Global emission projection from transportation sector and its uncertainty analysis

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  - Timing of Emission Standards
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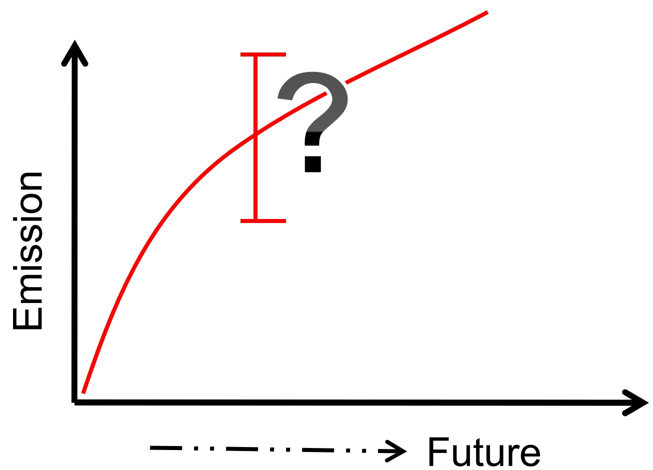
  - Uncertainty analysis
- **Conclusion**

Background

- Emission projections
  - Climate change
  - Strategies for air quality control
  - Mitigation policies
- Most current emission projection models
  - Deterministic
  - Single answer for each scenario

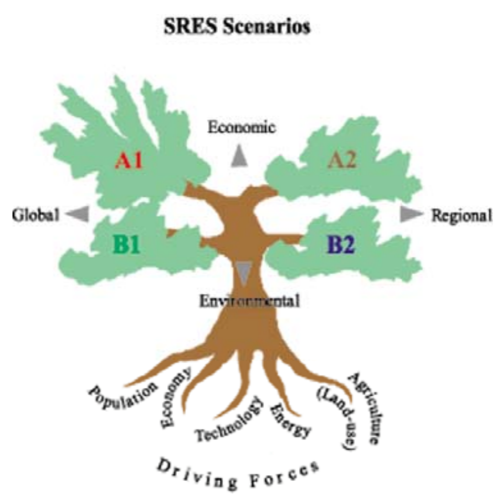


Objective

- To project emissions based on **technology driven model**
  - Present the development of our technology driven model- ***the Speciated Pollutant Emission Wizard (SPEW)-Trend***
  - Discuss emission projections of ***primary particulate matters (PM)*** from ***transportation sector***
- To **estimate uncertainties** and examine their impact on future emissions.
  - Perform ***sensitivity analysis*** and ***Monte Carlo simulations*** to explore the uncertainties inherent emission projections.

Major Data Sources

- **Historical data**
  - Fuel consumption: International Energy Agency (IEA) (road sector)
  - Economic variables: World Development Indicators (WDI) (e.g. GDP and population)
- **Future data**
  - Integrated Model to Assess the Global Environment(IMAGE)
  - Four scenarios (A1B, A2, B1, and B2) developed for the SRES (17 regions)
- **Emission standards**
  - Dieselnet; DELPHI; CONCAWE; UNEP,
- **Transportation data**
  - Total vehicles registered
  - Vehicle age distribution at a specific time



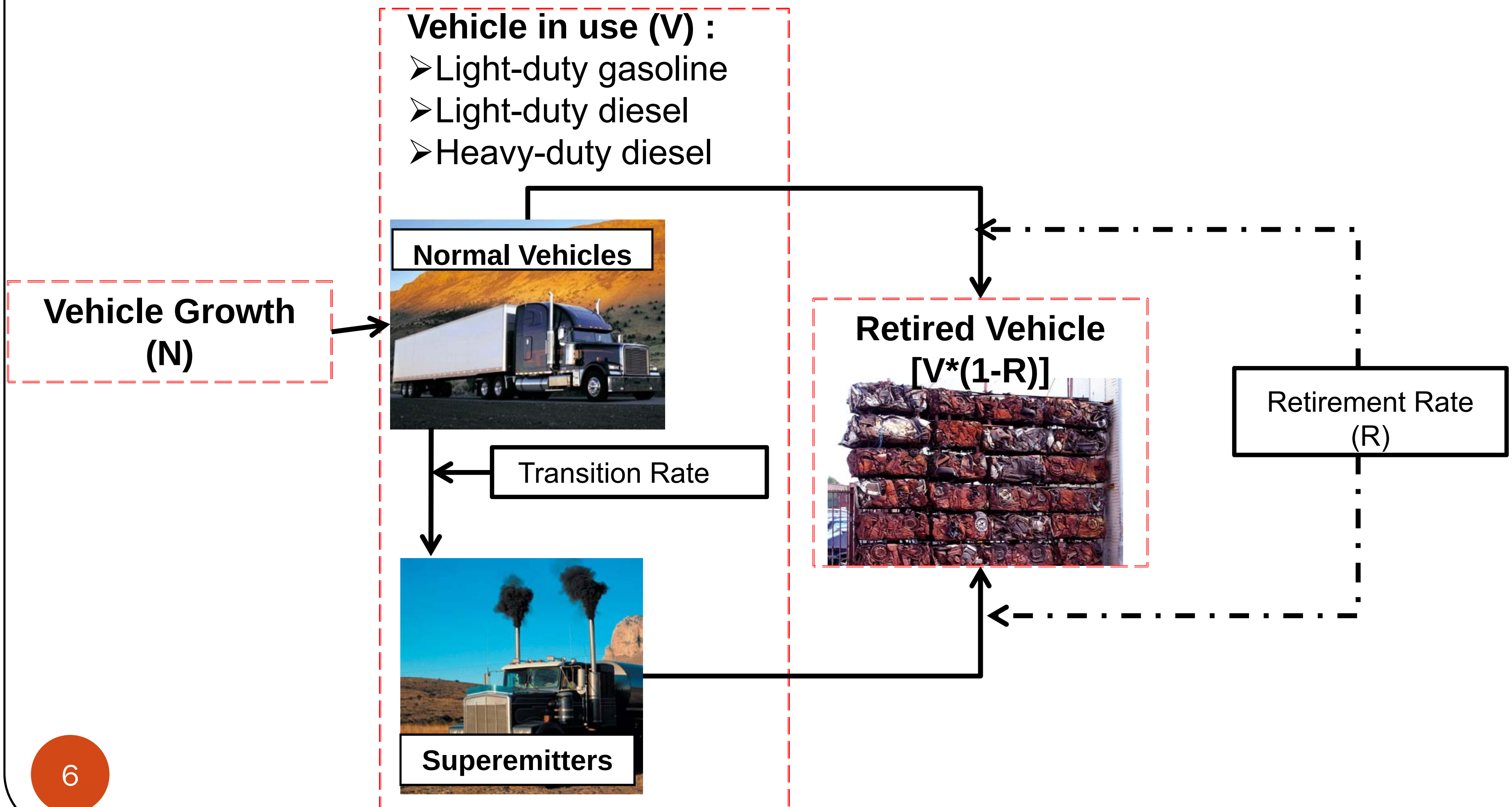
Fleet & Emission Model

$$V_{i,s}(t) = V_{i,s}(t-1)[1 - R_{i,s}(t)] + N_{i,0}(t)$$

$$E(t) = \sum_i \sum_s V_{i,s}(t) EF_{i,s}$$

Total emission

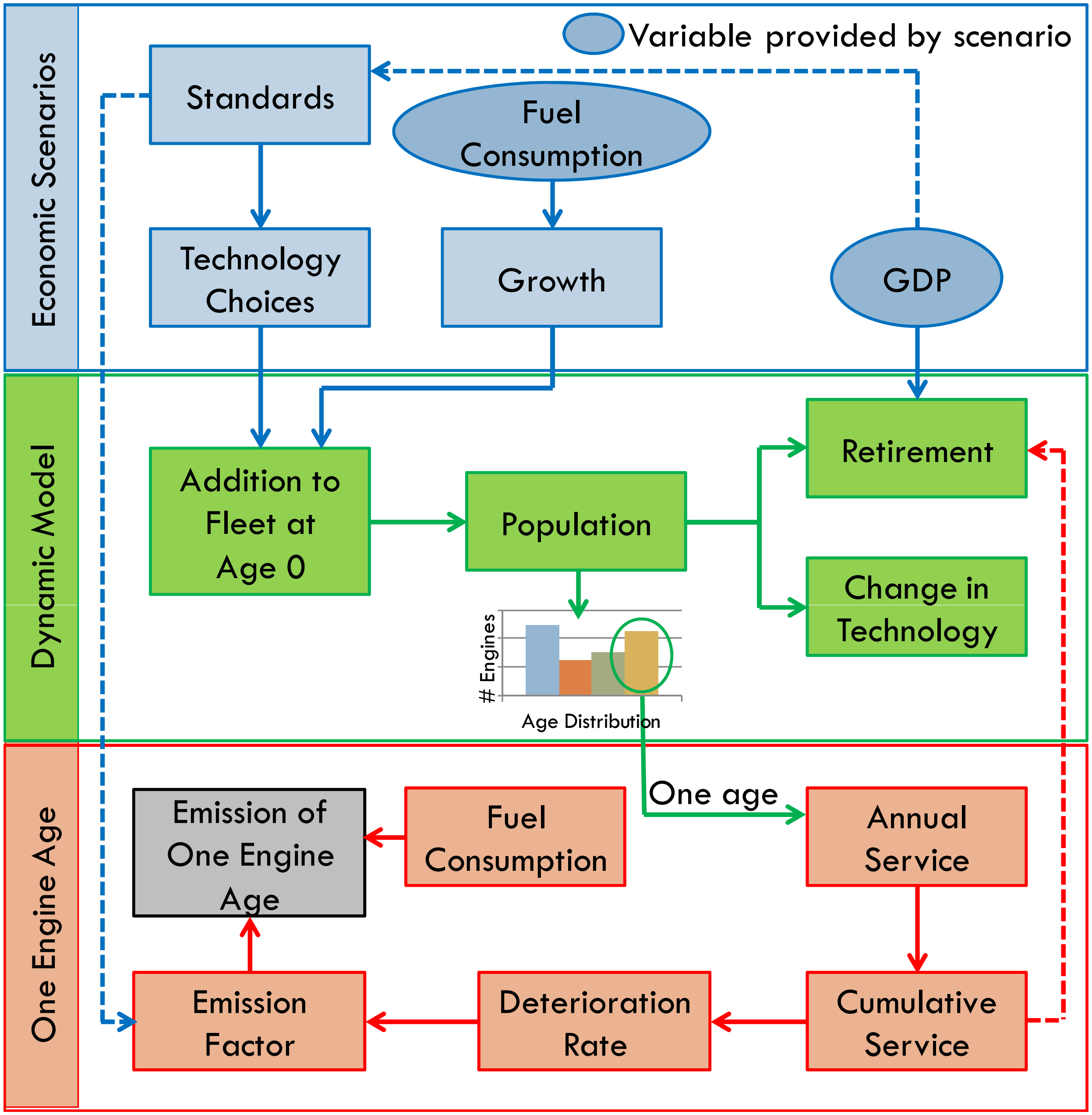
Emission factor



Vehicle Types

- **Light-duty gasoline & Light-duty diesel vehicles**
  - No regulations
  - Opacity standards
  - Euro I-Euro VI
  - Tier I & Tier II
  - Superemitters
- **Heavy-duty diesel vehicles**
  - No regulations
  - Opacity standards
  - Euro I-Euro VI
  - U.S. Standards 1988-2007
  - Superemitters

SPEW-Trend Flow Chart

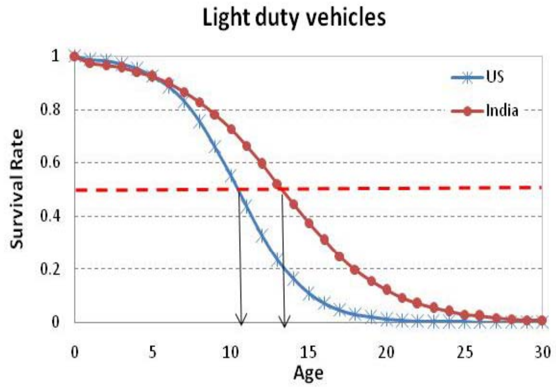


Retirement Rate

- **Governing Factors**
  - vehicle age
  - ratio of regional and global income (labor vs. price)→*loc_glob_gdprat*
    - when the cost of repairs is high relative to the price of new cars
    - Assumption: Prices of new vehicles → set by the global market; repair costs → local labor rates
- **Function:** logistic

$$Su = \frac{1}{1+\exp\left\{-\left[\alpha + age \times \left(\beta_1 + \beta_2 \times loc\_glob\_gdprat\right)\right]\right\}}$$

  - **α:** related to the onset of significant retirement
  - **β_1:** how quickly vehicles retire as they get older
  - **β_2:** scrappage decision based on the balance of vehicle cost and repair (income level)
- **Observation Data (Iterative procedure)**
  - total vehicles registered or in use for different years
  - vehicle age distribution at a specific point in time

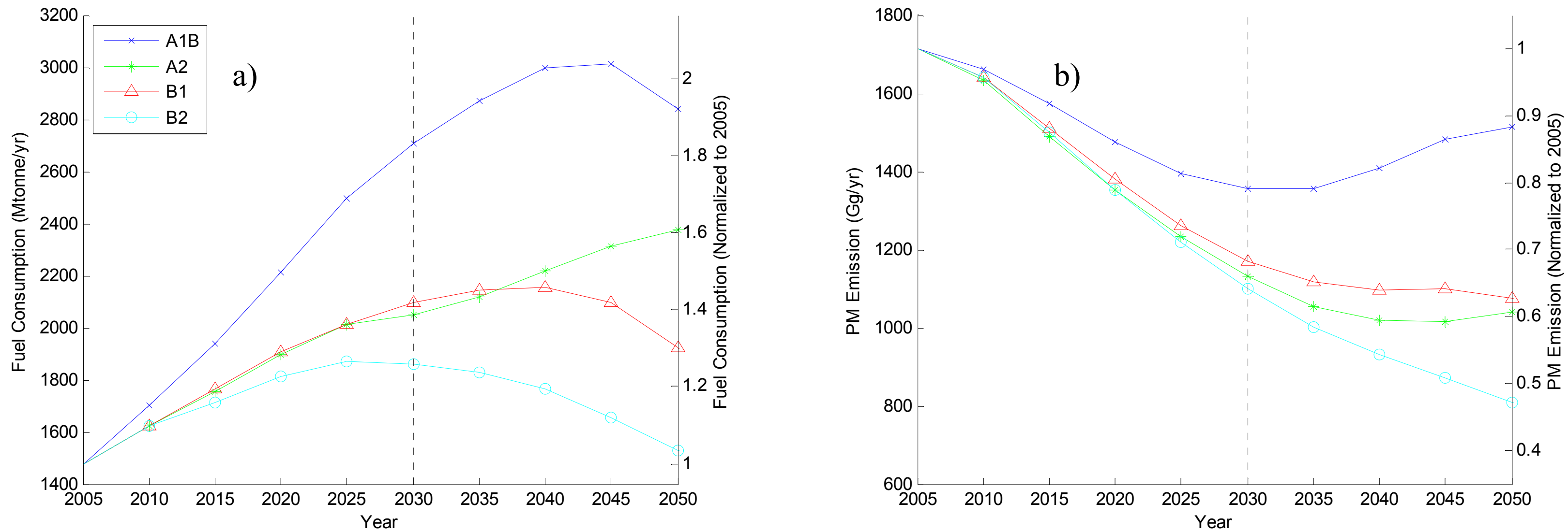


- Only loosely constrained by observations
- Observational data are limited on global scale
- Uncertainties arise from the iterative procedure and the derived relationships between retirement rate and income

Timing of Emission Standards

- Empirical assumptions about first adoption dates of standards
  - Trends in neighboring countries; air quality problems; income
  - **Group** I: A single country has the highest population (Dominant Country)
    - *Canada, U.S., Former USSR, South Asia, East Asia, and Oceania*
  - **Group II**: Heterogeneous in terms of standard adoption (Average)
    - *Middle East, Southeast Asia, South America, Eastern Europe*
  - **Group III**: Large countries have standards but remaining countries don't (Large countries+10 years)
    - *Central America, Northern Africa, Southern Africa*
  - **Group IV**: No current plans for standards (Income level)
    - *Eastern and Western Africa*
- The lag year between further advanced emission standards is assumed constant

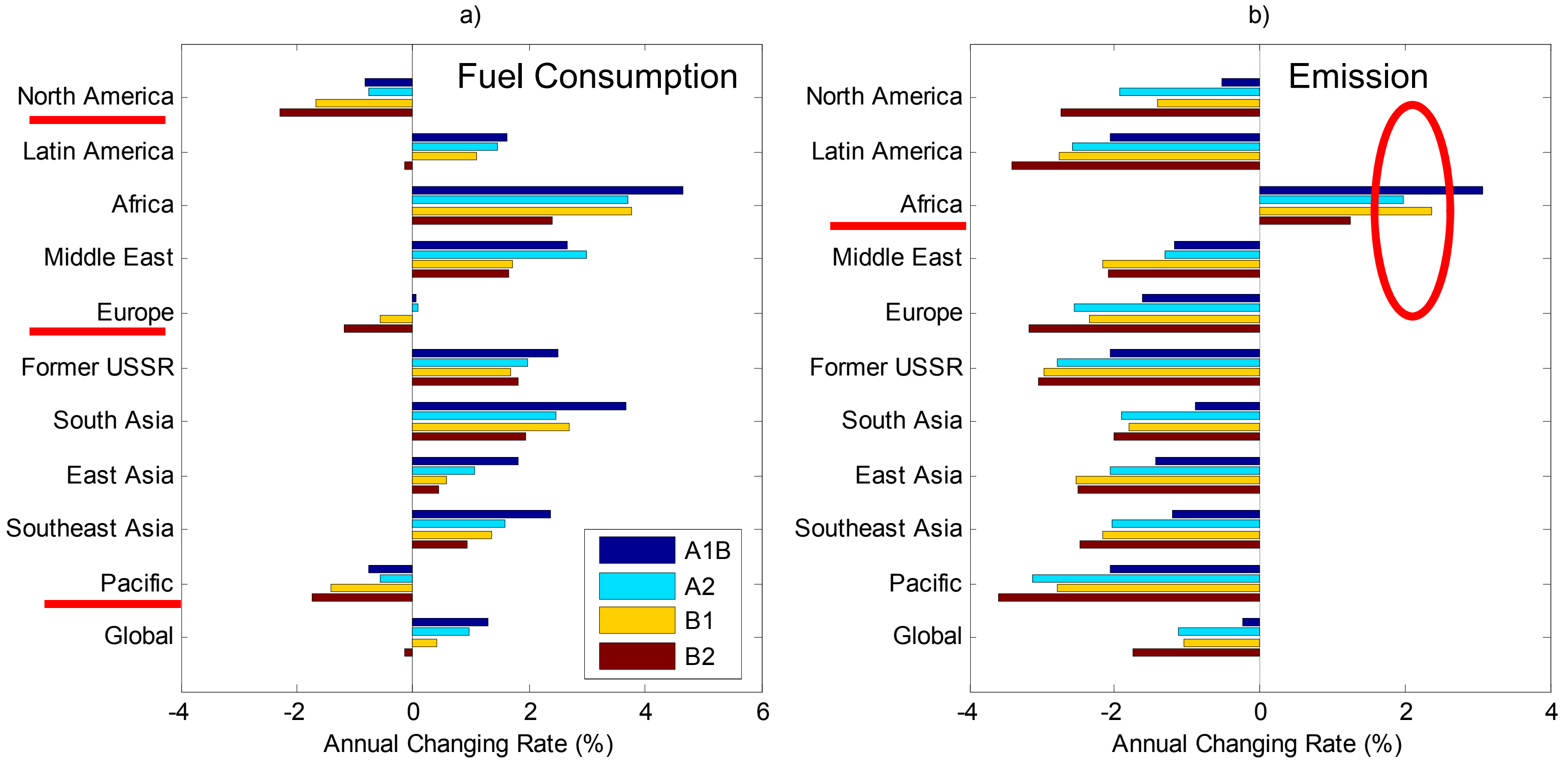
Results-Global Emissions



- Emissions **decrease continuously** for the first few years
- The **increase after 2035** under A1B and A2 can be explained by the significant emission **contribution from Africa**
- Global emission trends **do not match** those of fuel consumption

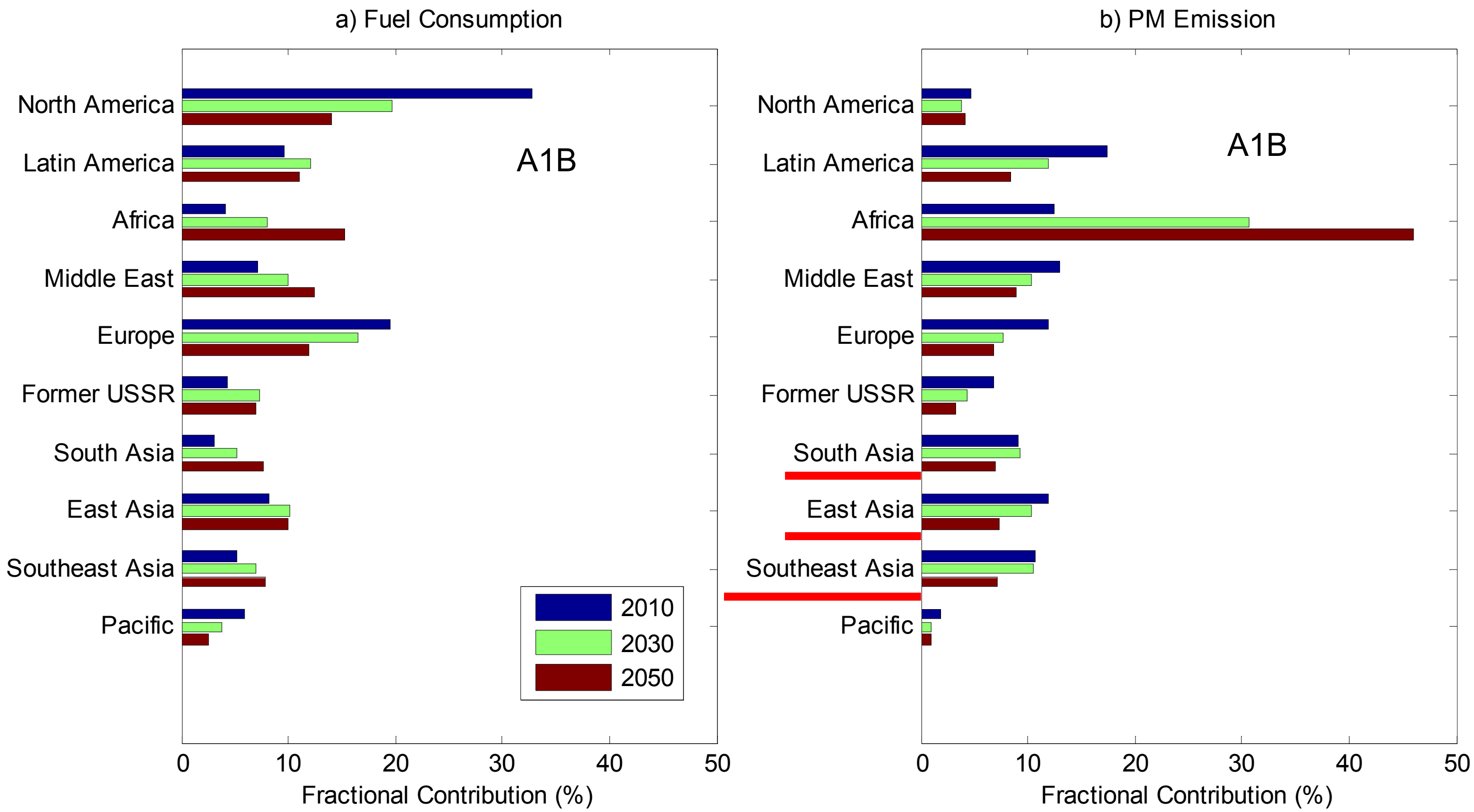
Regional Contributions

Average Annual Change from 2010 to 2050



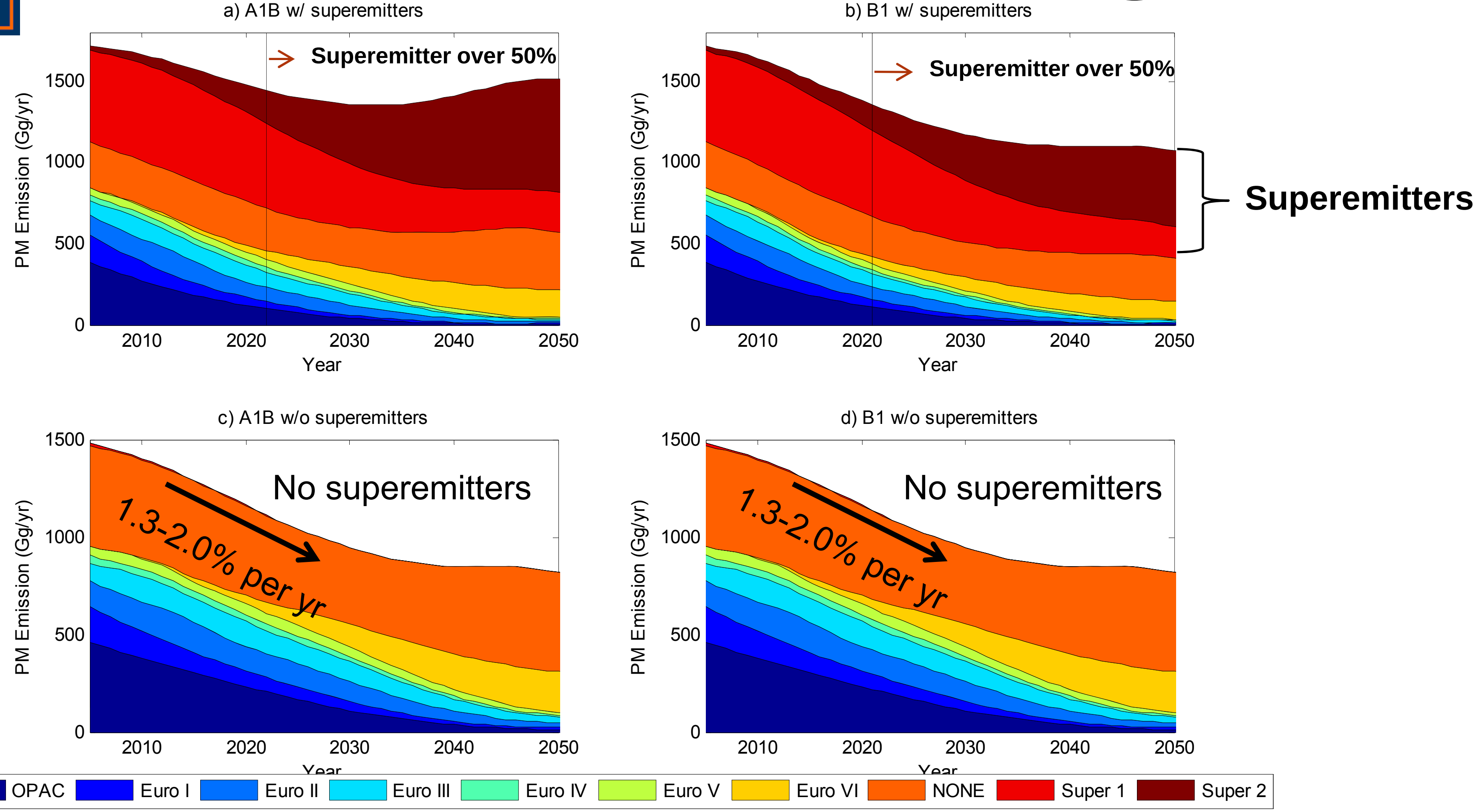
- **Emissions increase** significantly in only **Africa**
  - **Rapid growth** of vehicles with less-than-optimal emissions performance;
  - **Slow scrappage** of old vehicles

Fractional Contribution



- The **fractional contribution of Asian regions** (South Asia, East Asia, and Southeast Asia) **decreases** from 32% in 2030 to around 22% in 2050, also because of emission controls.

Emission Composition by Engine Type

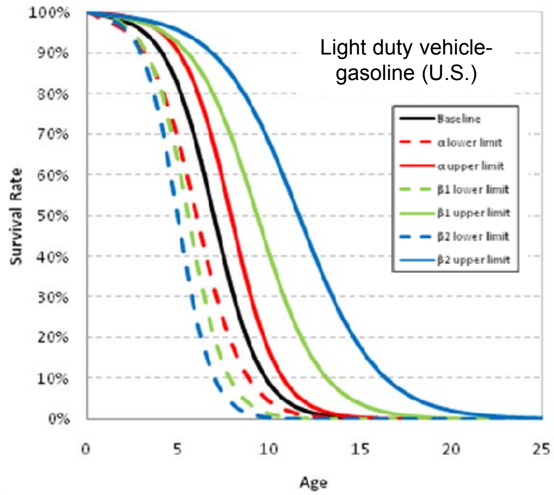


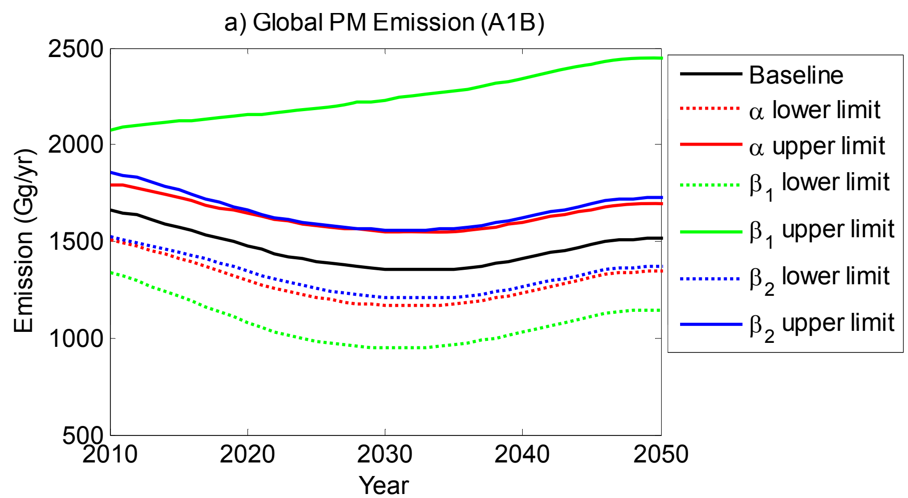
Emission contributions by vehicles under different emission standards

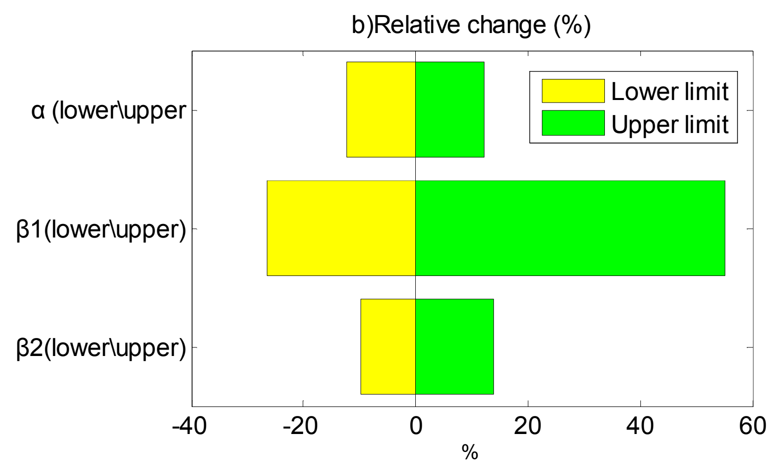
- Total emissions without the effects of superemitters are ~**55%** of those with superemitters

Uncertainty analysis-Sensitivity to Retirement Rate

$$Su(\mathbf{s}) = \frac{1}{\mathbf{1} + \mathbf{exp}\left[-\alpha - \beta_1 s - \beta_2 s \times loc\_glob\_gdprat\right]}$$



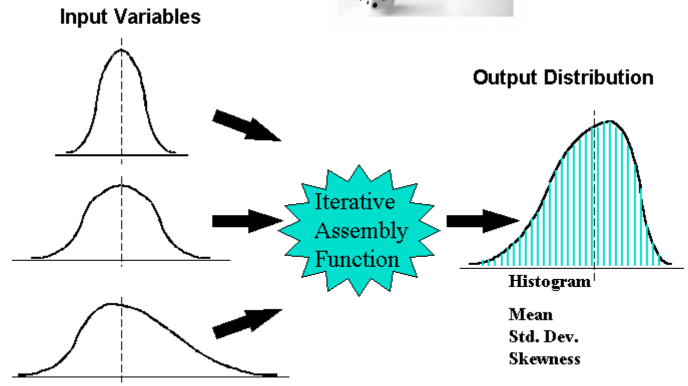




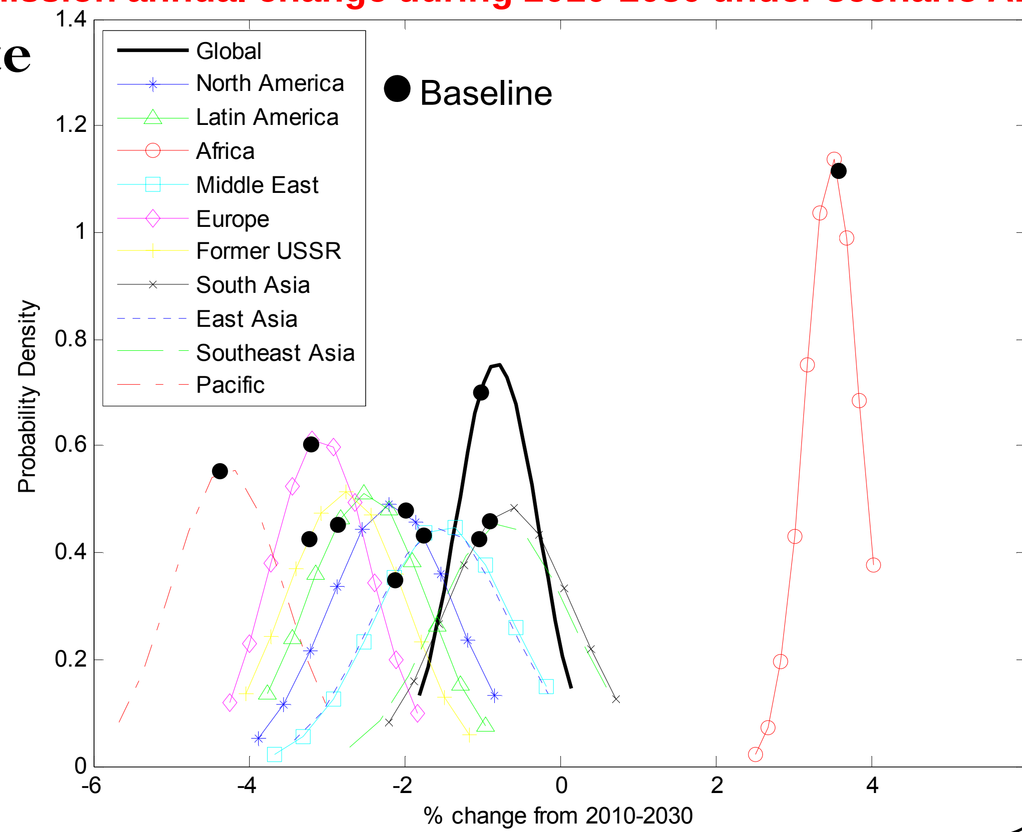
- Global emission varies around **-26% to +55% on average**, when β_1 is changed within 90% confidence interval
- β_1 provides the largest uncertainty

Monte Carlo Simulations

- 94 parameters in 3 categories by probability distributions.
  - Parameters in **retirement rate**
    - normal distribution
  - Parameters in determining the **timing of emissions standards**
    - uniform distribution
  - Parameters in estimation of **transition rate** from normal vehicles to superemitters
    - uniform distribution.



Emission annual change during 2010-2030 under scenario A1B



Conclusions

- The global emission projection shows **decreasing** global emission for the first 30 years; **a slight increase** followed by due to significant emission contribution from Africa

- **Superemitters drive the trend of PM emissions from on-road vehicles**.
  - If superemitters are eliminated, the global emission decline instead, with **an annual average rate of 1.3%-2%.**
  - Tighter standards cannot satisfactorily protect environmental quality unless superemitters are addressed specifically
  - Global emission trends will remain highly uncertain until the behavior of superemitters is better understood

- Sensitivities to parameters governing **retirement rates are highest**, causing changes in global emissions **from-26% to +55%** on average from 2010 to 2050.

- The results from **Monte Carlo simulations** show that the 95% confidence interval of global emission annual growth rate is **-1.9% to +0.2% per year under scenario A1B**.

Acknowledge

- Department of Energy
- Argonne National Laboratory
- Clean Air Task Force
- Bond Research Group

For More Information

- Yan. F, E. Winijkul, S. Jung, T. C. Bond and D. G. Streets, **Global emission projections of particulate matter: I. Exhaust emissions from on-road vehicles** (submitted)

- Yan. F, E. Winijkul, T.C. Bond, and D. G. Streets, **Global emission projections of particulate matter: II. Uncertainty analysis for on-road vehicles exhaust emission** (ready to submit)

- Winijkul, E., F. Yan, and T.C. Bond, **Current and future global diesel emission from non-road Equipment** (ready to submit)

Thank You☺

Any Questions?

Methodology

- **Basic Fleet Model**

Retirement rate

$$V_{i,s}(t) = V_{i,s}(t-1)[1 - R_{i,s}(t)] + N_{i,0}(t)$$

the number of vehicles :type I, age s, in year t or t-1

the number of new vehicles purchased

- **Total emissions**

$$E(t) = \sum_i \sum_s V_{i,s}(t) EF_{i,s}$$

Total emission

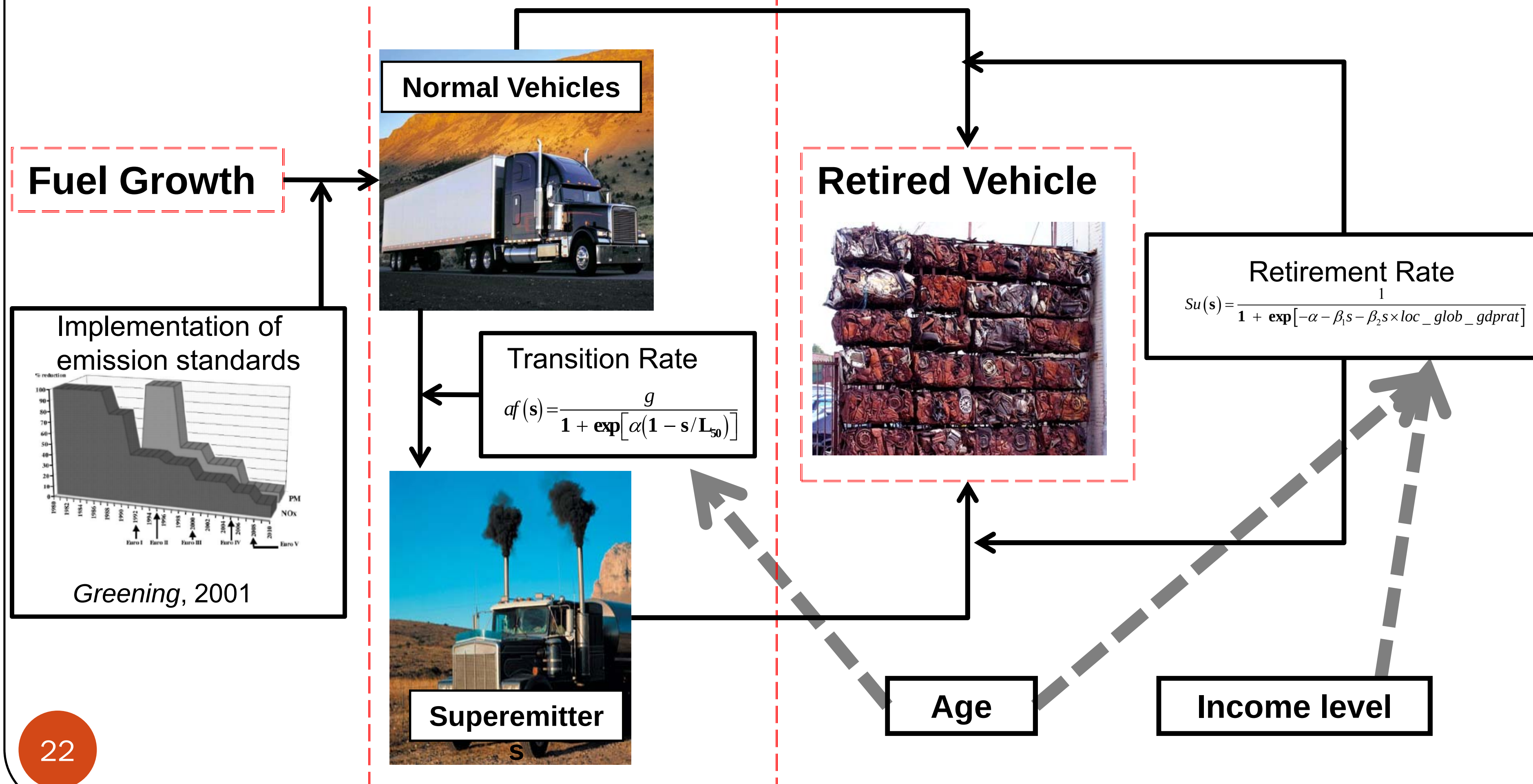
Emission factor

Fuel Consumption

$$V_{i,s}(t) = V_{i,s}(t-1)[1 - R_{i,s}(t)] + N_{i,0}(t)$$

Fuel in use:

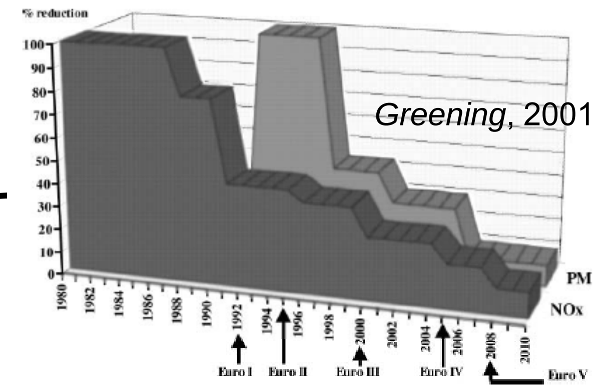
- Light-duty gasoline
- Light-duty diesel
- Heavy-duty diesel

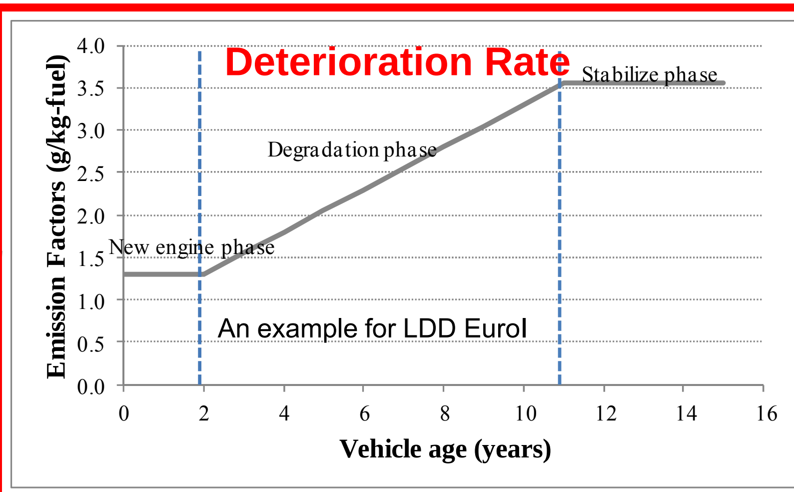


Emission Factors and Deterioration Rate

Emission Standard	New Vehicle PM Emission Factors (g/kg-fuel)		
	Light-duty gasoline	Light-duty diesel	Heavy-duty diesel
Non-regulation	0.05	1.9	4.2
Opacity	0.05	1.5	2.9
Euro I	0.01	1.3	1.7
Euro II	0.01	0.8	0.7
Euro III	0.01	0.5	0.5
Euro IV	0.01	0.3	0.1
Euro V	0.01	0.04	0.1
Euro VI	0.01	0.05	0.06
Older engine superemitter[1]	3.2[1]	8.3[1]	8.3[1]
Newer engine superemitter[2]	0.3[2]	2.9[2]	2.9[2]

Implementation of emission standards





Age

Emission factors by vehicle type, age and emission standards

SPEW-Trend Flow Chart