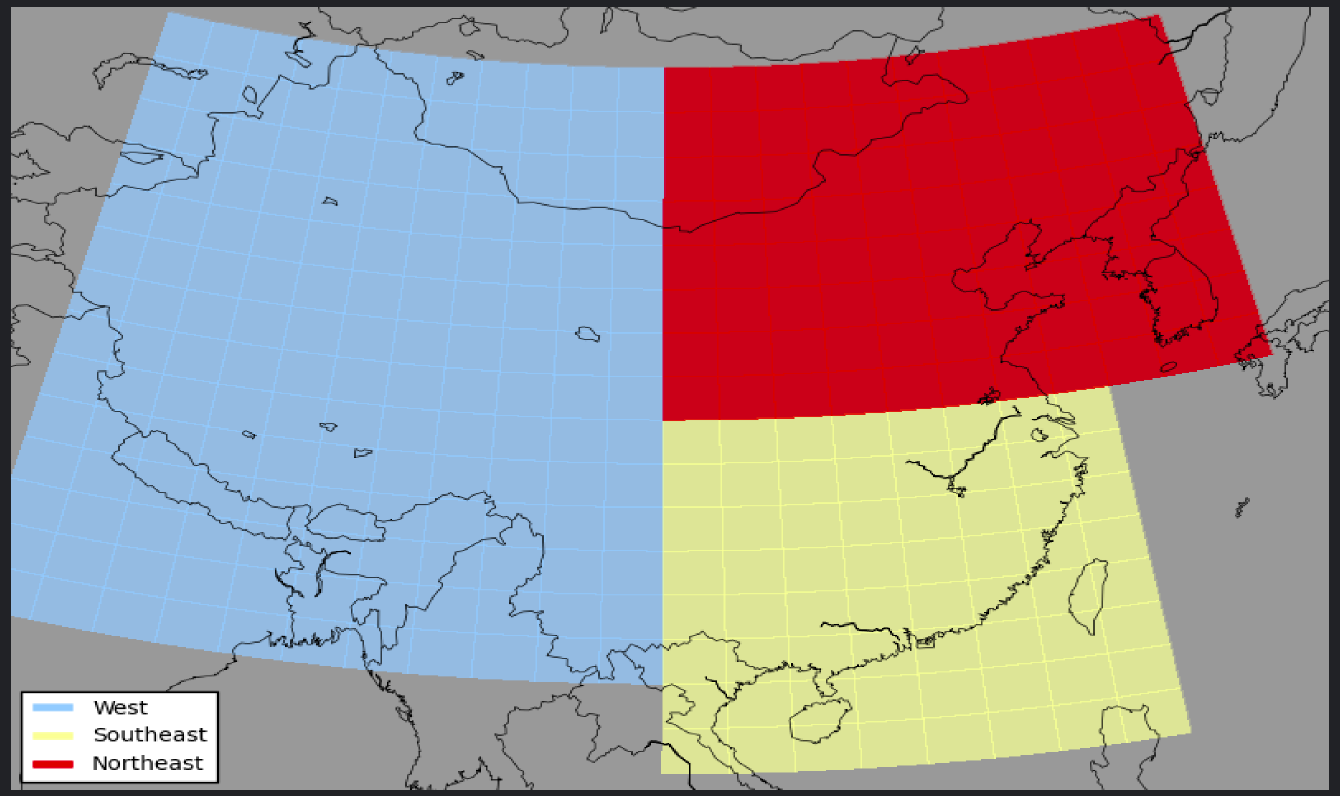
Aggregation and Slicing Datasets

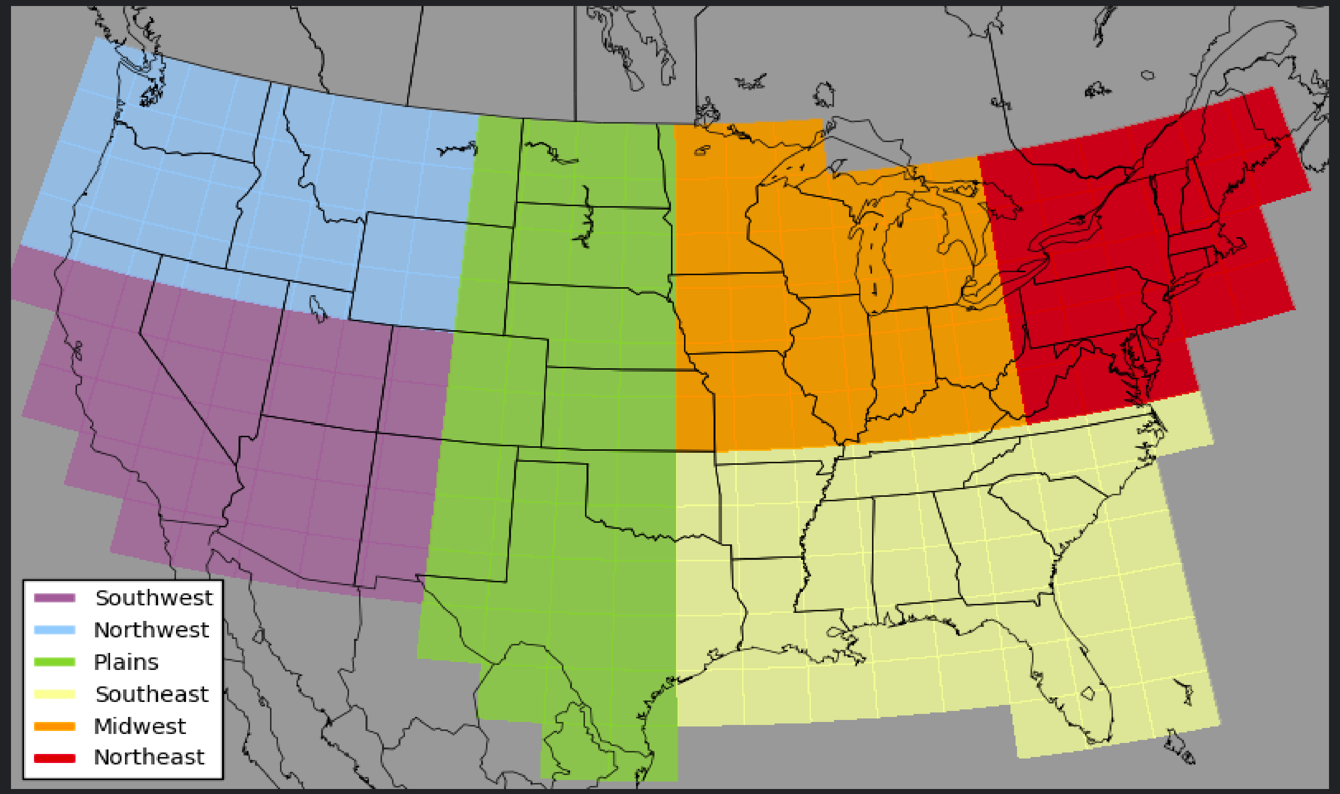
2

Making two dataset comparable and slicing the global datasets

To make the spatial form comparable, Python was used to aggregate EDGAR and ECLIPSE. 2.5^{o}x2.5^{o} longitude-latitude as spatial distribution and kTons/year as emission unit to compare

- To Compare global NOx and SO2 emissions
- To compare emissions on national level, using China and the US as examples
- To compare emissions on regional level by slicing the data





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Model Comparison

3

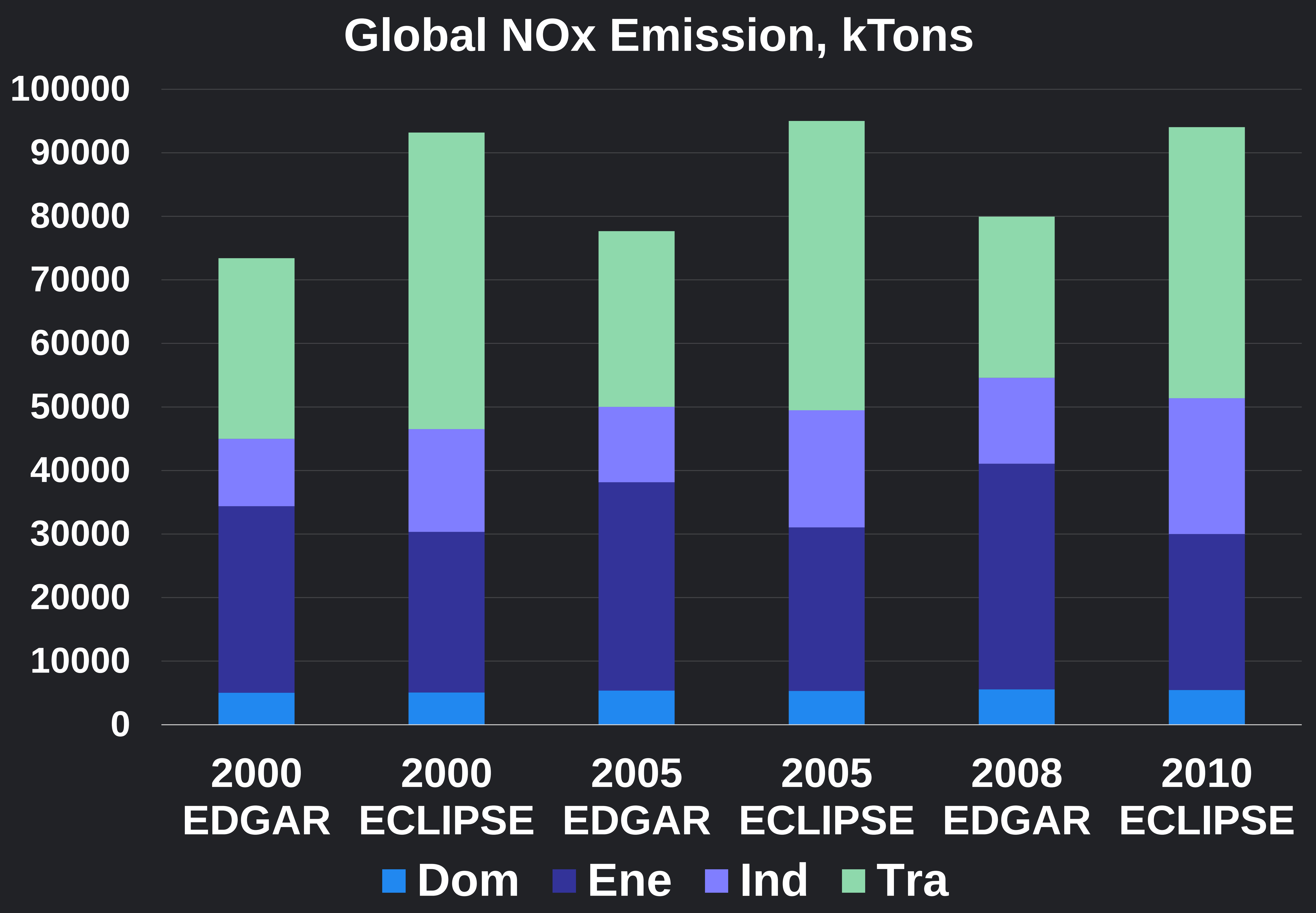
Investigate Assumptions and Model Designs

- Methodologies used to develop each datasets
- Section definitions for each datasets
- Assumptions used to develop each datasets

4

Data Comparison Result

Result – Global NOx



Transportation sector drives the most difference globally

ECLIPSE emissions are higher than EDGAR for all sectors except ENE

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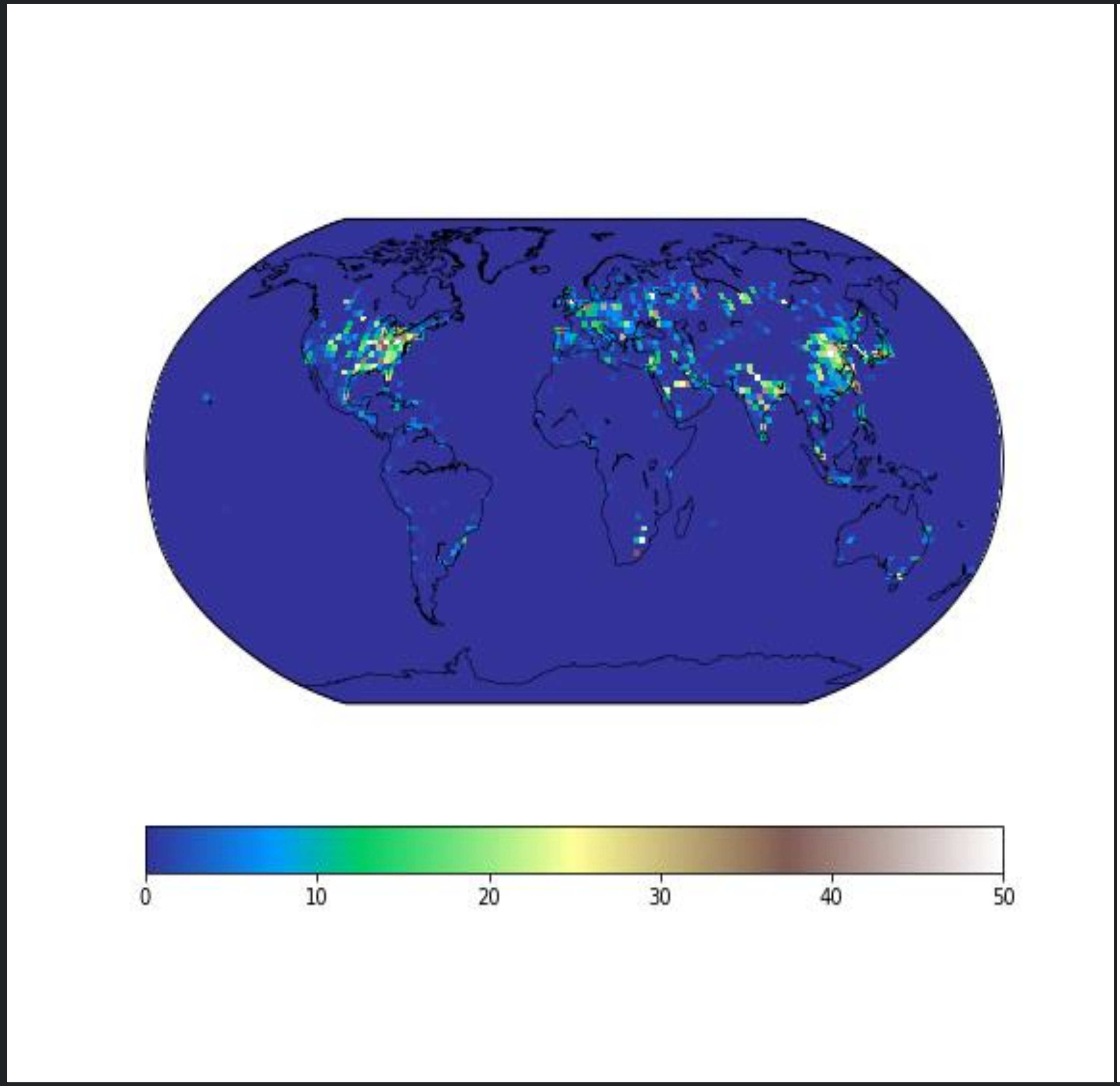
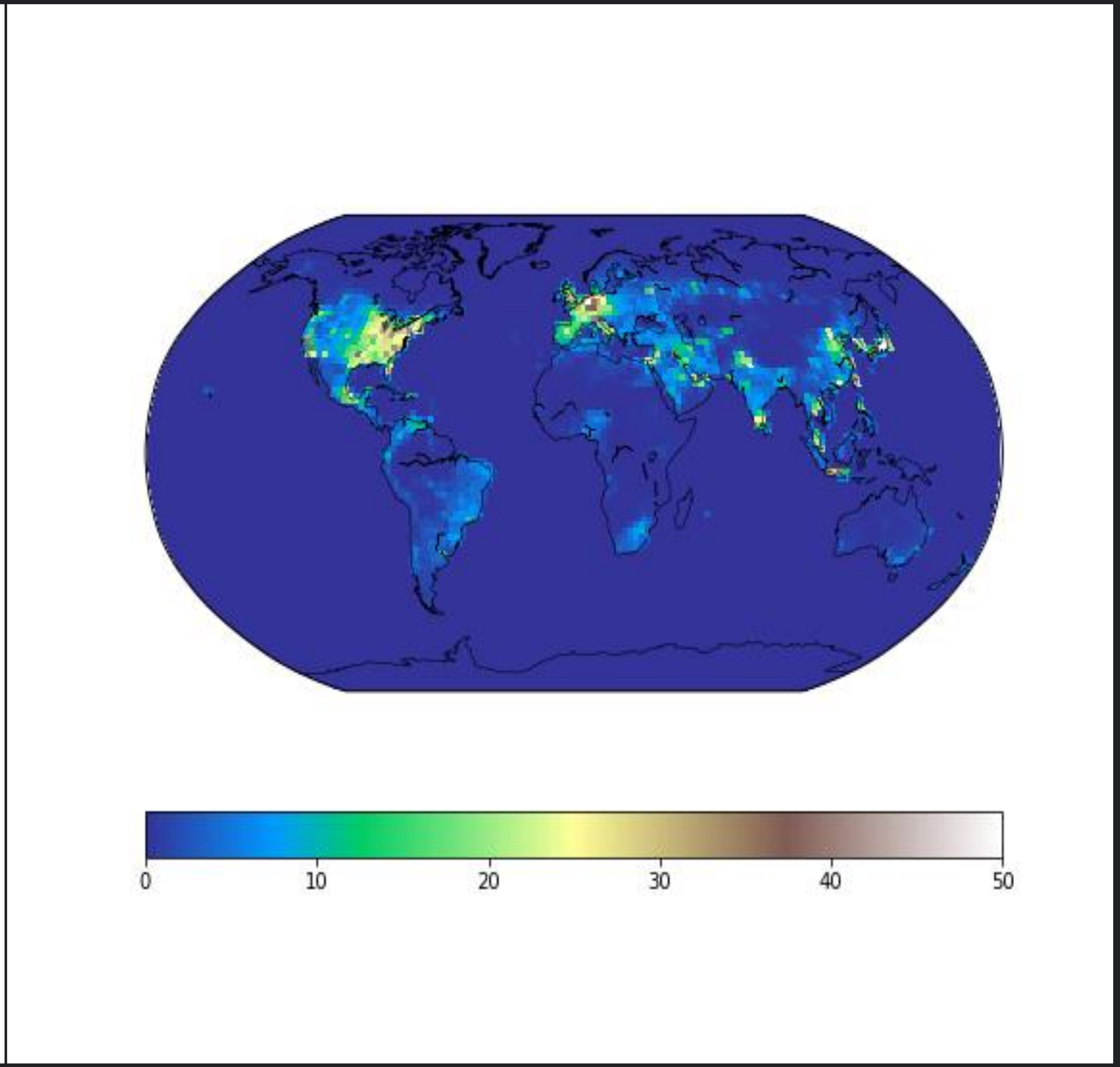
Global Spatial Plots for NOx kTons/y Emission in Summer 2000, Transportation Sector

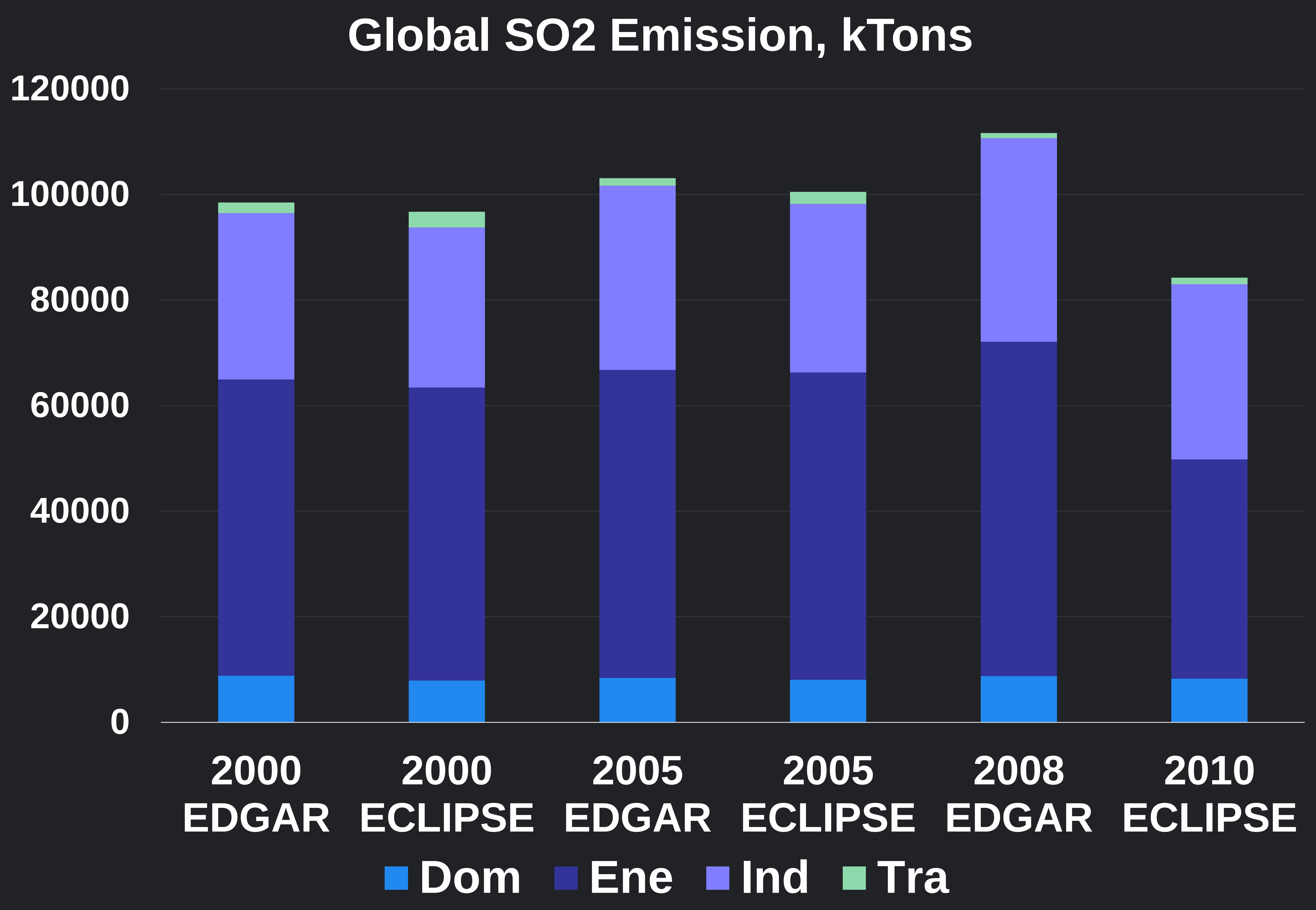


EDGAR



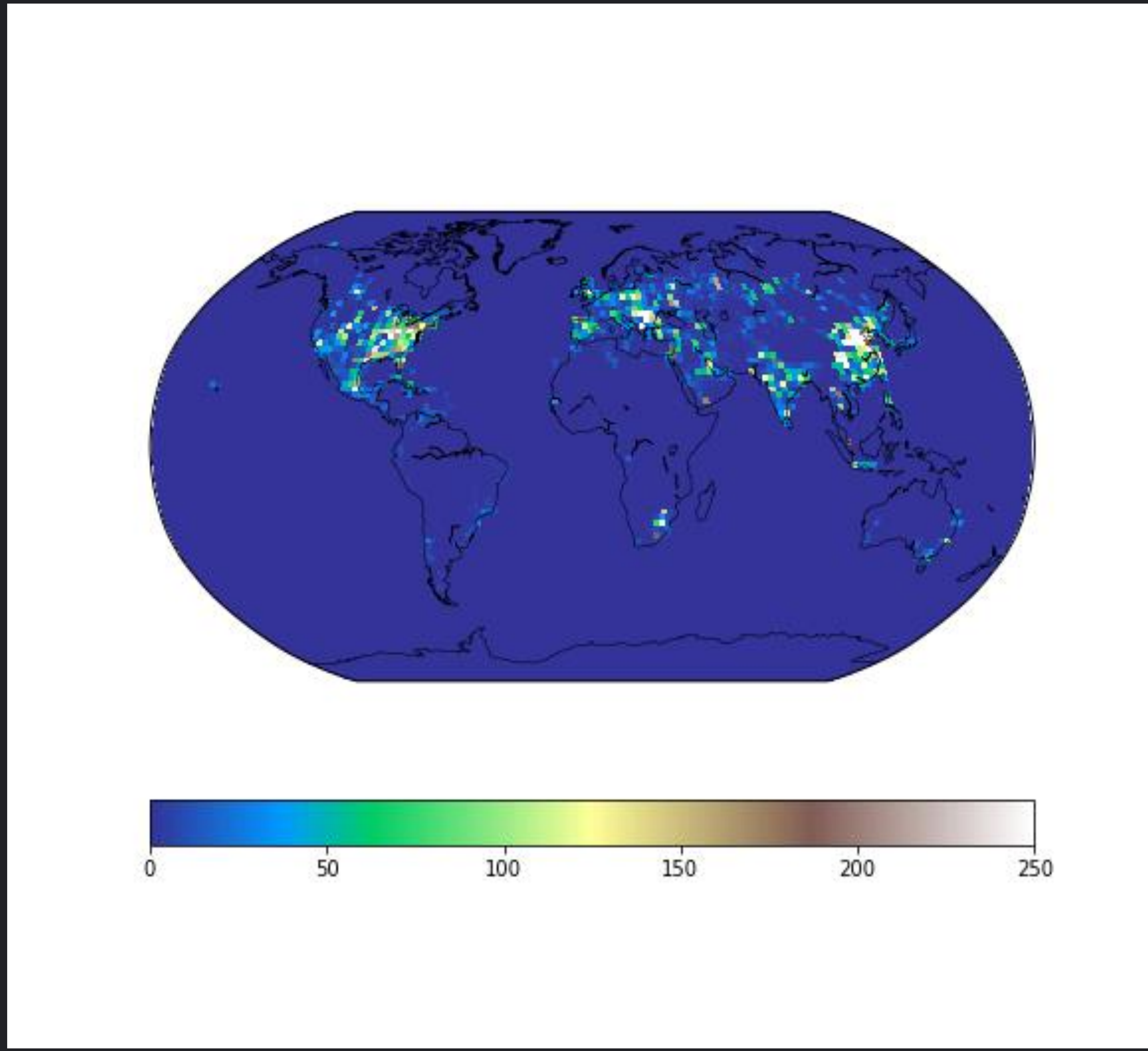
ECLIPSE

Result – Global SO2

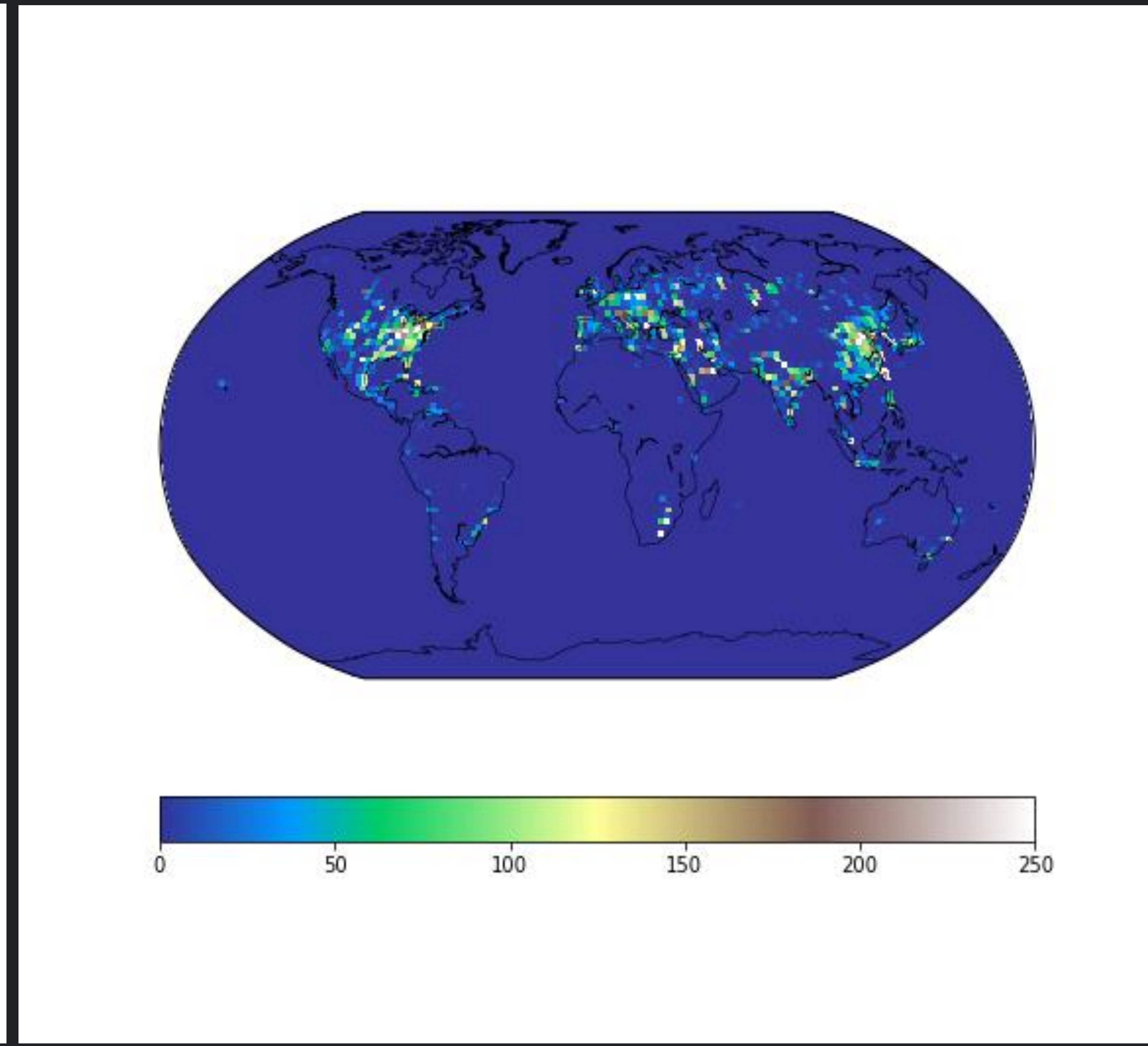


Emissions look similar globally

Global Spatial Plots for SO2 kTons/y Emission in Summer 2000, ENE Sector

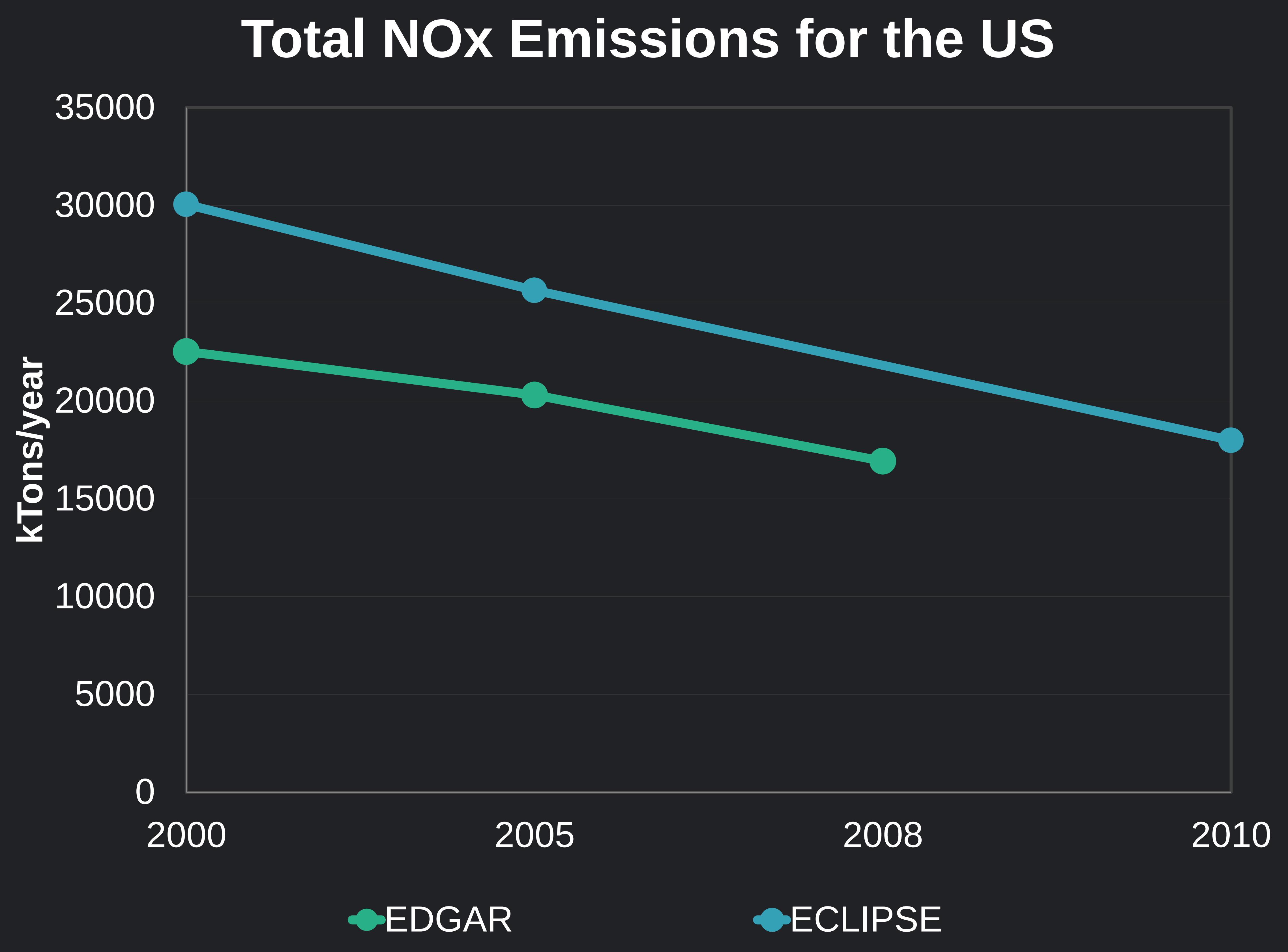


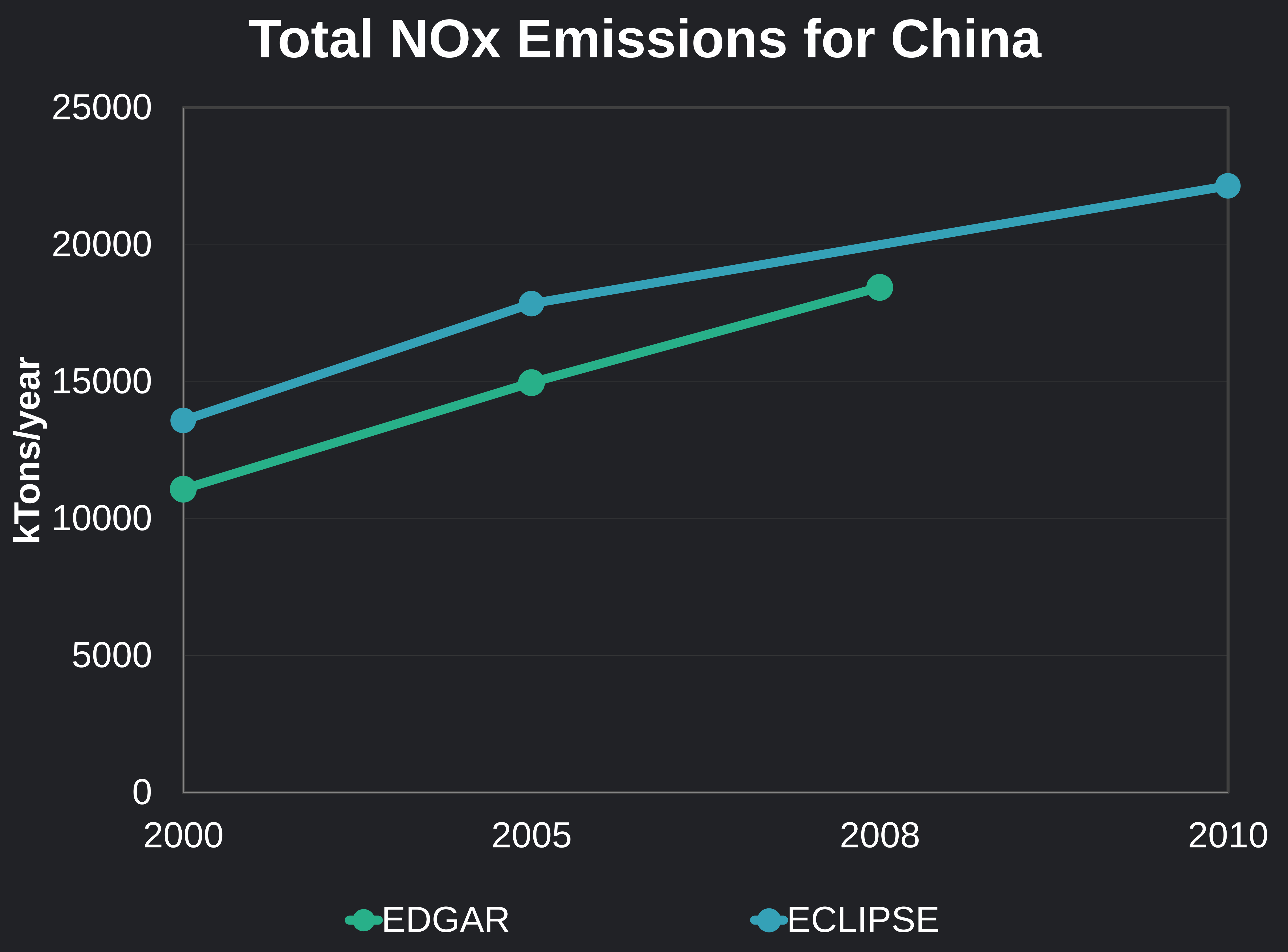
EDGAR



ECLIPSE

Result – NOx by Nation





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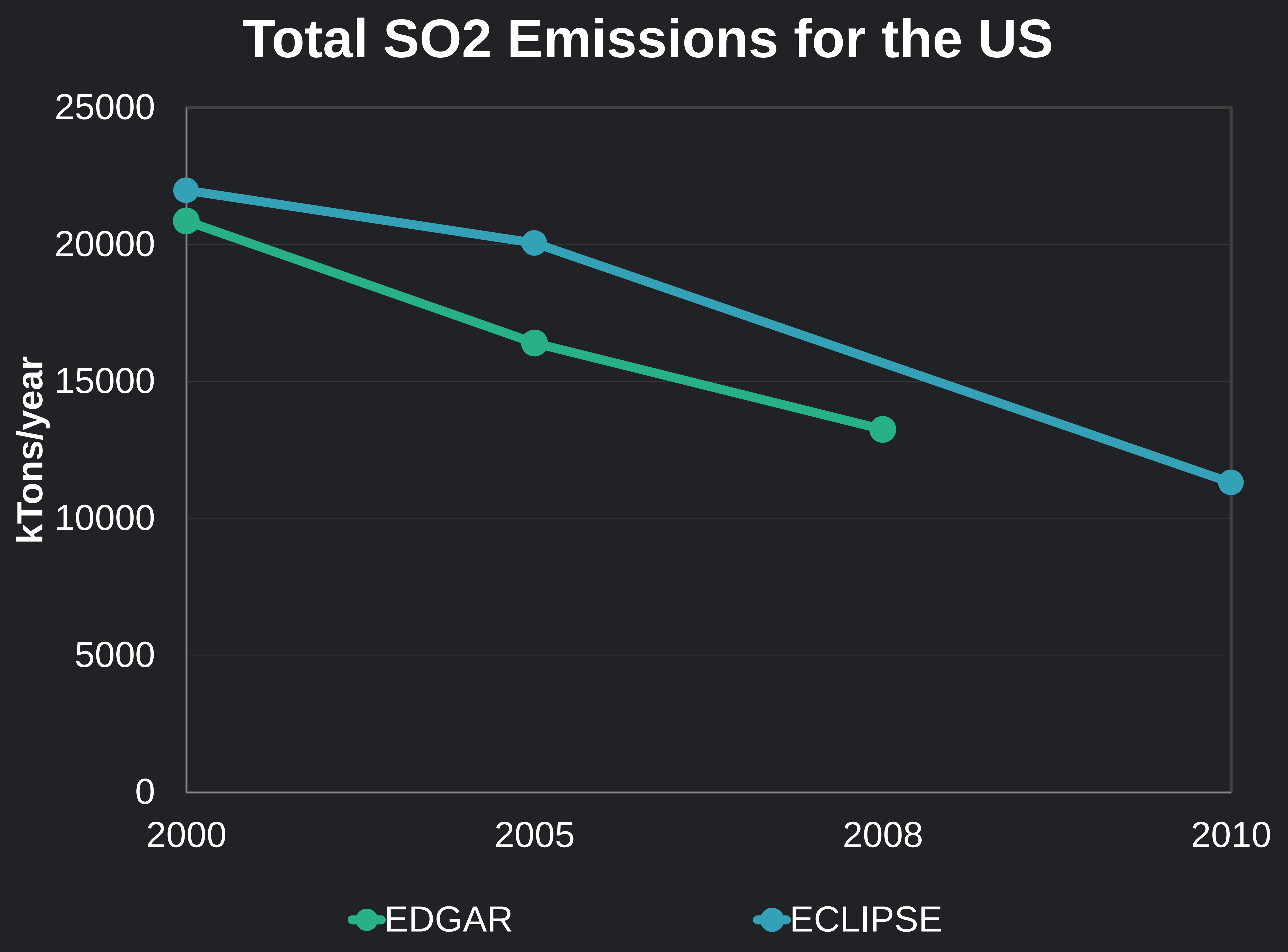
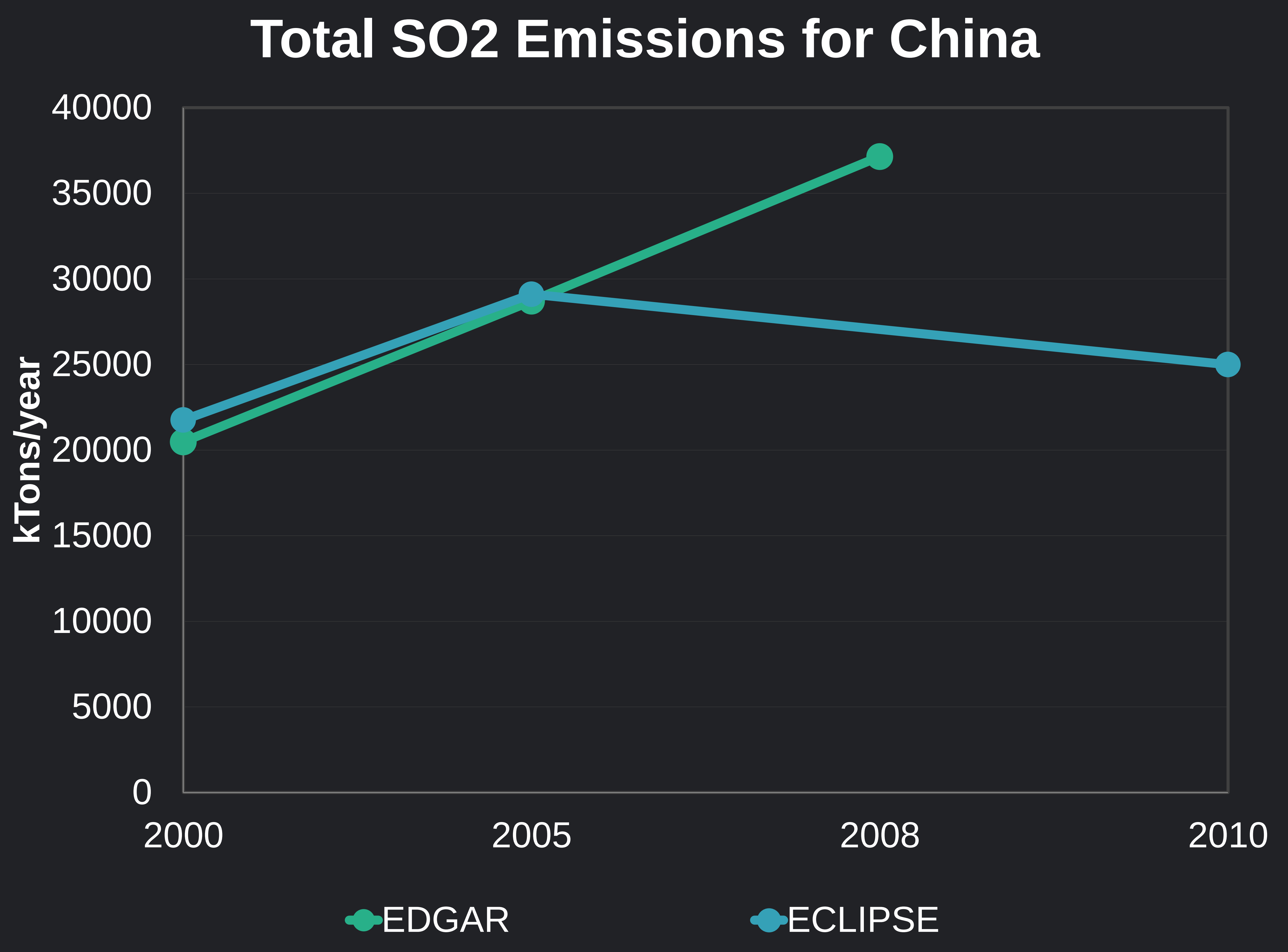
Result – SO2 by Nation





Result – SO2 Regional

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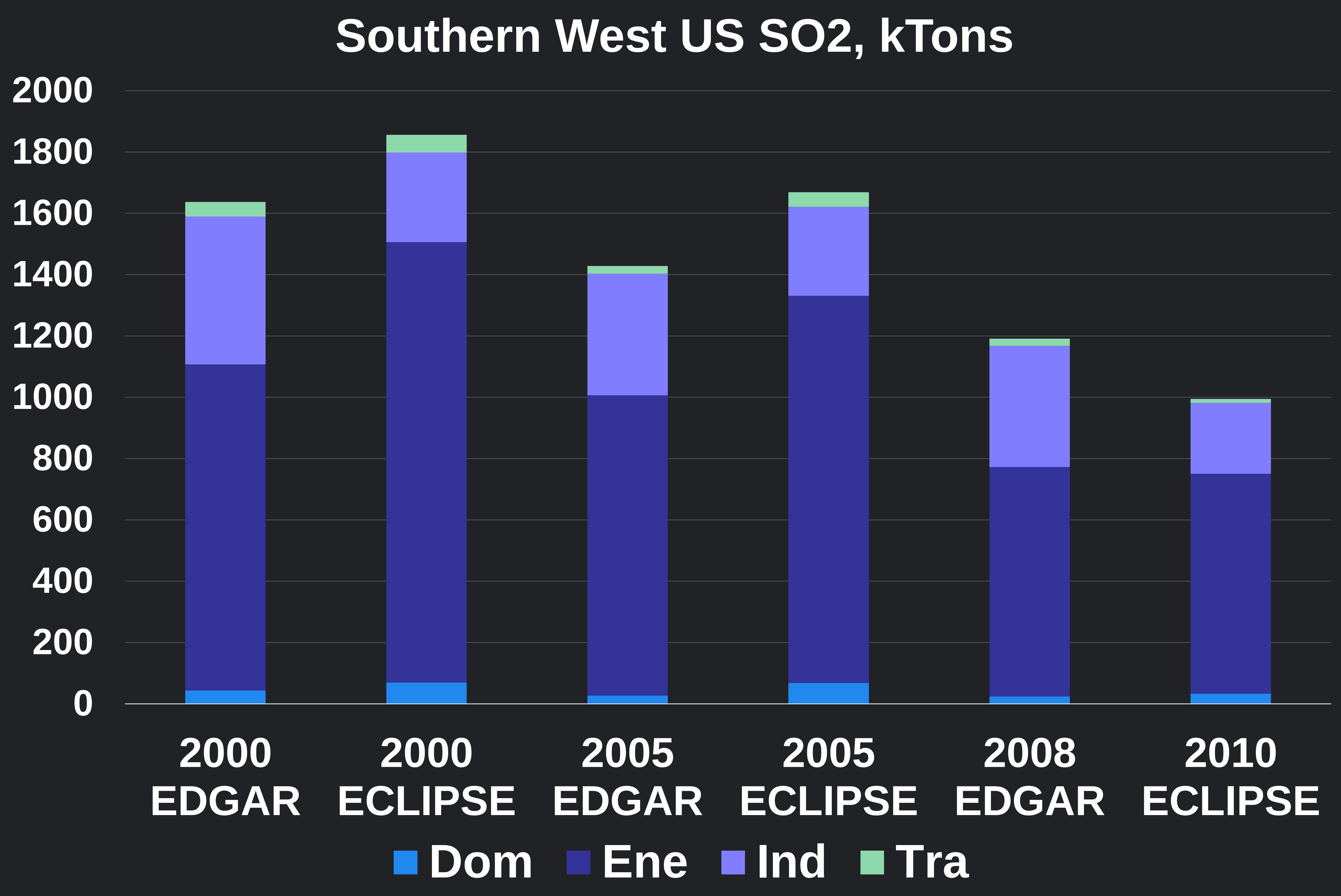


Globally the SO2 emissions look similar but varies a lot on regional level

5

Discussion for ECLIPSE Model

ECLIPSE Main Equation

$$E_{i,p} = \sum_{k}\sum_{m} A_{i,k}ef_{i,k,m,p}x_{i,k,m,p}$$

Subscripts

i - country

k -activity

m -abatement measure

p -pollutant

Variables and subscript names

$E_{i,p}$ - pollution emissions for given country;

$A_{i\,k}$ - activity level of the given activity type for a given country

ef_{ikmp}- represents the given emission factor of a given pollutant for a given activity for a selected country after a given control measure has been implemented ;

x_{ikmp} -proportion of a total given activity type where an emission control measure has been applied

Example

$$E_{i,p} = \sum_k \sum_m A_{i,k} ef_{i,k,m,p} x_{i,k,m,p}$$

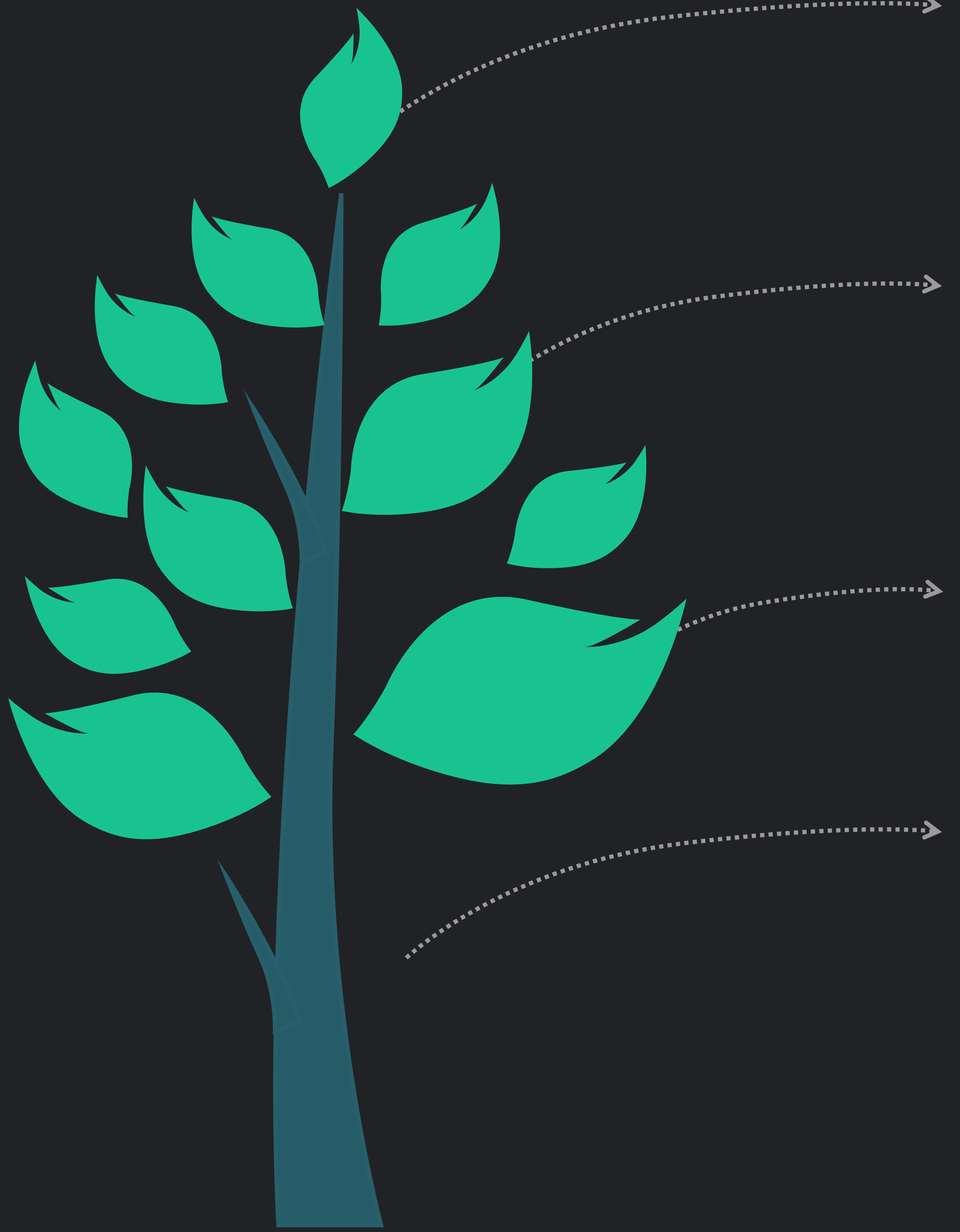
$$E_{i,p} = A_{i,k} ef_{i,k,m,p} x_{i,k,m,p}$$

$$Emissions_{China, SO_2\ in\ coal\ comsumption\ in\ power\ plants} =$$
$$Activity\ level_{China, coal\ consumption\ in\ power\ plants} *$$
$$Quantity\ of\ pollutant\ emitted_{China, coal\ consumption\ in\ power\ plants, pollution\ taxes, SO_2} *$$
$$\%\ Activity_{China,\ coal\ consumption\ in\ power\ plants, for\ which\ pollution\ taxes,\ for\ SO_2\ emissions\ is\ applied}$$

Four Selected Sectors

ECLIPSE NAME	BRIEF DESCRIPTION	ECLIPSE CODE
Domestic	Residential, commercial (combustion), services, agriculture etc	**DOM**
Energy/Power	Power Plant, inputs of non-fossil fuels as well as total electricity and heat generation	**ENE**
Industry	Fuel Combustion, Paper, Iron, Chemical Industry	**IND**
Transportation	Motor cycles, Vehicles, Buses, Railways etc	**TRA**

ECLIPSE V5a was simulated based on GAINS model, assumptions used include:



- Energy Use in Transportation
- Total Primary Energy Supply
- Building and Industrial sectors
- Cost calculation
- Conversion efficiency from non-combustion
- Other mobile source

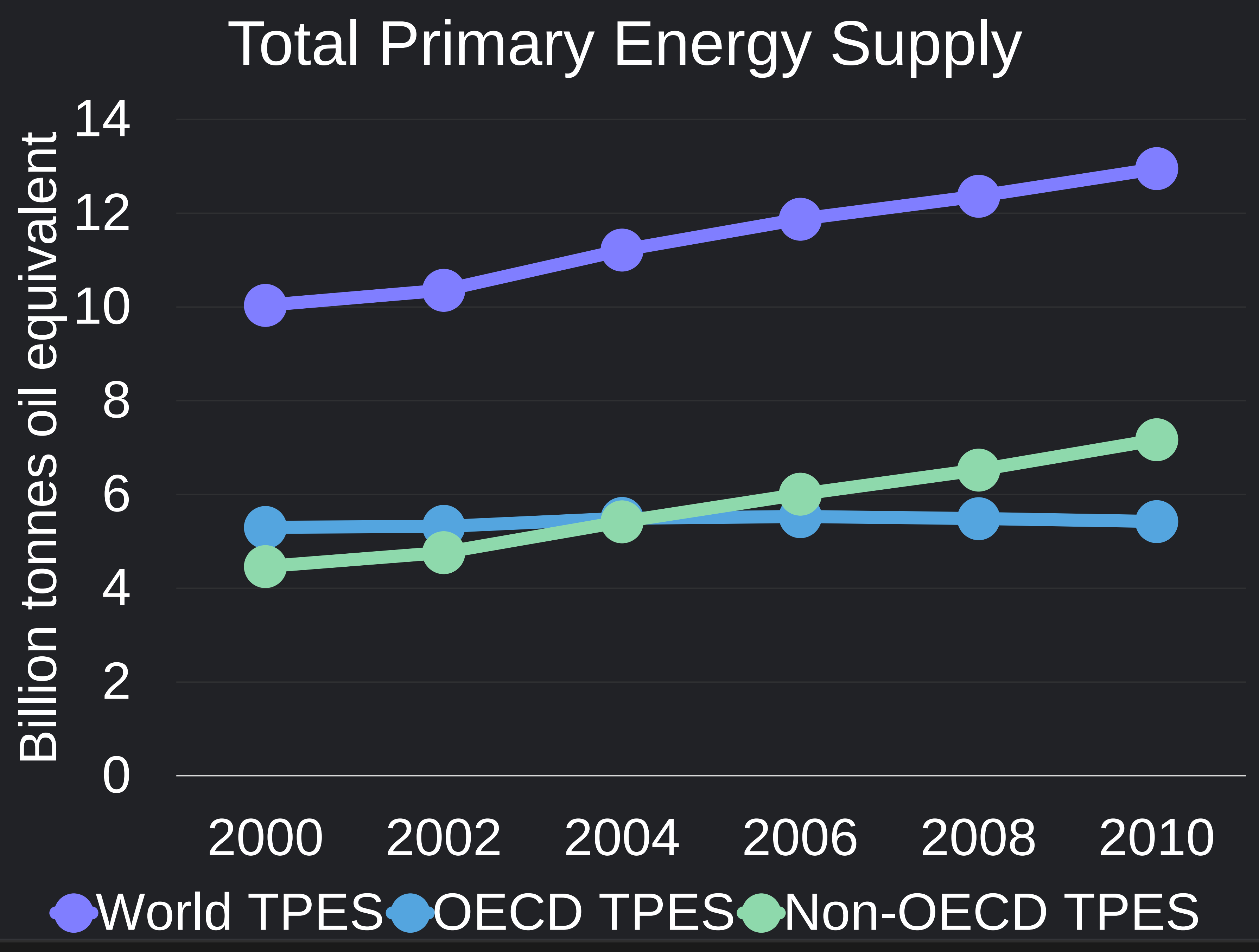
[redacted]

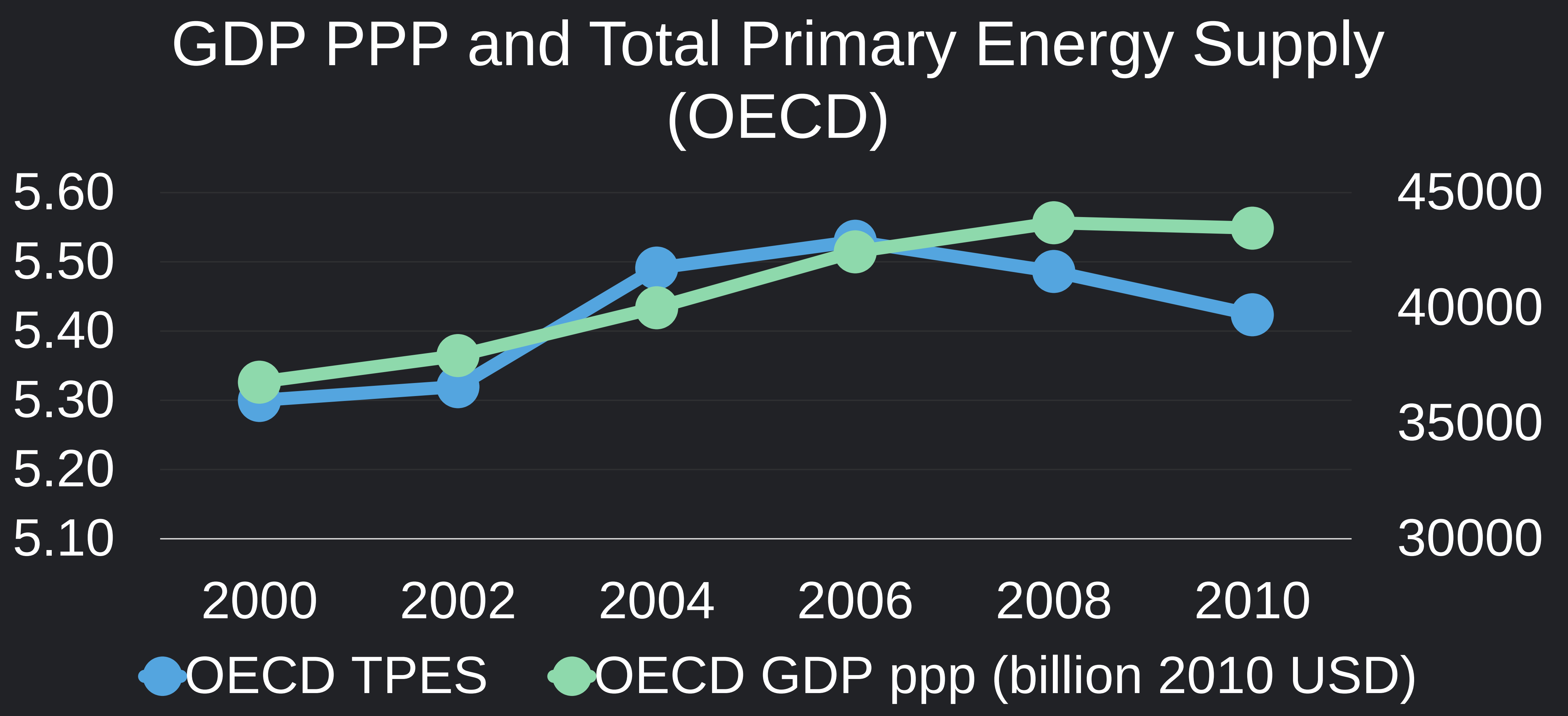
ECLIPSE Non-Policy Assumptions is factors have impact on emissions besides direct environmental policy

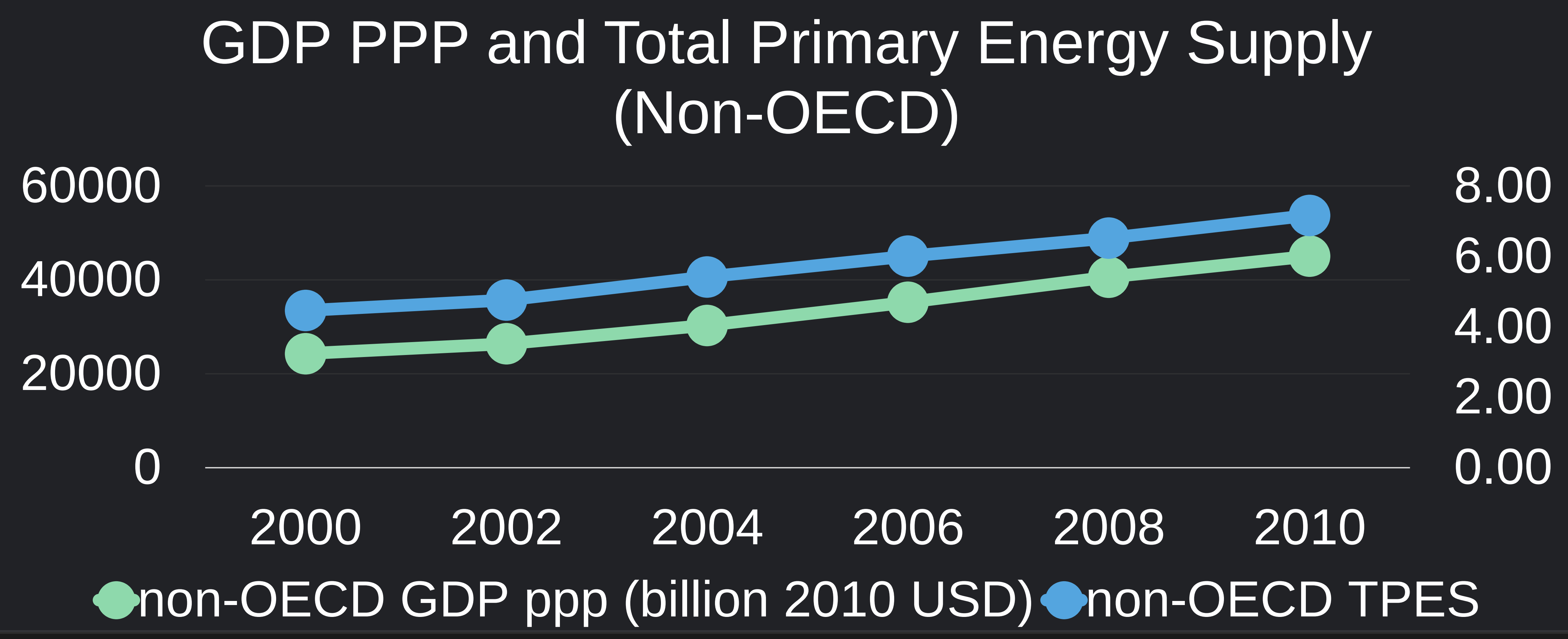
- **Economic Growth**
- **Population**
- **Energy Price**
- **Technology**

[redacted]

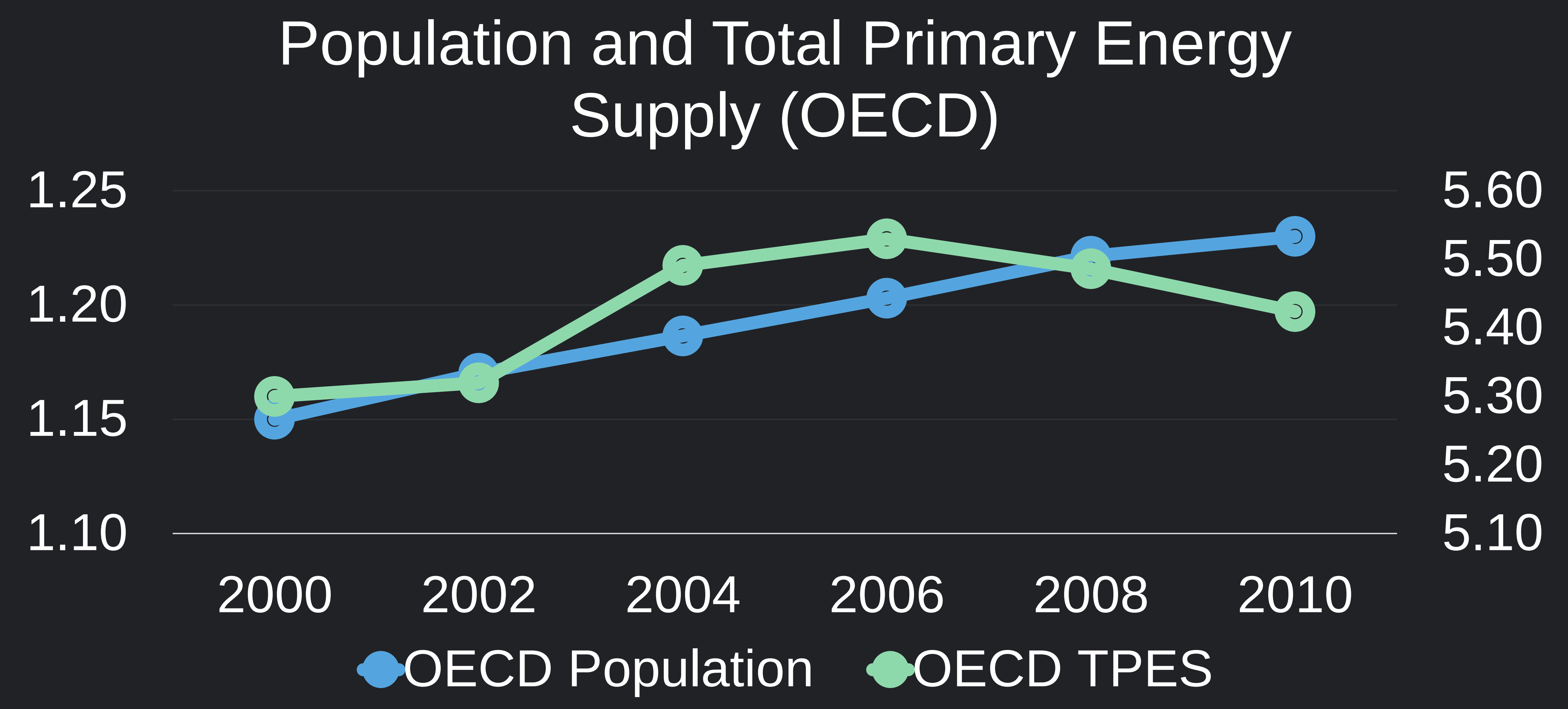
ECLIPSE Non-Policy Assumptions, Economy Growth and Energy Supply

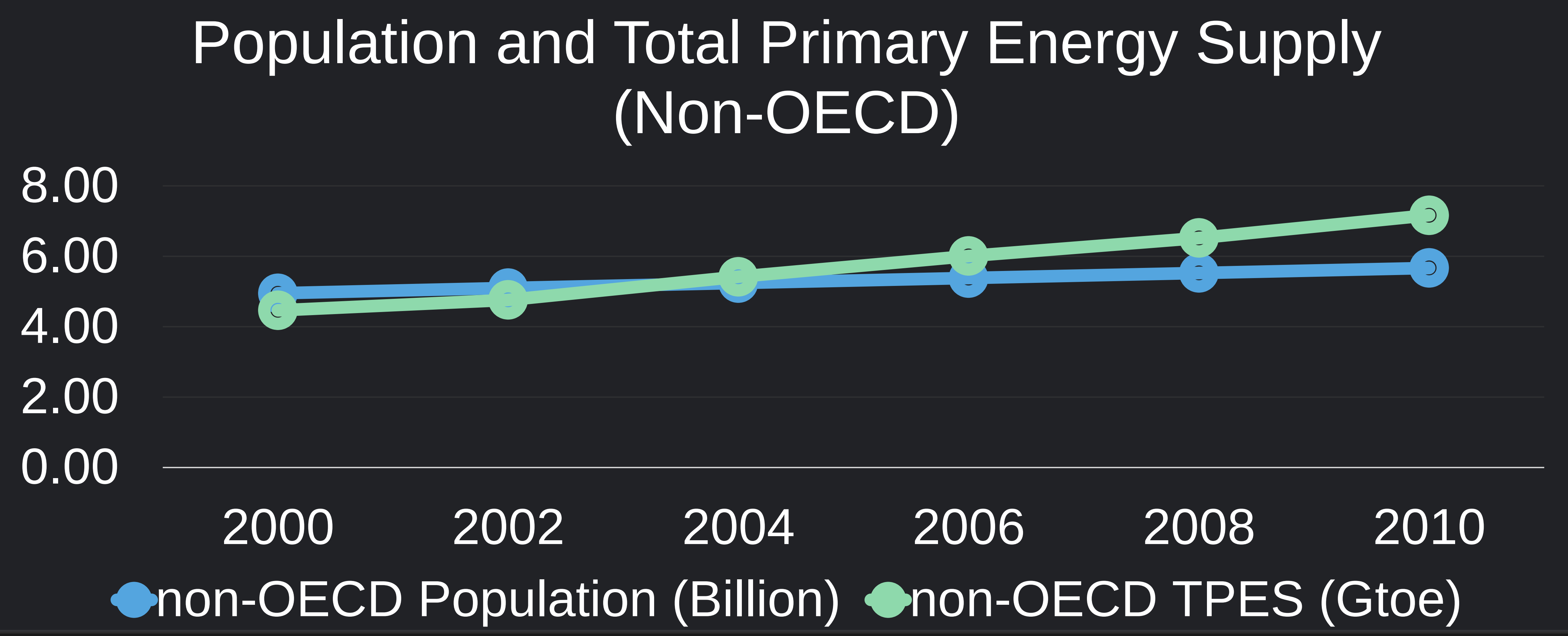






ECLIPSE Non-Policy Assumptions, Population and Energy Supply





ECLIPSE Non-Policy Assumptions

Energy Price

- Natural gas price trends
  - *Historically close correlation between oil and natural gas prices in OECD countries*
  - *Natural gas prices in the United States*
- Steam coal price differences

Technology

- Differ based in fuel type and sector

Discussion - ECLIPSE

Assumptions Made for the US

- Supporting renewable energy sources
- New Appliance Standards
- CAFÉ standard

Assumptions Made for China

- Policy Scenario: 120 GW hydropower, 5 GW solar power and 7 GW wind power by 2015

ECLIPSE Non-Policy Assumptions for Future Projection

- *Economic Growth*
  - Financial crisis, private sector and sovereign indebtedness
  - Non-OECD powerhouse
  - Non-OECD GDP +17% from 2010-2035

- Population
  Population increase in non-OECD countries
  Slow population growth in OECD countries and increased energy demand
  Link between energy use and income (urbanization)

ECLIPSE Non-Policy Assumptions for Future Projection

- *Energy Prices*
  - *Oil*

- Technology
  - *Technological development and energy supply costs*
  - *Slow technological change*

5

Discussion EDGAR Model

EDGAR Main Equation

$$EM_C(y,x) = \sum_{i,j,k} [AD_{C,i}\,(y) * Tech_{C,i,j}\,(y) * EOP_{C,i,j,k}\,(y) * EF_{C,i,j}(y,x) * (1 - RED_{C,i,j,k}\,(y,x))]$$

c - Country; y - Year; x – Compound; i – Sector; j – Technology; k – End-of-pipe Measurement

$EM_c(y,x)$ - Emissions from compound x in country c during year y
$AD_{c,i}(y)$ - Activity data for sector i
$TECH_{c,i,j}(y)$ - Penetration of emission control technology j
$EOP_{c,i,j,k}(y)$ - End-of-pipe measure k
$EF_{c,i,j}(y,x)$ - Other emission factors for uncontrolled compound emission
$RED_{c,i,j,k}(y,x)$ - Emission reduction due to k EOP

Selected Sectors

EDGAR NAME	BRIEF DESCRIPTION	ECLIPSE NAME
Energy for Buildings	Commercial/Institutional, Residential, Agriculture Underground/Surface Mining	**Domestic**
Power Industry + Fuel Exploitation + Fossil Fuel Fires	Energy producing industry, Oil, Exploration	**Energy/Power**
Combustion for Manufactory + Process Emissions	Fuel Combustion, Paper, Iron, Chemical Industry Manufacturing Industry	**Industry**
Road Transportation	Cars; Light/Heavy duty truck and buses; Motorcycles; Evaporative emissions	**Transportation**

[redacted]

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EDGAR V4.2 follows IPCC 2006 Guidelines to collect and document regional data:

- Data Collection for EDGAR:
  Energy related activity data is based on IEA's energy balance statistics and energy statistics

- Data Collection for IEA
  China: National Bureau of Statistics (NBS)
  US: Under instructions for OECD countries

Discussion - EDGAR

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$$EM_C(y,x) = \sum_{i,j,k} \left[AD_{C,i}(y) * TECH_{C,i,j}(y) * EOP_{C,i,j,k}(y) * EF_{C,i,j}(y,x) * \left(1 - RED_{C,i,j,k}(y,x)\right) \right]$$

Power Industry (ENE)

- **Process:** ***Self-generated heat plants***
- **Technology:** ***Grate firing***

Transportation (TRA)

- **Fuel:** ***Biodiesel***
- **Technology:** ***Heavy duty vehicles***

Global Technology Assumption

Discussion - EDGAR

$$EM_C(y,x) = \sum_{i,j,k} \left[AD_{C,i}(y) * TECH_{C,i,j}(y) * EOP_{C,i,j,k}(y) * EF_{C,i,j}(y,x) * \left(1 - RED_{C,i,j,k}(y,x)\right) \right]$$

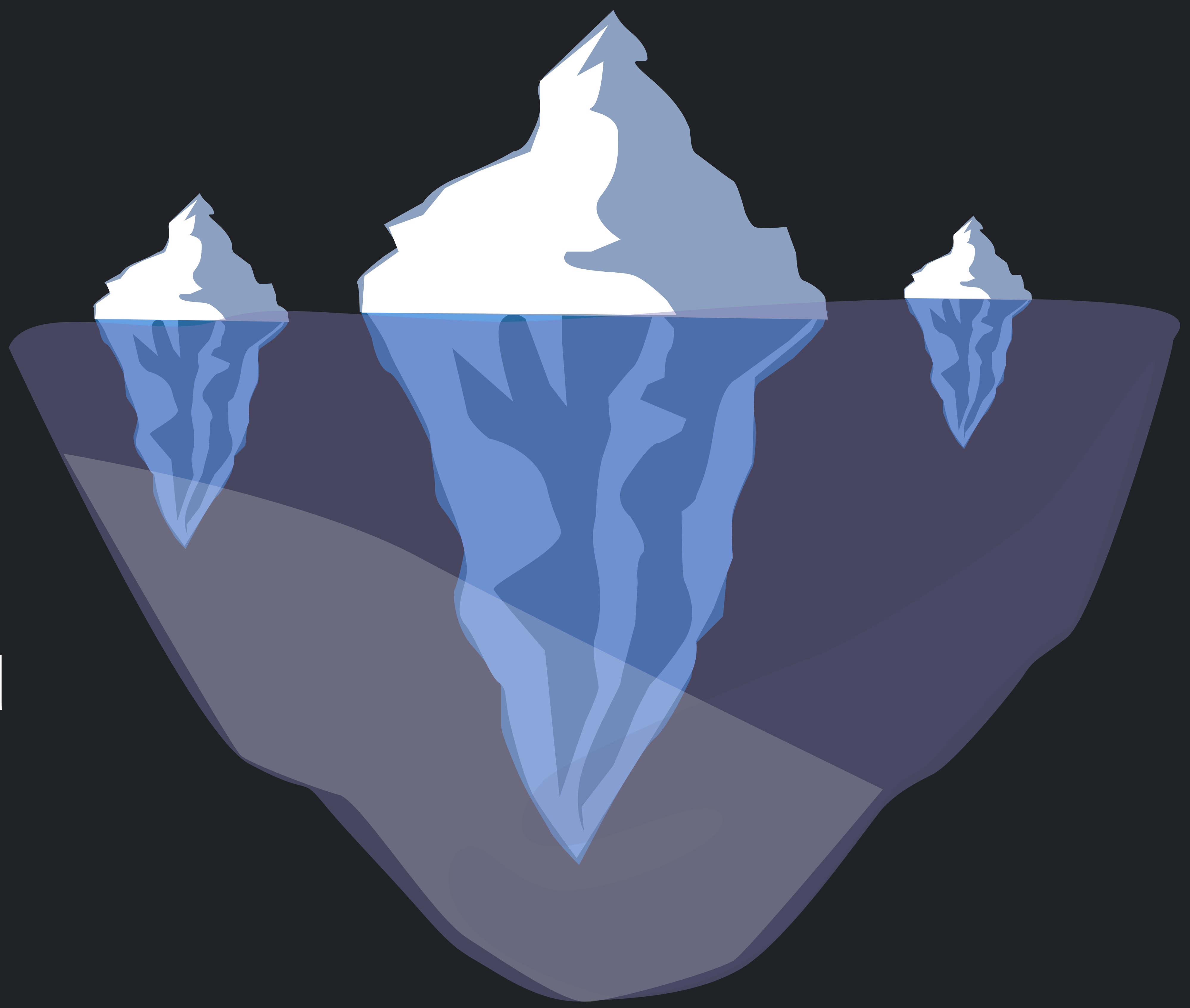
NOx EOP Abatement	Abatement Reduction	SOx EOP Abatement	Abatement Reduction
CM flue gas recirculation – in furnace	30%	Non-regenerative - dry	50%
Selective catalytic reduction	70%	Non-regenerative	90%
Selective non-catalytic reduction	40%	Non-regenerative - wet	90%

[redacted]

Discussion - EDGAR

Assumption made for China in model

- Gasoline is assumed to be consumed only in the transportation sector
- Secondary/ Tertiary source data are used for estimation

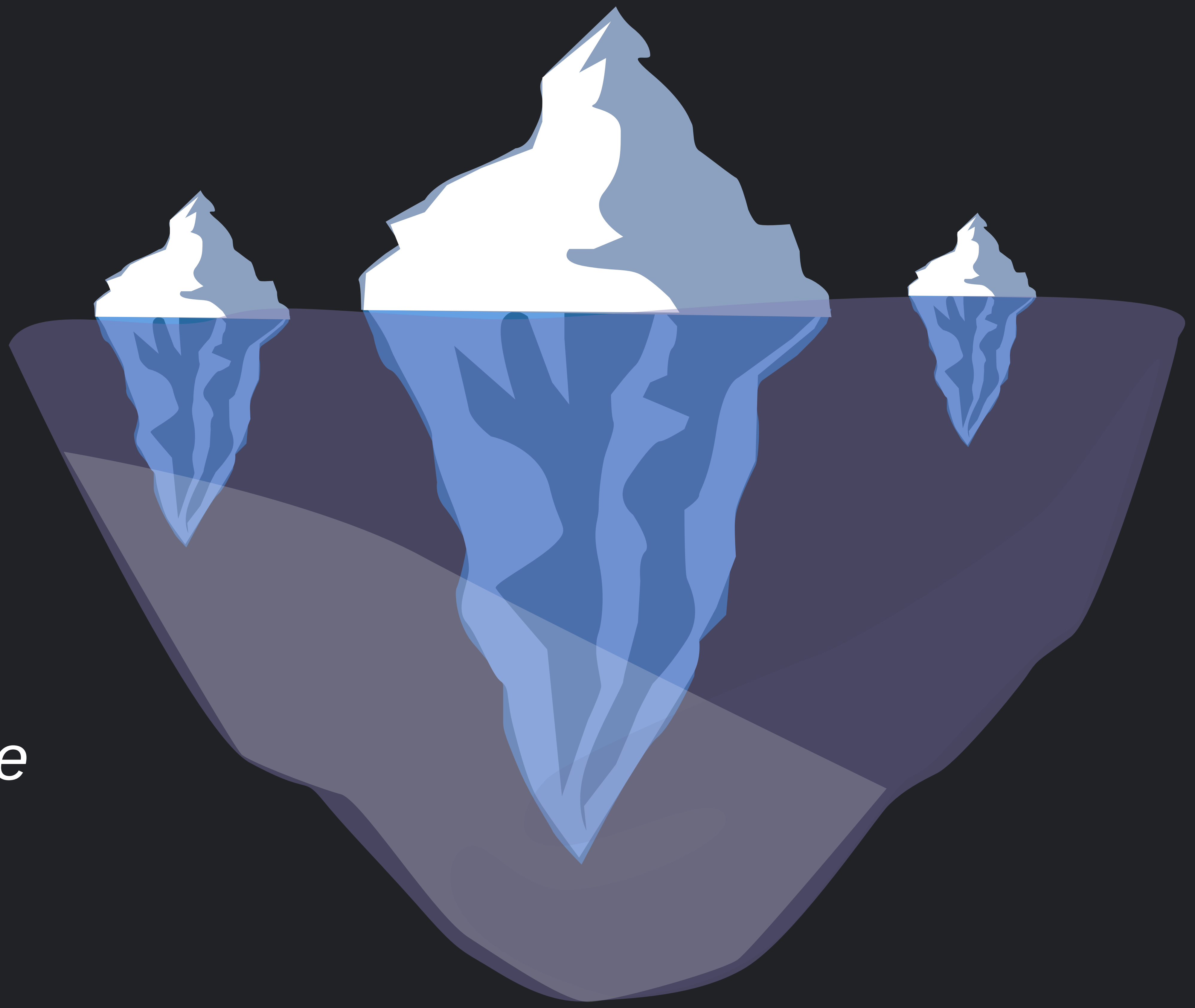


Assumption made for the US in model

- Different EDGAR versions may vary due to different editions of IEA's report

- EOP Abatement: Transportation

  - Light Duty Automotive Technology Trend Report (Crippa, et al., 2016): adopted technologies and the adoption ratio



6

Conclusion

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Global NOx Emission

1%

ENERGY/POWER
EDGAR > ECLIPSE
(2000, 2005)

50%-55%

TRASPORTATION
EDGAR < ECLIPSE
(2000, 2005)

DOMESTIC
EDGAR ~ ECLIPSE
(2000, 2005)

14%-21%

INDUSTRY
EDGAR < ECLIPSE
(2000, 2005)

65%

Global SO2 Emission

10%-
4.5%

ENERGY/POWER
EDGAR > ECLIPSE
(2000, 2005)

4%-
8.5%

TRANSPORTATION
EDGAR < ECLIPSE
(2000, 2005)
Composition is small

DOMESTIC
EDGAR > ECLIPSE
(2000, 2005)

1%

INDUSTRY
EDGAR > ECLIPSE
(2000, 2005)

48%-
60%

What Caused the Difference

Model

Data Source

Assumption

Sector Definition

Model

ECLIPSE Model

$$E_{i,p} = \sum_{k} \sum_{m} A_{i,k} ef_{i,k,m,p} x_{i,k,m,p}$$

EDGAR Model

$$EM_C(y,x) = \sum_{i,j,k} [AD_{C,i}(y) * Tech_{C,i,j}(y) * EOP_{C,i,j,k}(y) * EF_{C,i,j}(y,x) * (1 - RED_{C,i,j,k}(y,x))]$$

Data Source

	ECLIPSE	EDGAR
US	• IEA's Energy Technology Perspectives 2012 • IEA's World Energy Outlook 2011 • Thematic Strategy on Air Pollution (TSAP)	• IEA's energy balance statistics 2014 • EIA's Annual Energy Outlook 2013 • EPA's automotive technology report 1974 to 2013
CHINA		• IEA's energy balance statistics 2014 • NBS's report to IEA • Secondary and tertiary sources

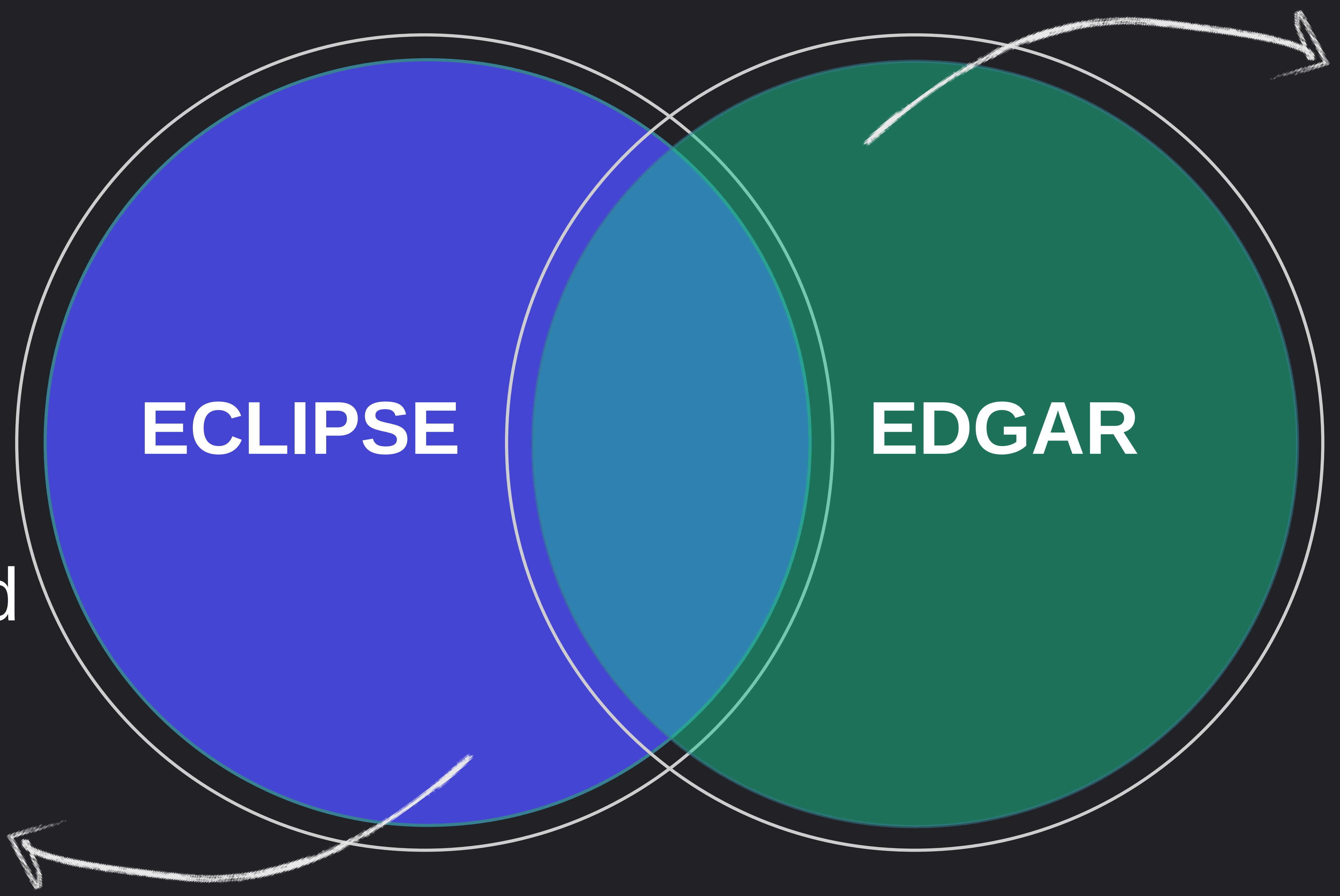
Conclusion

Assumption

	ECLIPSE	EDGAR
US	• Renewable energy sources are supported • New Appliance Standards • CAFÉ standards	• Source categorization • Assumptions in IEA, EIA, and EPA's report
CHINA	• 120GW of hydropower, 5GW solar power and 70 GW wind power by 2015 • Increased use of Flue Gas Desulfurization units	• Source categorization • Gasoline is only consumed in transportation sector • Renewable penetration are estimated from tertiary sources

Although sector definitions are similar, sub-sectors are not 100% overlapped

TRA
- Other non-road machinery, inland waterways



ENE
- Oil: Fuel Exploitation

DOM
- Stationary, underground surface mines
- Process Emission during production and application

7

Acknowledge and Q&A

Acknowledge

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Thanks to Dr. Kyle Bradbury, who lent us a hand when we needed.

Q&A

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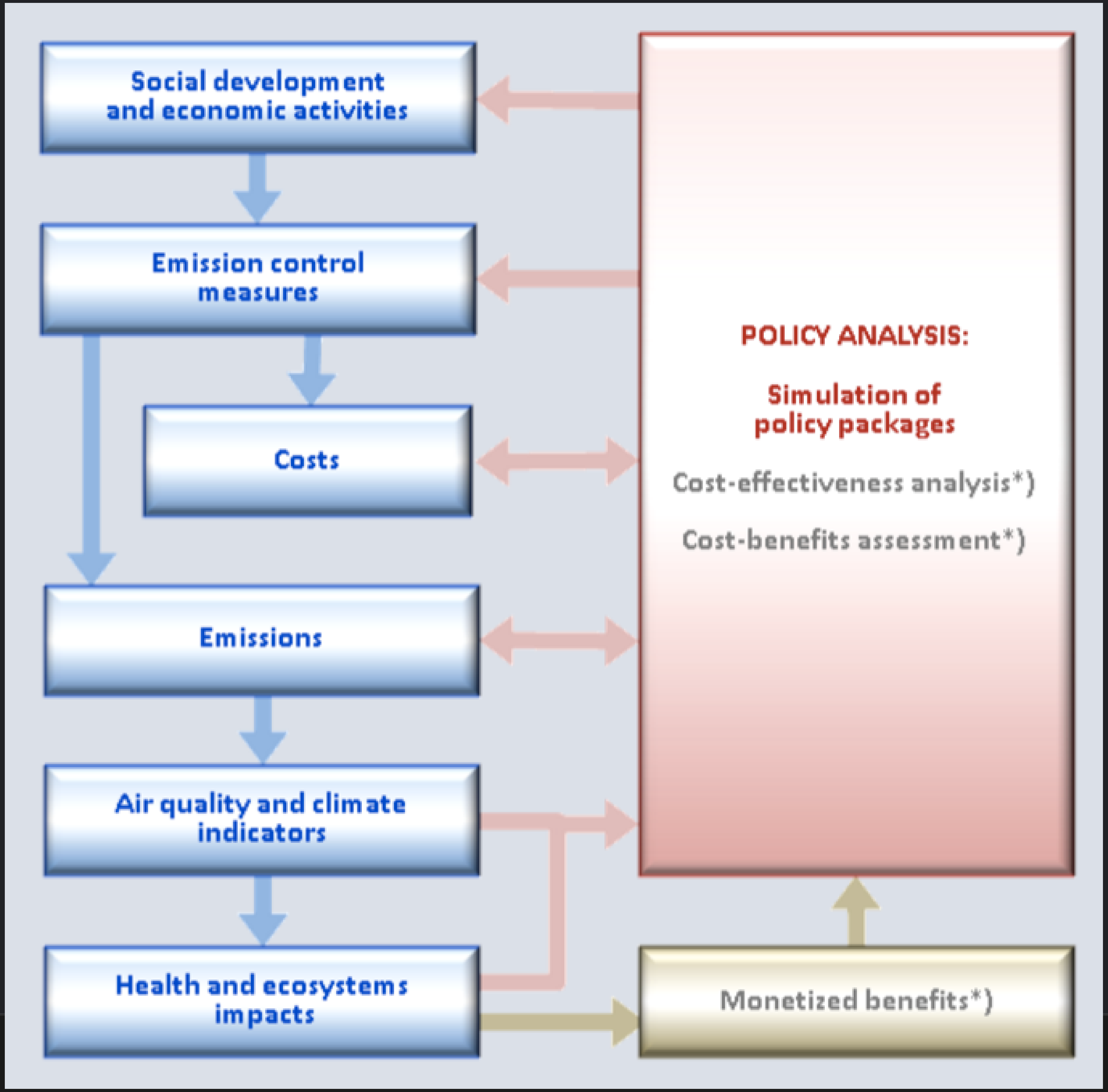
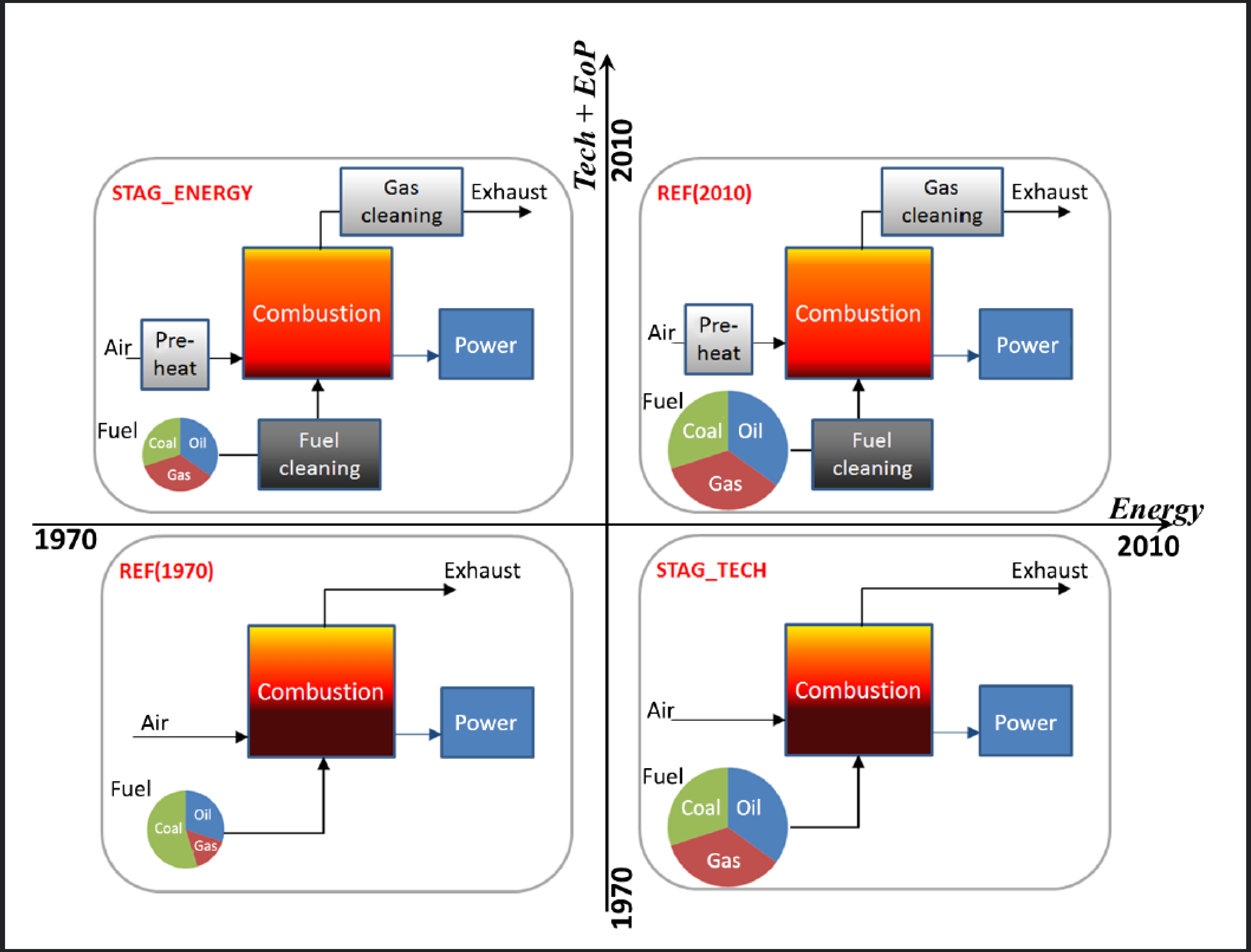
User Interface _ ECLIPSE

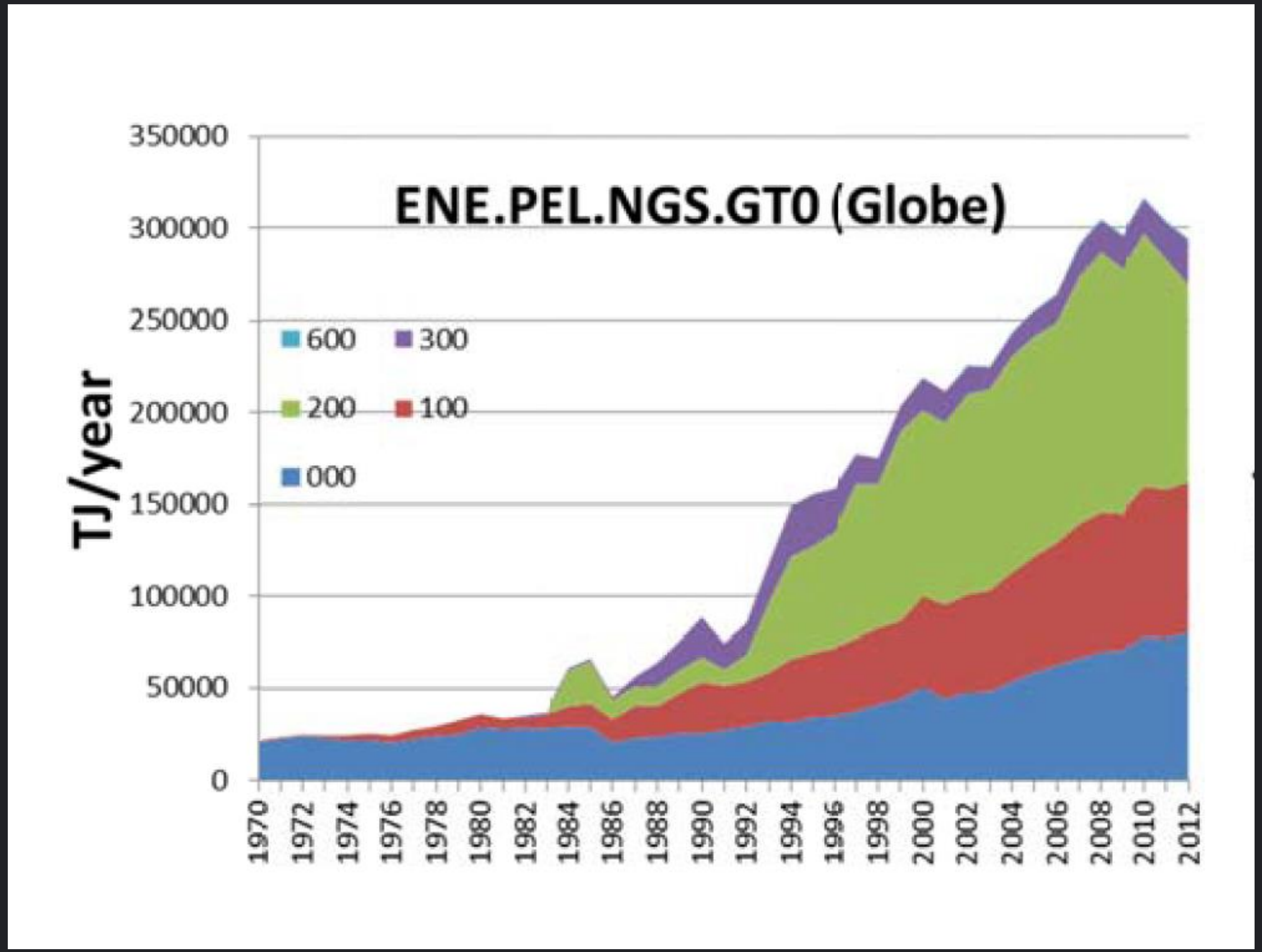


Scenarios_EDGAR



Source: Crippa, M., Janssens-Maenhout, G., Dentener, F., Guizzardi, D., Sindelarova, K., Muntean, M., ... Granier, C. (2016). Forty years of improvemnets in European air quality: regional policy-industry interactions with global impacts. *Atmospheric Chemistry and Physics, 16,* 3825-3841. doi:10.5194/acp-16-3825-2016

User Defined Scenario_EDGAR



Source: Crippa, M., Janssens-Maenhout, G., Dentener, F., Guizzardi, D., Sindelarova, K., Muntean, M., ... Granier, C. (2016). Forty years of improvemnets in European air quality: regional policy-industry interactions with global impacts. *Atmospheric Chemistry and Physics, 16,* 3825-3841. doi:10.5194/acp-16-3825-2016

For example:

User:

Public electric production with NG with gas turbine = ENE.PEL.NGS.GT0;

Choose NOx, SO2, PM abatement: 000 to 600;

Get the “Tech” emission factor.

13 Sectors_EDGAR

Code	Sector in EDGAR	Brief Definition from IPCC 1996
ENE	Power Industry	Emissions from fuel combusted by fuel extraction or energy producing industry
REF	Oil Refineries	Petroleum refining; Distribution of oil production
TRF	Transformation Industry	Manufacture of solid fuels and other energy industries; Mobile; Solid fuel transformation; Iron and steel production
IND	Combustion for Manufacturing	Manufacturing Industries and Construction (Iron and Steel, Non-ferrous Metals, Chemicals, Pulp Paper and Print, Food Processing, Beverage and Tobacco)
TRO	Road Transportation	Cars; Light/Heavy duty truck and buses; Motorcycles; Evaporative emissions
TNG	Railways, other	Railways; Other transportation (pipeline transportation, off road)
SHIP	Shipping	International marine (bunkers); National navigation
RCO	Energy for Buildings	Commercial/Instututional; Residential; Agriculture/forestry/fishing (stationary, off-road vehicles and other machinery, fishing); Underground/surface Mining
PRO	Fuel Exploitation	Oil: Exploration, production, transportation, refining, storage, Venting and flaring
PPA	Process Emission	Industrial process: Solvent and other product use
AGR	Agriculture	Manure management; Rice; Rain fed; Deepwater; Agricultural Soils; Field burning of agricultural residues; Cereals; Pulses; Tuber and roots; Sugar canes; others
SWD	Waste	Waste
OTH	Fossil Fuel Fires	Other