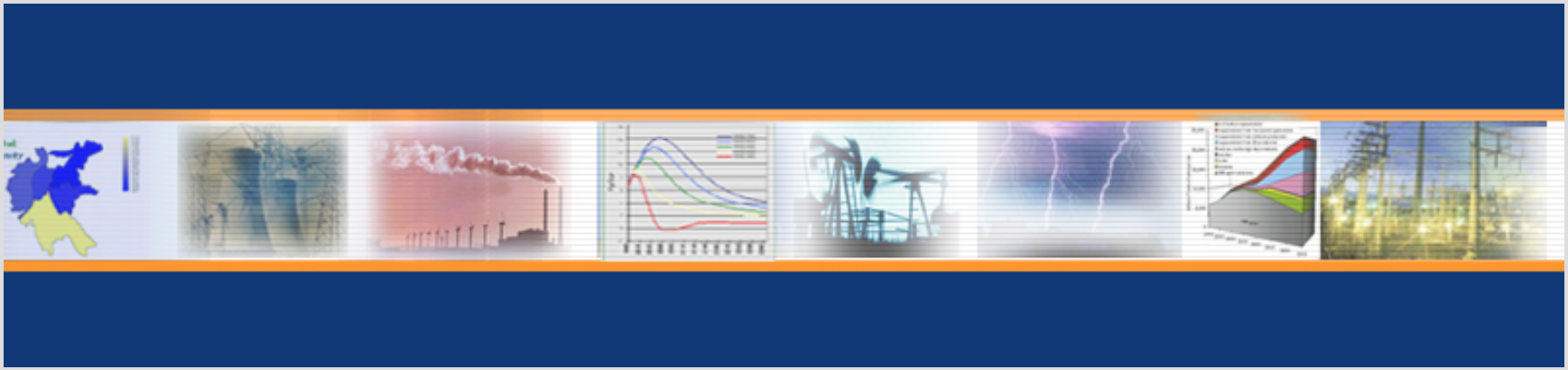
Indian Institute of Management, Ahmedabad

Emissions Inventory and Modeling: India Presentation



Presented by
P.R. Shukla

Presented at The 11th International AIM Workshop, NIES, Tsukuba, Japan, February 19-20, 2006

Presentation Agenda

1. Multi-gas emissions inventory assessment (Period: 1985 to 2005)

   Gases

   - CO_2
   - CH_4
   - N_2O
   - F-Gases
   - BC/OC
   - Local Air Pollutants (SO_2, NO_X, CO, TSP)

2. AIM model applications

   Multi-gas Emissions Scenarios

   Modeling for Low Carbon Society

   Use of AIM CGE Model for South-Asia Cooperation Scenarios

3. Contributions, Capacity Building and Dissemination

4. Conclusions and Future Work

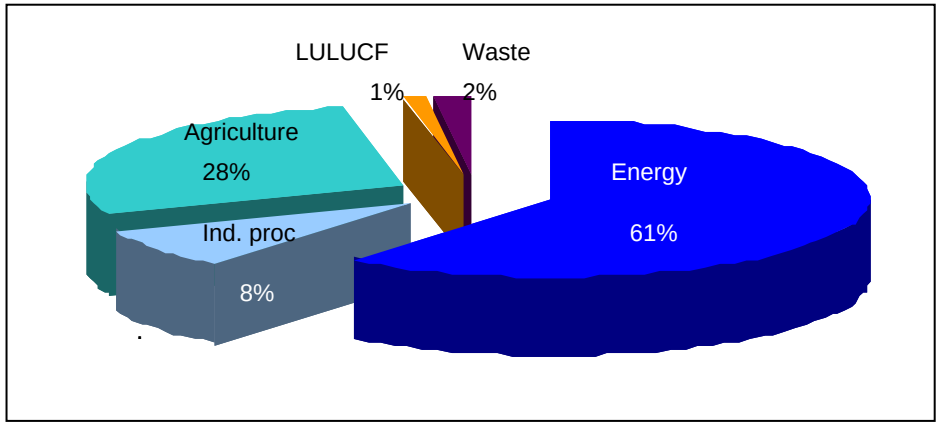
Multi-gas emissions inventory assessment

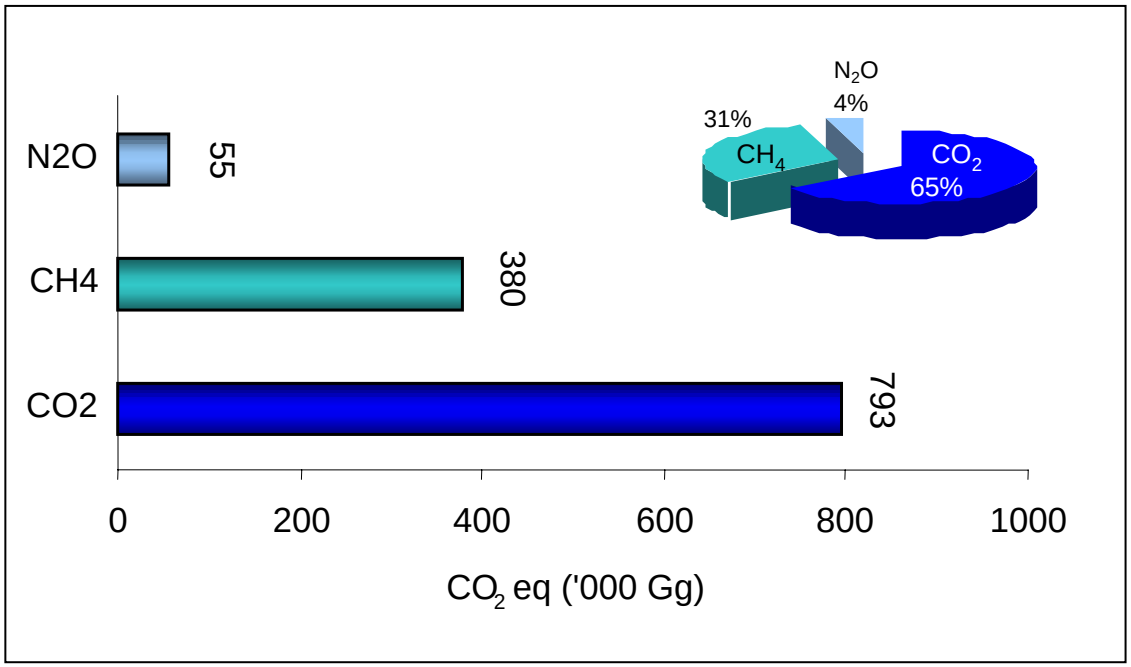
(Period: 1985 to 2005)

Gases

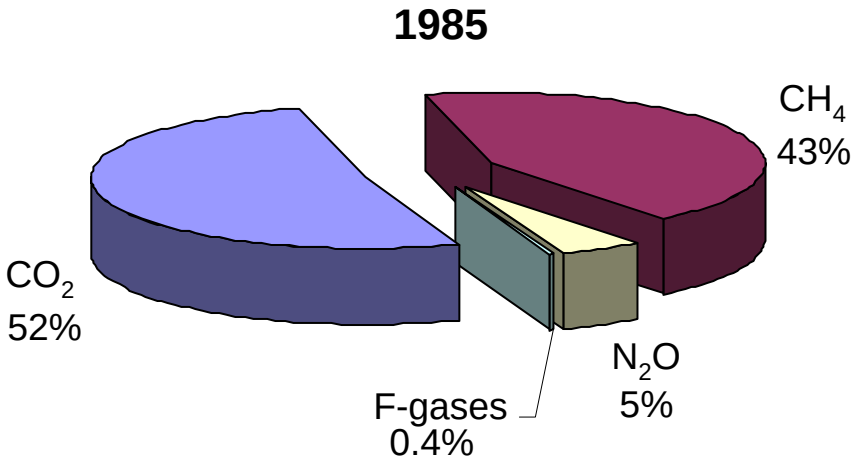
- CO_2
- CH_4
- N_2O
- F-Gases
- BC/OC
- Local Air Pollutants (SO_2, NO_X, CO, TSP)

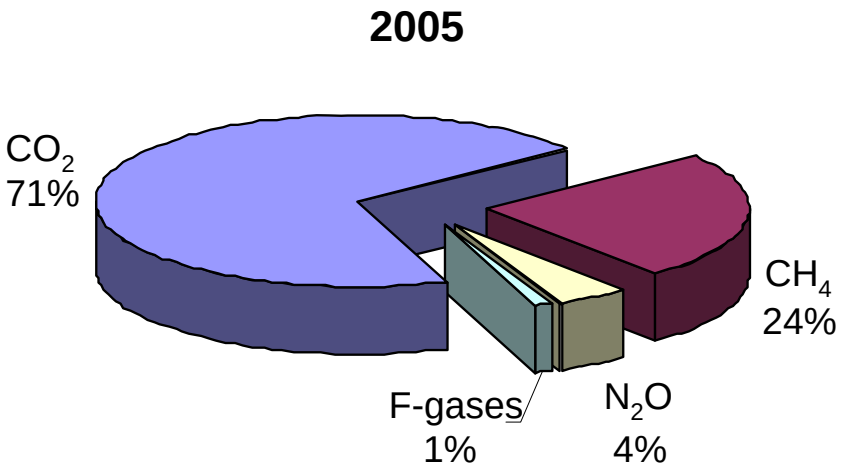
GHG Emissions from sectors in India: 1994





GHG Share trend: 1985 to 2005





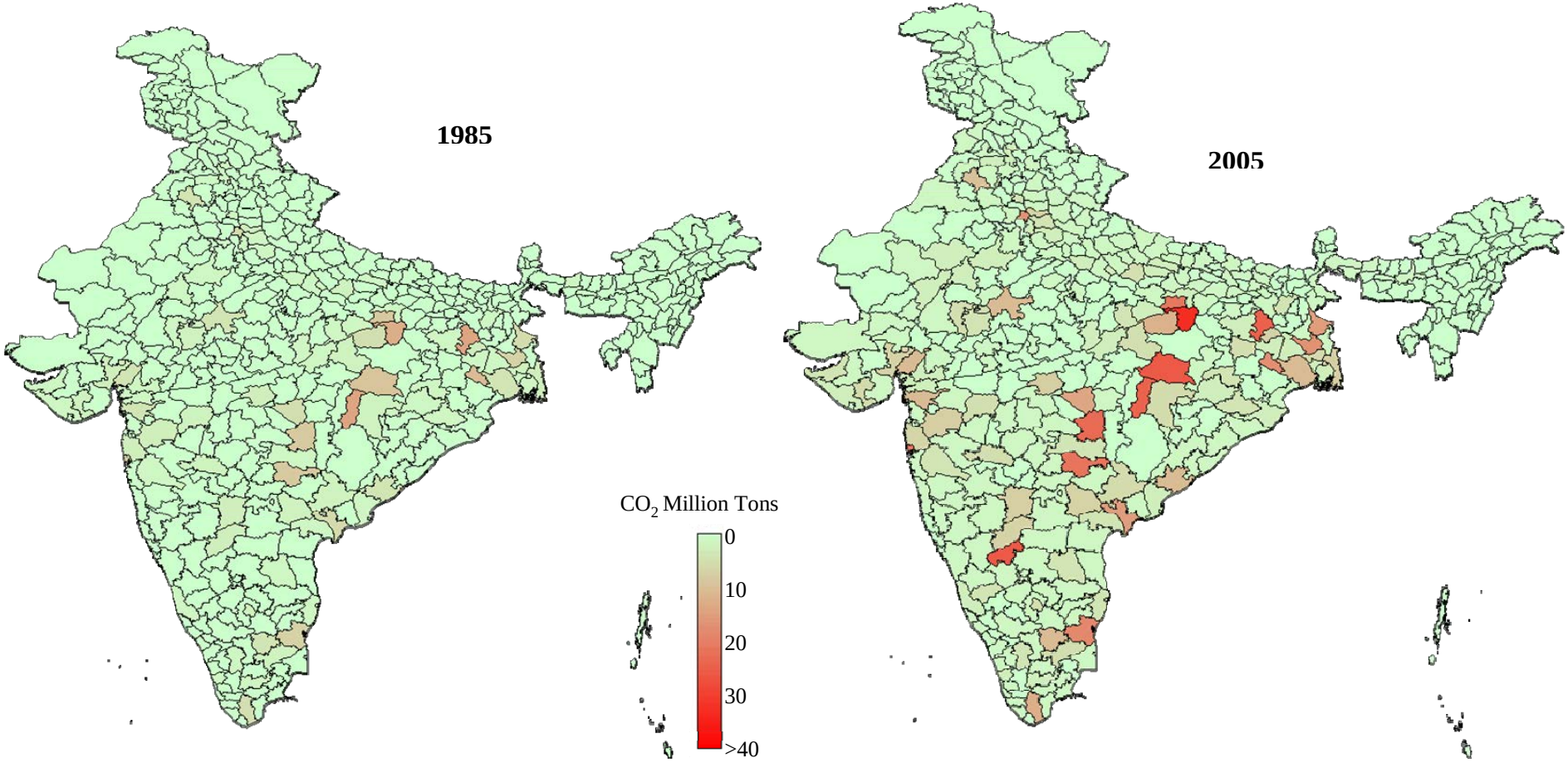
Post NATCOM Changes

- Earlier estimates used few India specific coefficients + IPCC default emission factors
- NATCOM updated emissions coefficients and estimate activity levels
- Increase of 8% emissions from previous estimates of CO_2
- Change in carbon emissions factors, esp. Indian coal, explains 1.4% of increase
- Industrial process emissions from sources that were not captured in earlier estimates. These add about 26 Mt-CO2 to the "Other industries" category, explaining 3.2% of the upward revision
- Improvement activity data and reallocation of emissions for some categories, such as "other sectors" and "Other industries". Activity data changes contributed 2.6% of the upward revision

Sector Contribution to CO_2 emissions: Tg-CO_2

Sector	1985	1990	1995	2000	2005	CAGR % (1985-2005)
Power	146	213	379	517	638	7.7
Road	45	67	82	116	143	5.9
Railway	20	14	6	5	6	-5.8
Aviation	2	2.5	3	4	5	4.7
Shipping	0.4	0.5	0.6	0.8	1	4.7
Cement	28	43	56	77	98	6.5
Iron & steel	56	74	83	92	103	3.1
Fertilizer	20	22	23	23	24	1.0
Other industries	62	82	91	98	109	2.9
Other sectors	57	76	92	97	102	3.0
All India	**436.4**	**594**	**815.6**	**1029.8**	**1229**	**5.3**

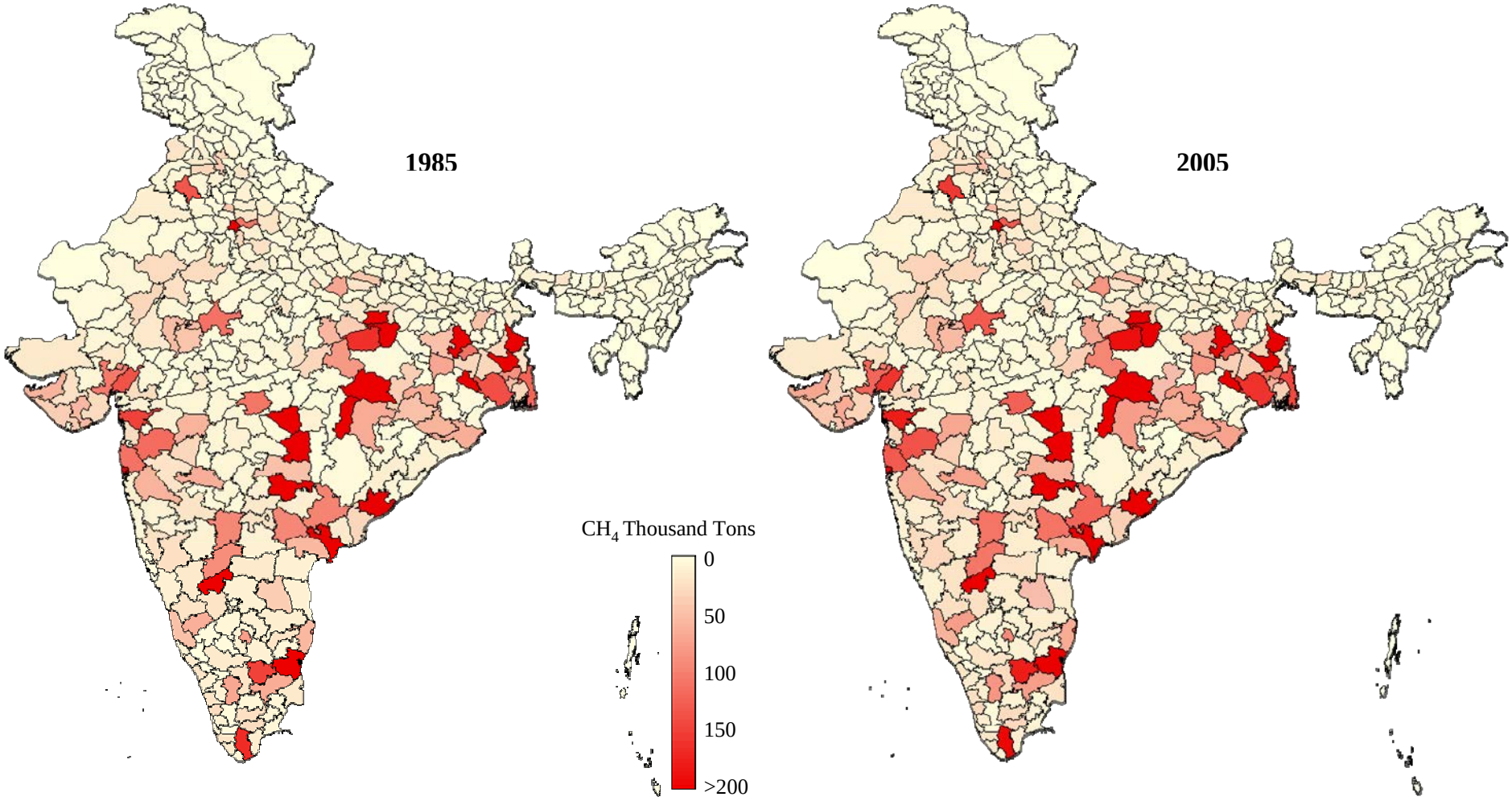
District level CO_2 emissions: 1985 & 2005



CH_4 emissions: Tg-CH_4

Source categories	1985	1990	1995	2000	2005	CAGR % (1985-2005)
Enteric fermentation	8.80	9.00	9.42	9.60	9.62	0.4
Paddy Cultivation	4.01	4.02	4.08	4.03	4.02	0.0
Biomass burnt for energy	1.61	1.62	1.67	1.76	1.80	0.6
MSW disposal	0.62	0.68	0.75	0.84	0.96	2.2
Manure Management	0.90	0.95	0.99	1.01	1.00	0.5
Oil and natural gas related	0.23	0.50	0.65	0.94	1.13	8.4
Waste Water disposal	0.36	0.39	0.45	0.56	0.67	3.2
Coal Production	0.51	0.57	0.67	0.72	0.79	2.2
Agriculture crop residue burning	0.17	0.18	0.181	0.18	0.18	0.3
Total CH_4	**17.21**	**17.92**	**18.85**	**19.64**	**20.18**	**0.8**

District level CH_4 emissions



N_2O emissions from various source categories Gg- N_2O

Source categories	1985	1990	1995	2000	2005	CAGR % (1985-2005)
Synthetic fertilizer use	80	94	109	129	151	3.2
Field burning of agri residue	15	18	21	21	20	1.4
Indirect soil emissions	17	19	21	25	30	2.9
Manure management	4	5	6	6	8	3.9
Fossil fuel combustion	7	9	12	15	19	4.9
Industrial processes	6	7	9	12	16	5.0
Waste	5	6	7	8	9	2.8
Total N_2O	**134**	**158**	**185**	**217**	**253**	**3.2**

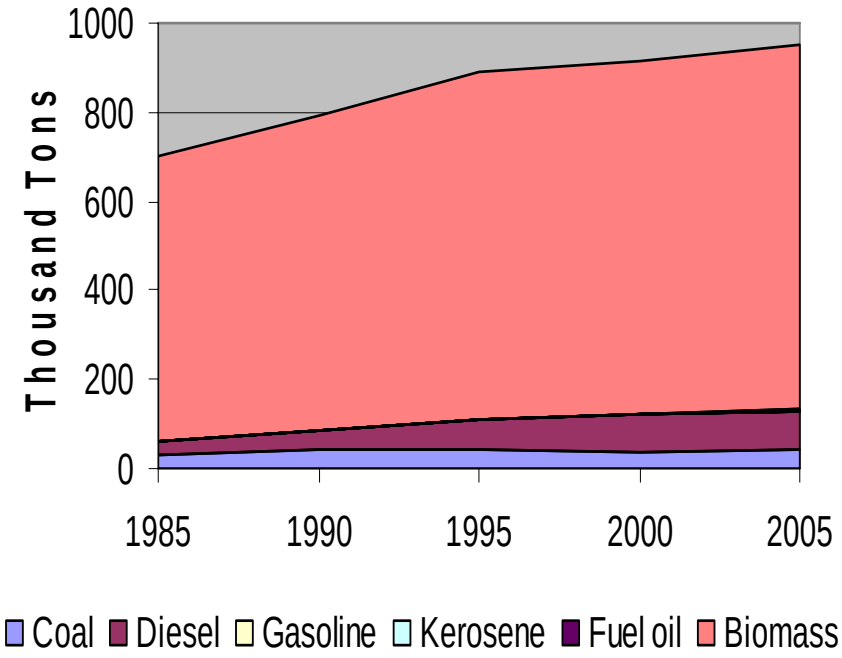
PFC emissions: Gg

Emissions	**1985**	**1990**	**1995**	**2000**	**2005**	**CAGR % (1985-2005)**
CF_4 (Gg)	0.373	0.621	0.682	0.867	1.057	5.3
C_2F_6 (Gg)	0.037	0.062	0.068	0.087	0.106	5.3
CF_4 (Gg-CO_2 Eq.)	2425	4040	4435	5637	6867	5.3
C_2F_6 (Gg-CO_2 Eq.)	343	572	628	798	972	5.3
Imports (CO_2 Eq.)	263	438	540	687	930	6.5
Total PFCs (Gg-CO_2 Eq.)	**3031**	**5049**	**5603**	**7121**	**8769**	**5.5**

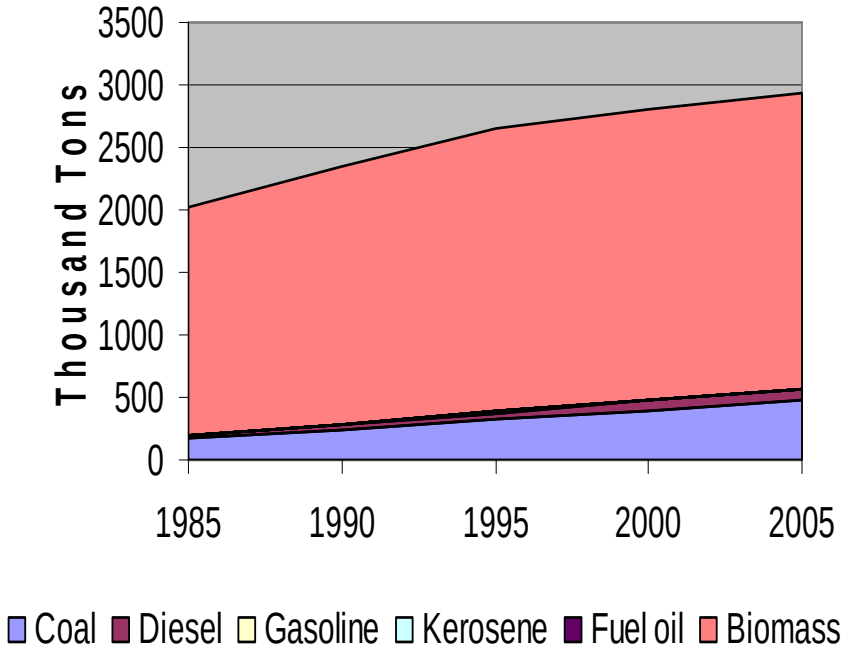
HFC emissions: Gg-CO2 Equivalents

Emission	1990	1995	2000	2005	CAGR (%)
HFC-134a	-	-	285	1437	38
HFC-152a	-	1	2	6	23
HFC-227ea	-	61	137	271	16
HFC-23	873	2004	4936	9500	17
Total HFCs	**873**	**2066**	**5076**	**9777**	**17**

Black and Organic carbon emissions 1985-2005 ('ooo Ton)



Black Carbon



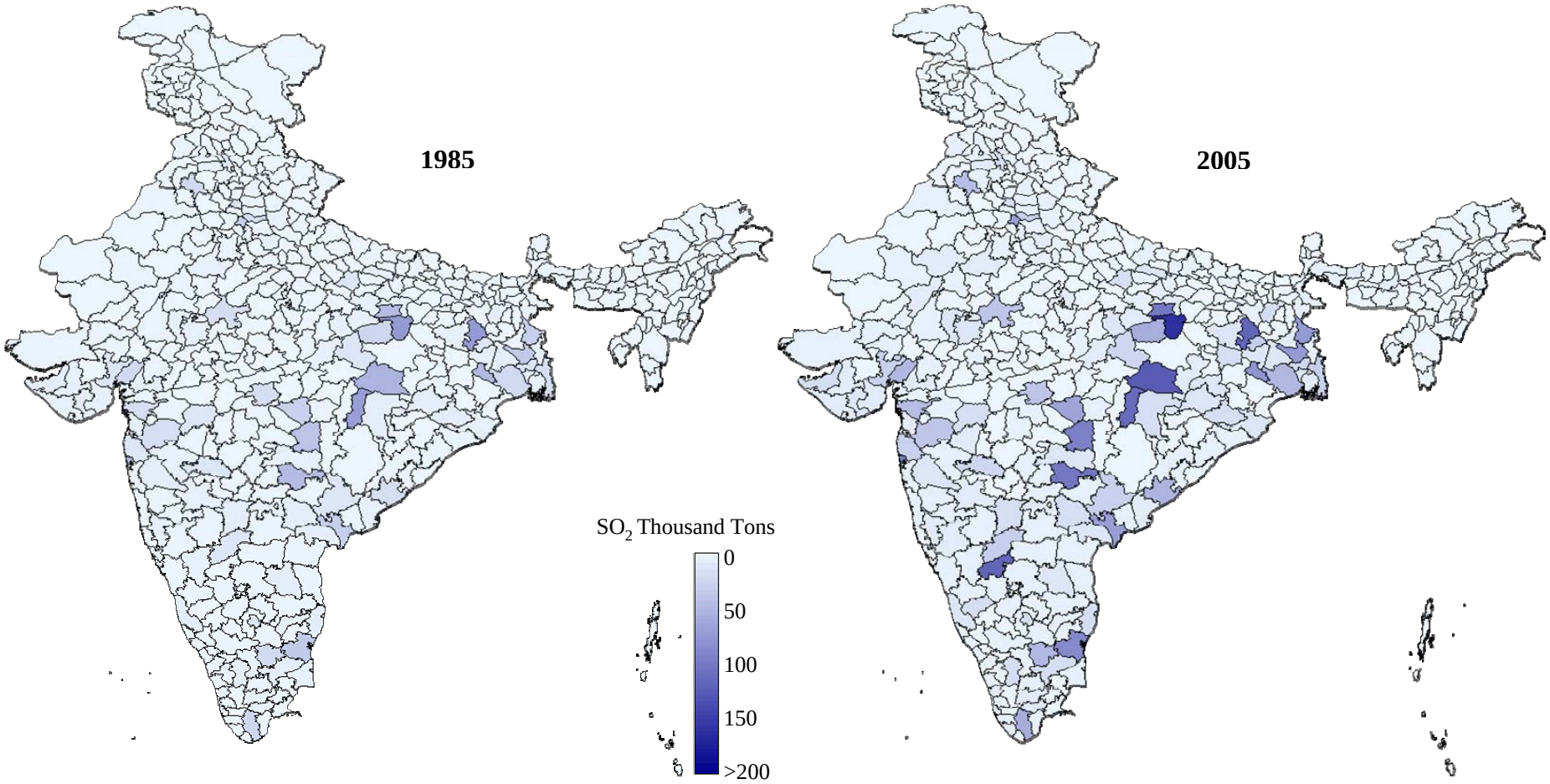
Organic Carbon

Note: These are mean values using early estimates of activities and coefficients and therefore are highly uncertain.

Sector level SO2 emission estimates in Tg-SO2

Source/Sector	1985	1990	1995	2000	2005	CAGR (1985-2005)
Power	0.723	1.047	1.745	2.300	2.720	6.8
Steel	0.210	0.262	0.280	0.310	0.347	2.5
Fertilizer	0.125	0.106	0.125	0.124	0.130	0.2
Cement	0.074	0.097	0.108	0.160	0.206	5.2
Other Industries	0.438	0.576	0.605	0.651	0.724	2.5
Road	0.255	0.201	0.243	0.138	0.085	-5.3
Rail	0.130	0.069	0.027	0.011	0.012	-11.2
Shipping	0.006	0.008	0.010	0.013	0.015	4.6
Aviation	0.008	0.009	0.006	0.007	0.009	0.8
Biomass burning	0.215	0.216	0.217	0.215	0.210	-0.1
Sulfuric Acid	0.040	0.045	0.053	0.061	0.066	2.5
Lead Smelting	0.006	0.008	0.011	0.013	0.015	4.6
Zinc Smelting	0.015	0.016	0.014	0.015	0.016	0.3
Copper Smelting	0.016	0.027	0.041	0.050	0.052	6.1
Other sectors	0.130	0.160	0.178	0.190	0.192	2.0
All India	**2.39**	**2.85**	**3.66**	**4.26**	**4.80**	**3.5**

District level SO2 emissions



Sector level NOx emission estimates in Tg-NOx

Source categories	1985	1990	1995	2000	2005	CAGR % (1985-2005)
Power	0.377	0.620	0.964	1.283	1.547	7.3
Road	0.520	0.670	0.985	1.380	1.696	6.1
Rail	0.120	0.101	0.100	0.110	0.132	0.5
Navigation	0.010	0.012	0.014	0.018	0.023	4.3
Aviation	0.018	0.024	0.033	0.042	0.051	5.4
Cement	0.040	0.060	0.085	0.116	0.148	6.7
Steel	0.123	0.152	0.181	0.206	0.231	3.2
Brick	0.078	0.094	0.109	0.133	0.165	3.8
Other industries	0.204	0.229	0.263	0.287	0.315	2.2
Biomass burning	0.586	0.633	0.670	0.670	0.650	0.5
Nitric acid production	0.002	0.004	0.006	0.011	0.013	9.8
Other sectors	0.030	0.040	0.046	0.049	0.051	2.7
All India (Tg-NO_X)	**2.11**	**2.64**	**3.46**	**4.31**	**5.02**	**4.4**

Sector level CO emission estimates in Tg-CO

Sectors	**1985**	**1990**	**1995**	**2000**	**2005**	**CAGR % (1985-2005)**
Residential	31.3	32.1	33.3	34.8	35.9	0.7
Transport	1.99	2.5	3.22	4.47	5.35	5.1
Power	0.035	0.054	0.09	0.12	0.15	7.6
Brick	0.21	0.3	0.42	0.57	0.78	6.7
Other industries	0.03	0.04	0.05	0.05	0.07	4.3
All India	**33.6**	**35**	**37**	**40**	**42.2**	**1.2**

Sector level TSP emission estimates in Tg-TSP

Sources	**1985**	**1990**	**1995**	**2000**	**2005**	**CAGR % (1985-2005)**
Residential	3.94	4.13	4.19	4.23	4.18	0.3
Power	2.60	2.91	3.26	1.57	0.79	-5.8
Transport	0.93	1.38	1.69	2.04	2.19	4.4
Cement	0.23	0.30	0.40	0.51	0.54	4.5
Brick	0.36	0.41	0.50	0.66	0.88	4.6
Other industries	0.01	0.02	0.02	0.04	0.05	8.4
Other sectors	0.05	0.06	0.07	0.08	0.09	3.0
All India	**8.12**	**9.21**	**10.13**	**9.13**	**8.72**	**0.4**

Multi-gas emission trends for India over 1985-2005 in Tg

Emissions	1985	1990	1995	2000	2005	CAGR % (1985-2005)
CO_2	436	593	816	1030	1229	5.3
CH_4	17.21	17.92	18.85	19.64	20.18	0.8
N_2O	0.134	0.158	0.185	0.217	0.253	3.2
PFC (CO_2 Eq.)	3.03	5.05	5.60	7.12	8.77	5.5
HFC (CO_2 Eq.)	-	0.87	2.07	5.08	9.78	17
SF_6 (CO_2 Eq.)	-	-	-	0.09	2.08	89
GHG (CO_2 Eq.) #	**842**	**1025**	**1277**	**1522**	**1752**	**3.7**

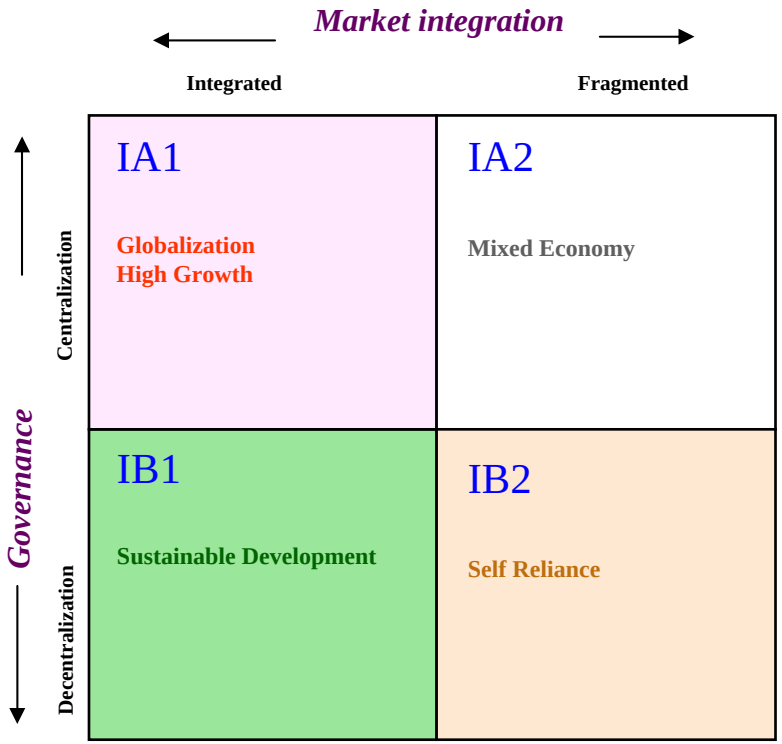
Includes CO_2, CH_4, N_2O, PFC, HFC and SF_6.
Global warming potentials of 1, 21 and 310 are used for CO_2, CH_4 and N_2O respectively.

SO_2	2.39	2.85	3.66	4.34	5.02	3.8
NO_X	2.11	2.64	3.46	4.31	5.02	4.4
CO	33.6	35	37	40	42.2	1.2
TSP	8.12	9.21	10.13	9.13	8.72	0.4

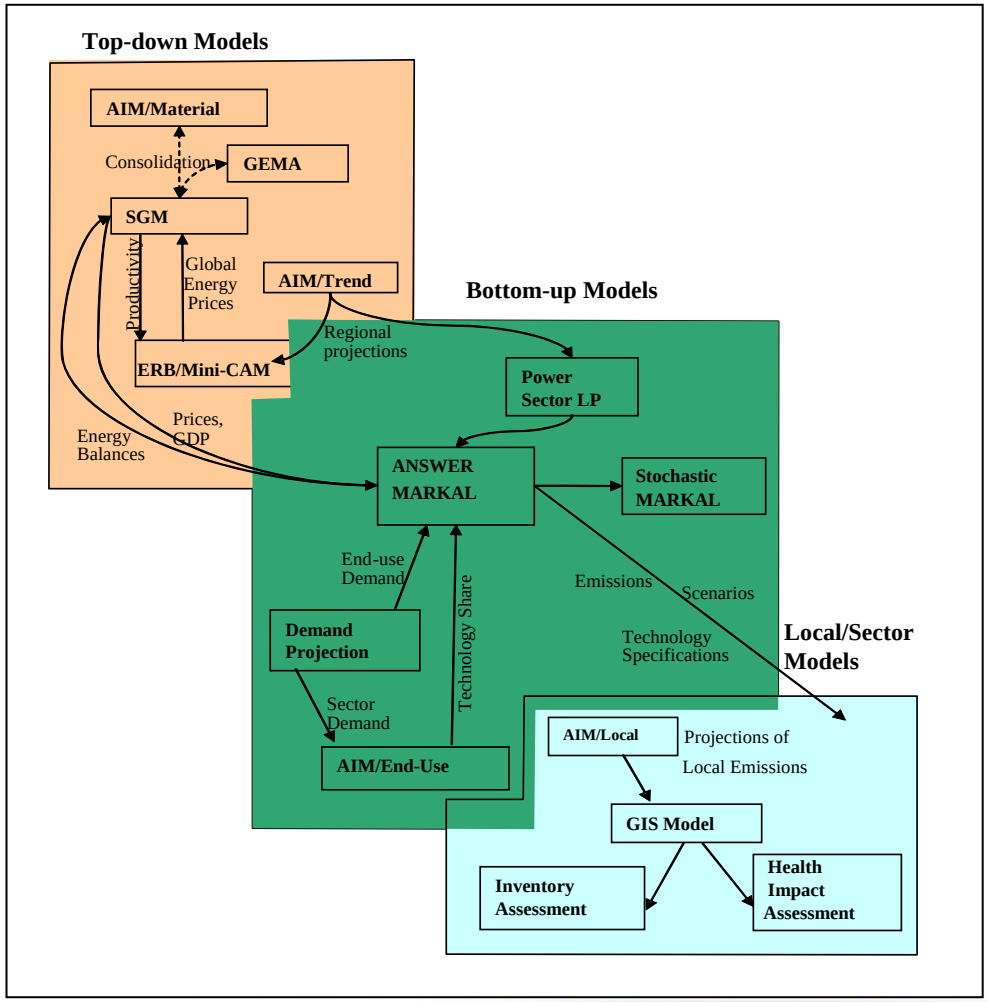
AIM model applications

- Multi-gas Emissions Scenarios
- Modeling for Low Carbon Society
- Use of AIM CGE Model for South-Asia Cooperation Scenarios

Indian Emissions Scenarios and Modeling Framework



Modeling Framework

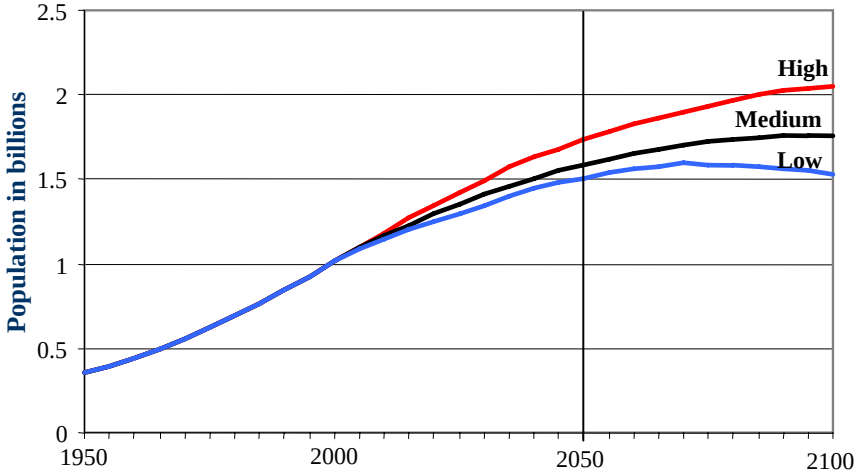


Drivers of Future Emissions

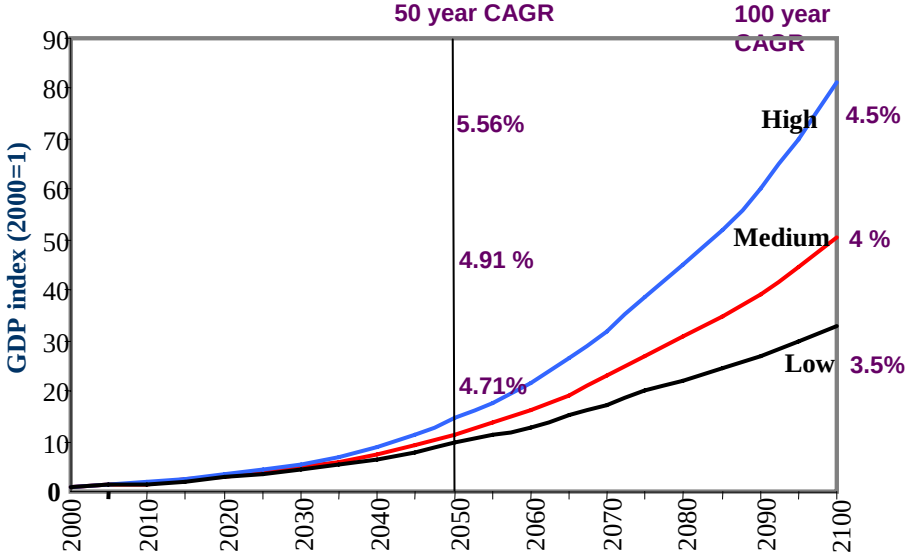
Conventional Drivers

- Population
- Economic Growth
- Energy Resources
- Technologies

Population



Economic Growth



Emerging Drivers for Developing Countries

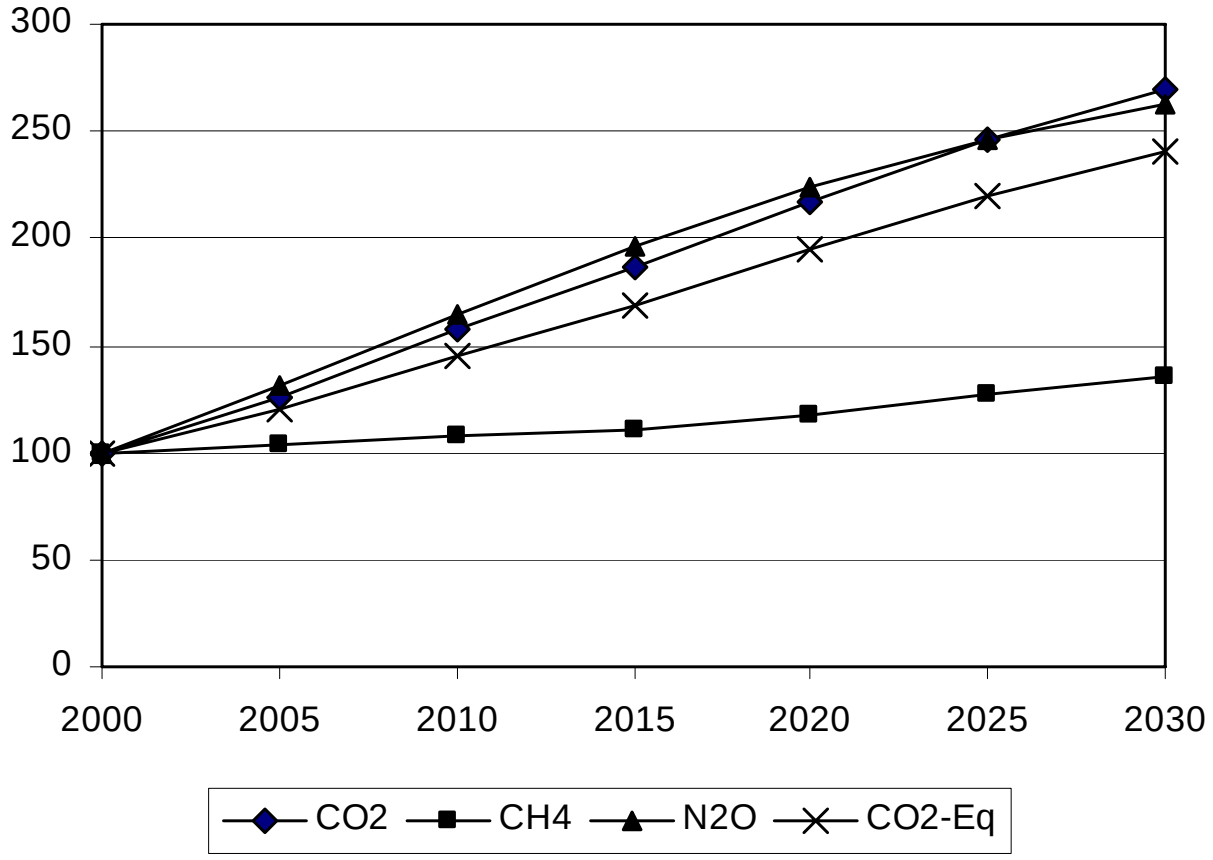
- Transition Processes (Lock-ins)
- International Labor Markets
- Human Capital
- Knowledge Flows
- Governance (Risks, Investments)

Multi-gas Emissions Scenarios

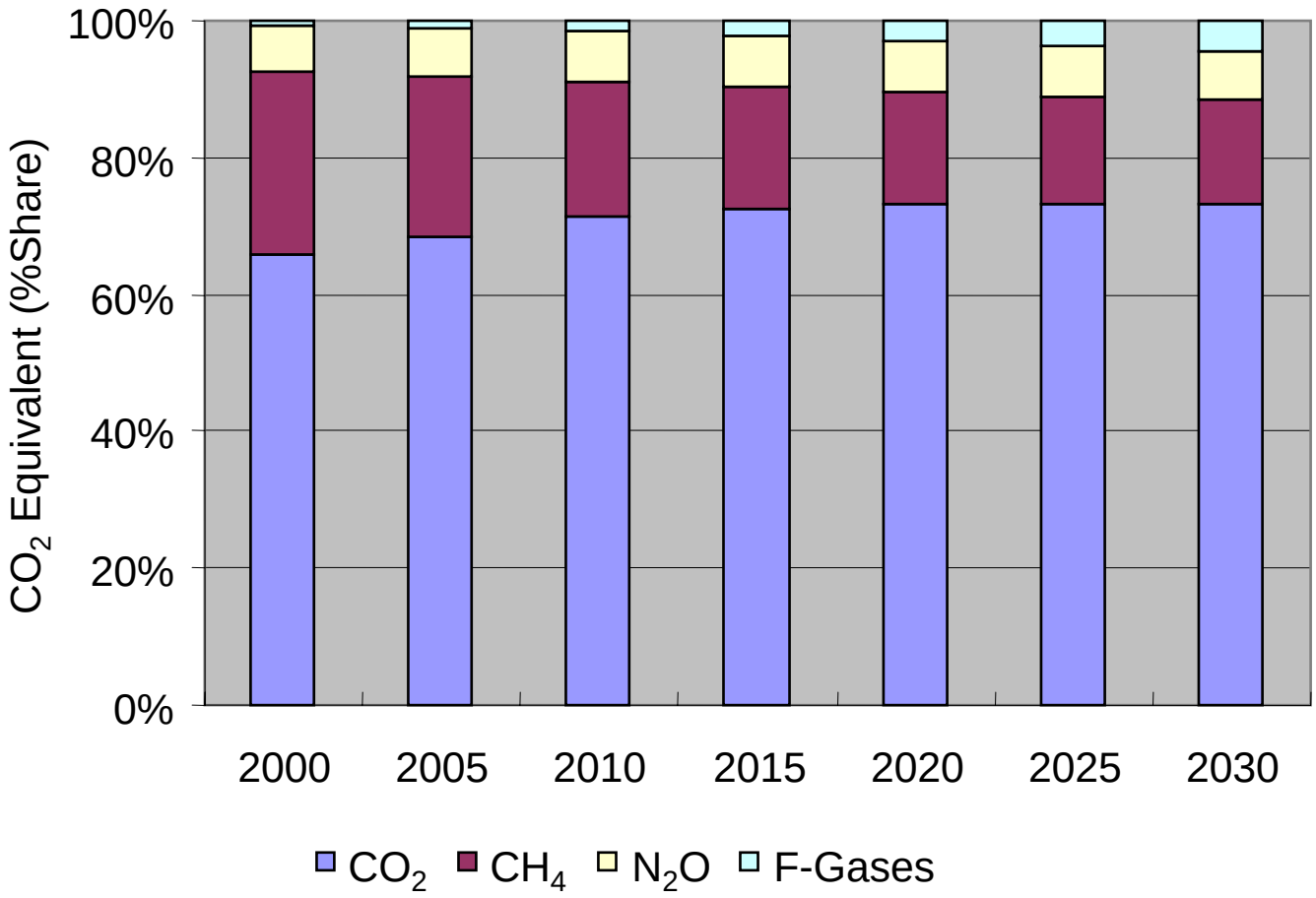
Indian emission projections (Tg): Reference scenario (IA2) results

Emissions (Tg)	**2000**	**2010**	**2020**	**2030**
CO_2	956	1507	2080	2572
Methane	18.63	20.08	21.73	24.36
N_2O	0.308	0.505	0.689	0.807
CO_2 equivalent GHG[a]	1454	2115	2839	3507

Indian emission growth: Reference scenario (IA2) results



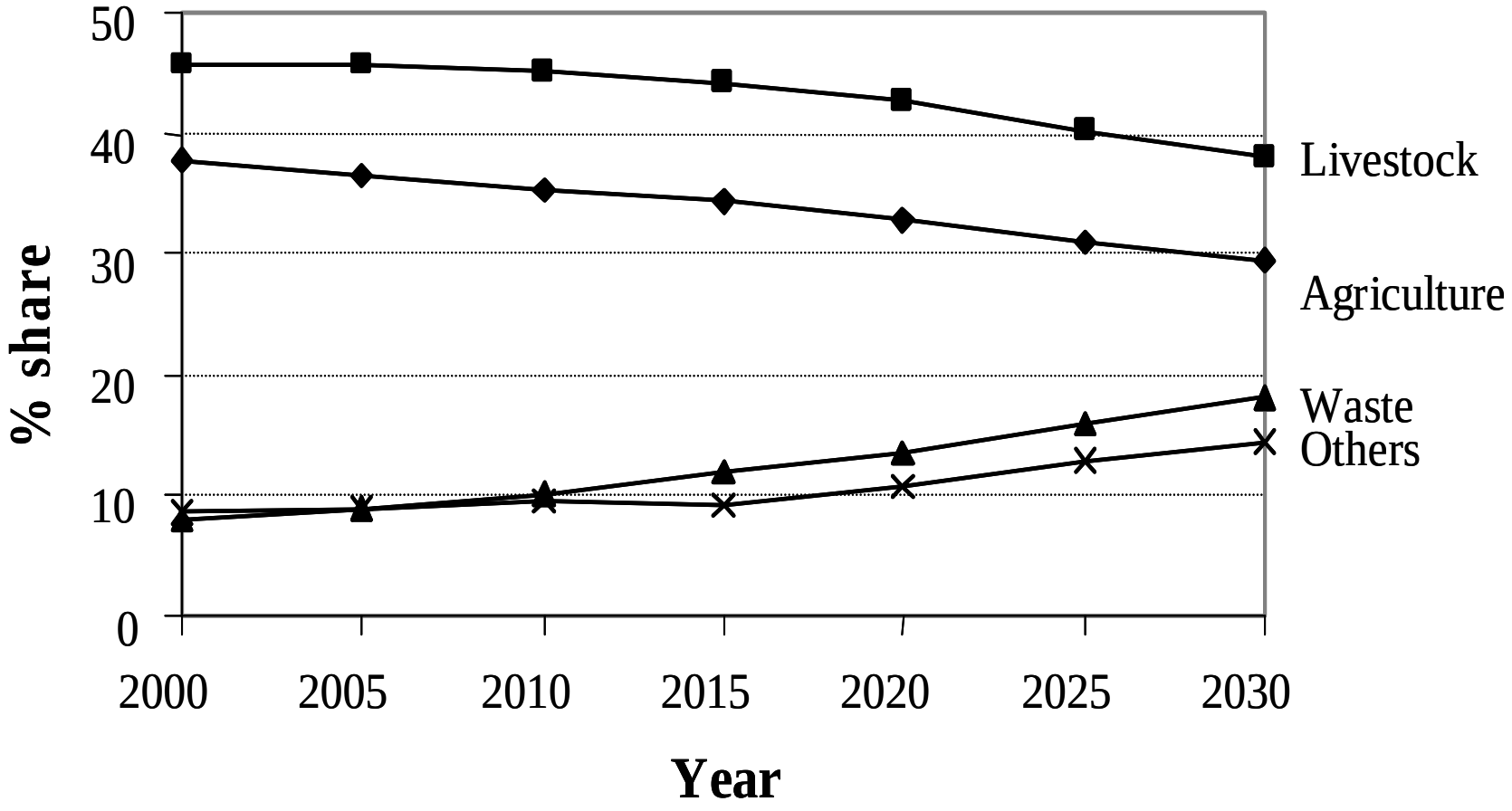
Share of CO_2, CH_4 and N_2O under IA2 scenario



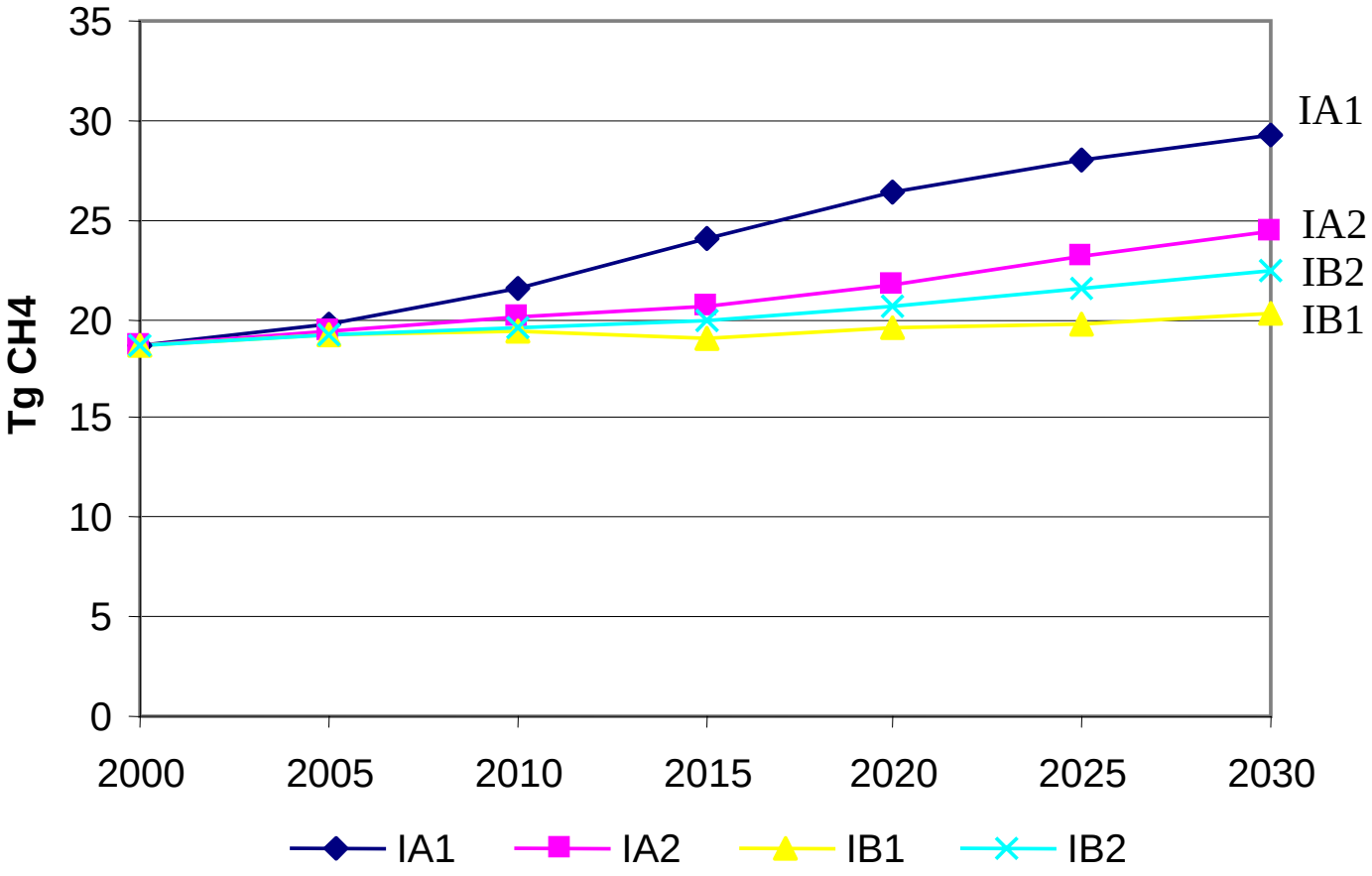
CH_4 emission projections for India under Reference scenario (IA2)

Sources	2000	2010	2020	2030
Agriculture residue	0.10	0.12	0.14	0.16
Biomass consumption	2.91	3.00	3.07	3.11
Coal production	0.72	1.07	1.86	2.89
Oil & natural gas	0.88	0.85	0.50	0.61
Enteric fermentation in animals	7.59	8.04	8.23	8.25
Manure management	0.95	1.00	1.03	1.03
Paddy cultivation	4.00	3.98	3.93	3.87
Municipal solid waste	1.02	1.46	2.30	3.64
Waste water	0.46	0.56	0.67	0.80
Total CH_4 (Tg)	18.63	20.08	21.73	24.36

Changing contributions for future CH_4 emissions under IA2 scenario



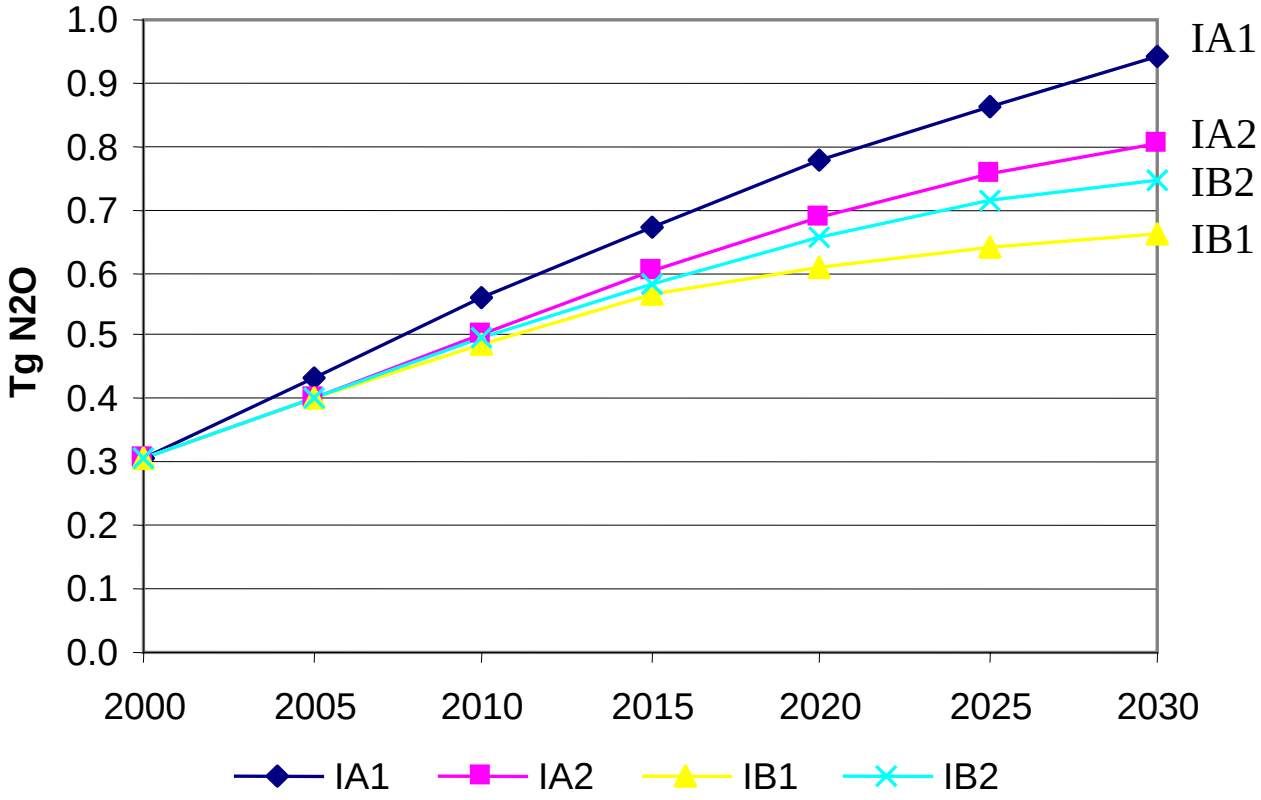
Future Methane emissions under alternate scenarios



N_2O emission projections for India under Reference scenario (IA2)

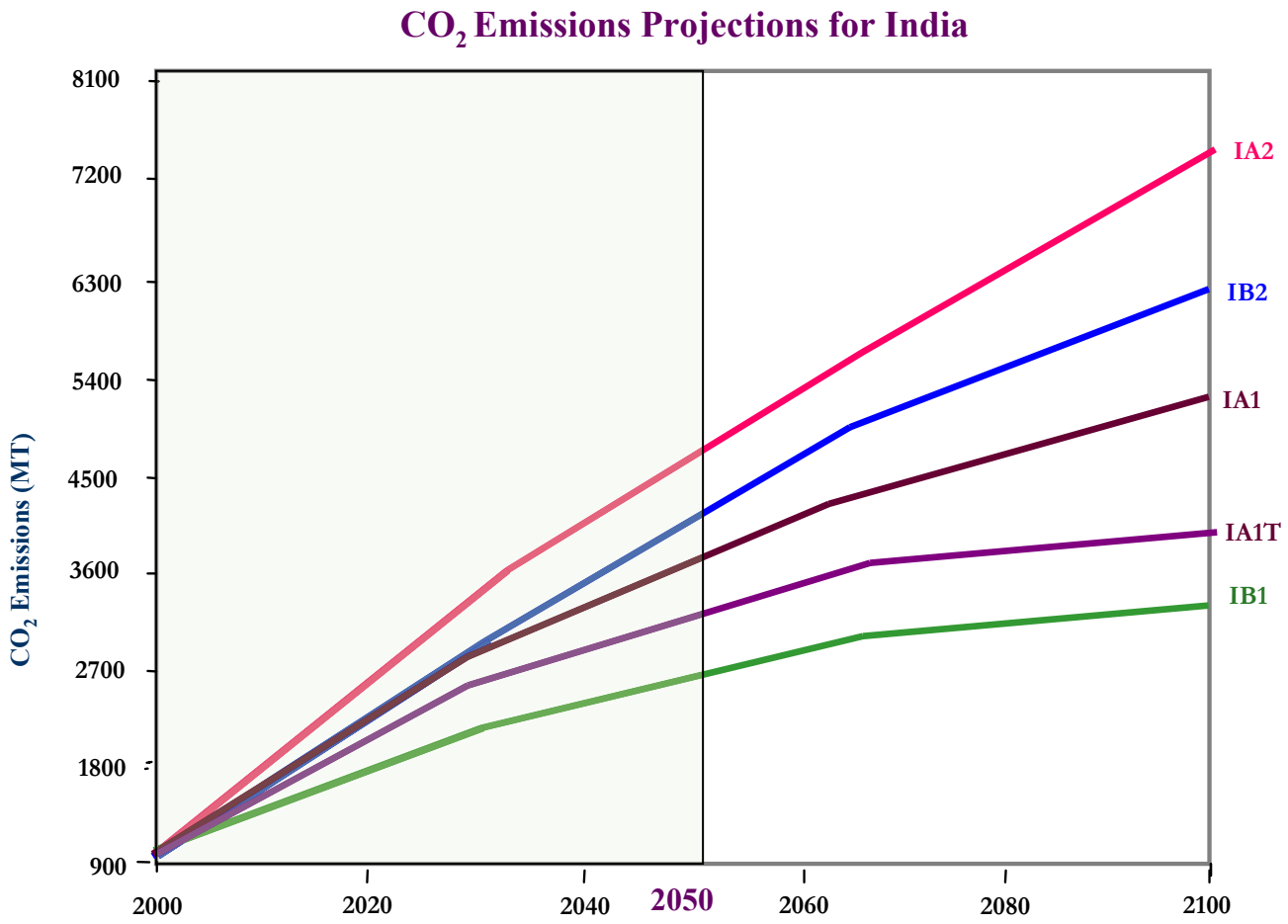
Sources (Gg)	2000	2010	2020	2030
Coal combustion	9.9	16.8	24.0	28.0
Oil product combustion	2.0	3.6	6.4	10.0
Field burning of agriculture residue	33.9	41.5	42.6	33.4
Biological nitrogen fixation	5.6	6.6	7.8	9.1
Natural gas combustion	0.0	0.0	0.0	0.0
Synthetic fertilizer use	206.1	368.4	524.9	626.8
Livestock	12.2	14.1	16.3	18.8
Industrial processes	12.1	23.0	31.0	38.0
Indirect emissions	26.0	30.7	36.2	42.6
Total N_2O (Gg)	307.8	504.6	689.0	806.7

Future N_2O emissions under alternate scenarios



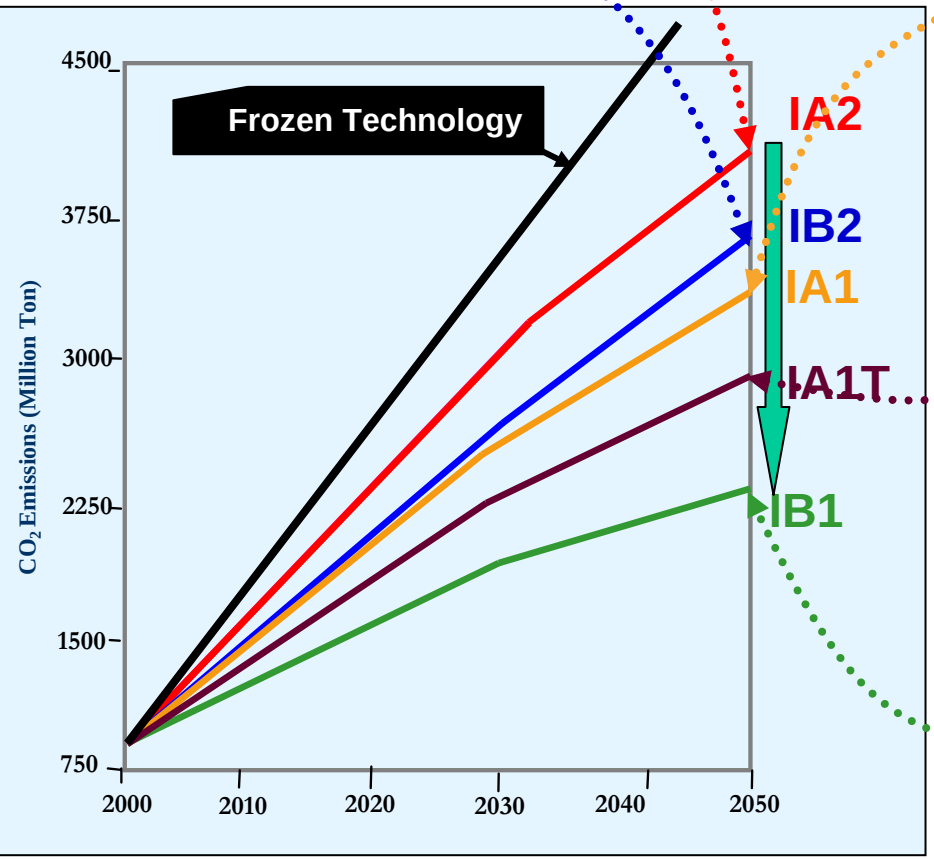
Modeling for Low Carbon Society

Indian Emissions Scenarios



Low Carbon Society (2050): Technologies in Scenarios

Conventional Technology Paths: Include significant endogenous technological change



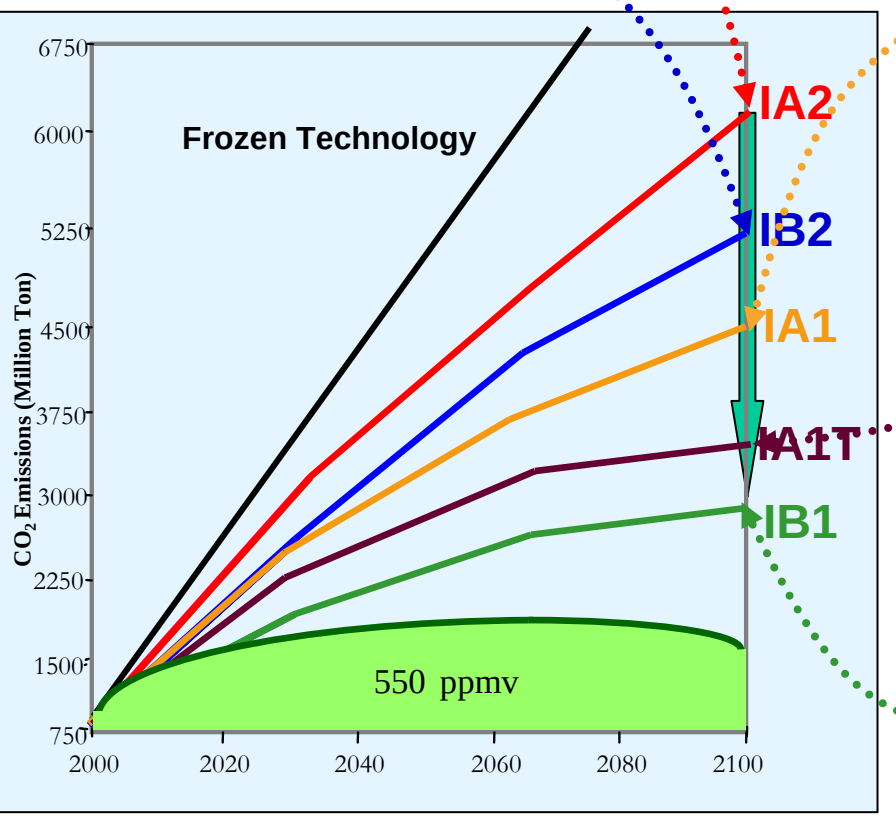
- Synfuels, Next-Gen Nuclear Fission
- Fuel cell vehicles, Pipeline networks
- Energy efficient appliances/ infrastructure
- Coal liquid, IGCC, Hydrogen from gas

- Nuclear (Thorium), Carbon-free hydrogen
- Information highways, High speed trains
- Advanced materials, Nanotechnology

- Push for renewable energy & recycling
- Bikeway, Advanced car sharing system
- Substitution of transport by IT
- Dematerialization, Material substitutions
- Sustainable habitats & land-use practices

Towards GHG Stabilization (2100): Technologies in Scenarios

Conventional Technology Paths



- Synfuels, Gas hydrates, Nuclear fission
- Fuel cell vehicle: Carbon-free hydrogen
- Energy efficient appliances/ infrastrucutre
- CO_2 Capture/ Storage, pipeline networks

- Nuclear Fusion, Backstops
- Information highways, High speed trains
- Advanced materials, Nanotechnology

- High share of renewable Energy
- Lifestyle changes, Eco-friendly choices
- Substitution of transport by IT
- Dematerialization, material substitutions
- Sustainable habitats, Public amenities

AIM CGE Model Application
(Included in APEIS Project Presentation)

Contributions, Capacity Building and Dissemination

1. Multi-gas emissions inventory assessment (Period: 1985 to 2005)
   - First time historical estimation of F-Gases and BC/OC for India **(Indian Coefficients)**
   - Inputs to India's National Communications exercise **(updating/enhancing emissions inventories)**
   - Provide Accurate Data for Baseline Assessment for CDM Projects

2. AIM Model Applications **(Contributions, Capacity Building and Interfaces)**
   - Multi-gas Emissions Scenarios for India **(paper for EMF 21/ Energy Journal)**
   - Modeling for Low Carbon Society and Stabilization Assessment **(Inputs to World Bank, COP11 and papers in International Journals)**
   - Use of AIM/CGE model for Gas Market Development and South-Asia Cooperation Scenarios **(Capacity building of Indian researchers in top-down modeling)**

3. Dissemination and Interfaces
   - IPCC New Scenarios & AR4
   - Eco-Asia
   - APN's CAPaBLE Project
   - UNEP's "Development and Climate" Project
   - IEA's Global Energy Outlook
   - India's National Communications Project

Conclusions and Future Work

1. Multi-gas Emissions inventory assessment
   - Improving estimates for F-Gases and BC/OC
   - Baseline information for CDM Projects (F-Gases, Electricity Sector)
   - Comparative assessment of Inventory database with other countries in Asia-Pacific

2. AIM model applications
   - New Emissions Scenarios – Improving Specifications of Issues and Dynamics from Asia
   - Updating AIM Country Model for India
   - Aim CGE Model Development for India
   - Harmonize modeling with International Cooperation towards Low Carbon Society
   - New applications to support global clean energy and climate change programs and initiatives

3. Capacity building, dissemination, interfaces and contributions to National and International Assessment Initiatives together with the AIM team