UCL Energy Institute

Mitigating the Climate Impact of Aviation – Is Technology Enough?

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Invitation to an RAeS/HAW lecture in cooperation with the DGLR and VDI

Mitigating the Climate Impact of Aviation – Is Technology Enough?

Dr **Antony Evans**
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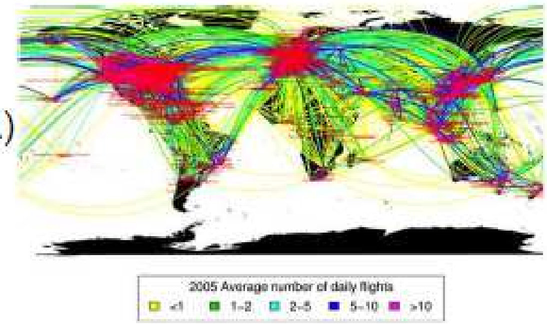


Lecture
followed by discussion

Entry free !
No registration required !

Date: Thursday, 12th June 2014, 18:00
Location: HAW Hamburg
Berliner Tor 5, (Neubau), Hörsaal 01.12

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences
Praxis Seminar Luftfahrt

Since 1960 demand for air travel has grown by more than 7% per year worldwide, and it is forecast to continue to grow strongly, at around 5% per year over the coming decades. As a result, while other sectors are reducing their climate footprint, aviation's is growing, despite significant technological developments over the past decades. What can we do to catch up? Many new fuel saving aircraft technologies are under development, including laminar flow technology, open rotors, blended wing body aircraft, biofuels etc. But will these technologies be adopted by airlines in sufficient numbers without policy intervention? Will this be enough to produce carbon neutral growth, or better? And does carbon neutral growth mean climate neutral growth? Answering these questions requires a systems level analysis, accounting for complex economic effects. This lecture will examine these questions based on analysis from the Aviation Integrated Modelling project.

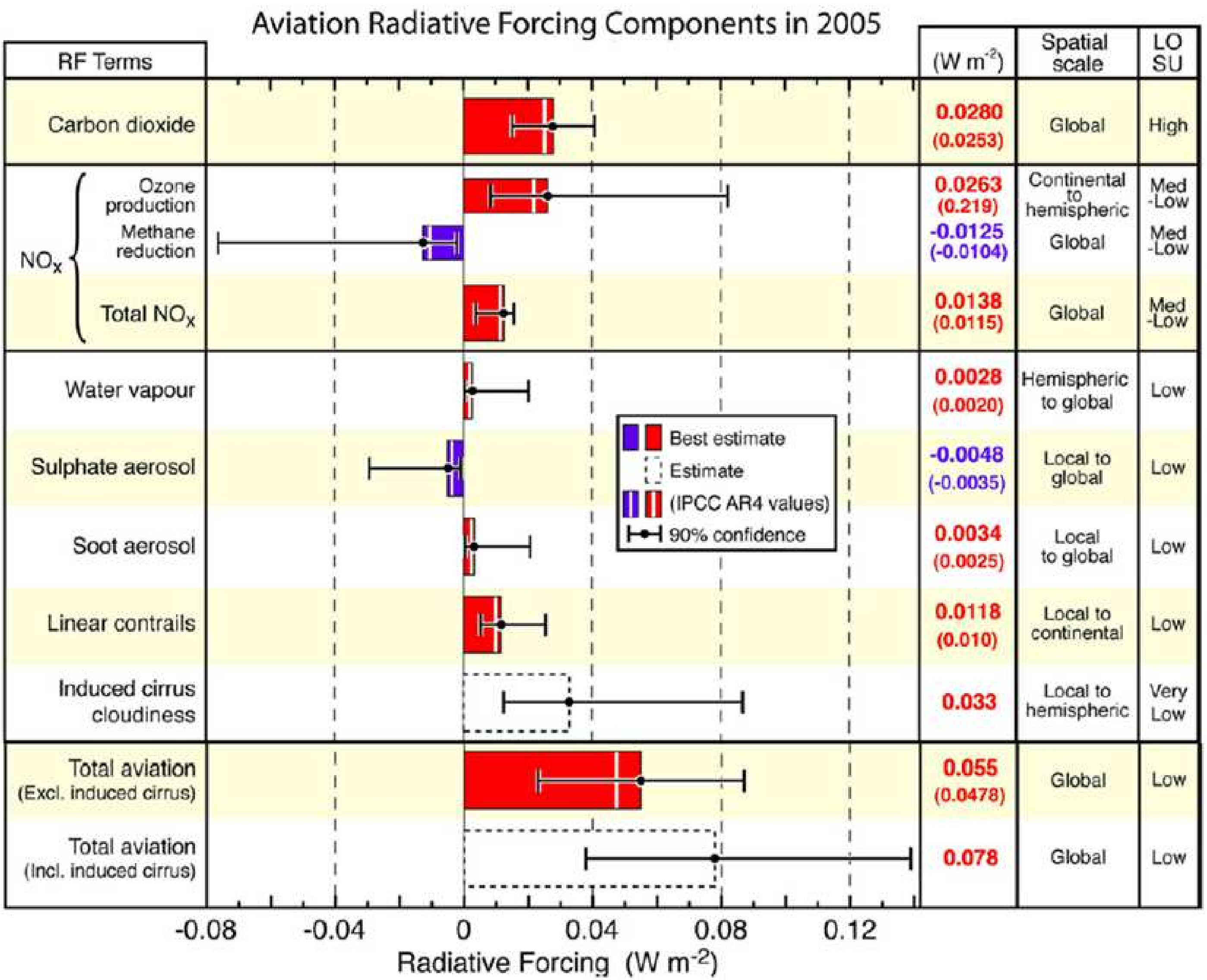
Tony Evans is a lecturer in Energy and Air Transport at the University College London (UCL) Energy Institute, and has over 15 years of experience in the analysis of air transport systems. He has two Masters degrees from MIT and a PhD from the University of Cambridge. He did postdoctoral research at both MIT and Cambridge before being awarded a postdoctoral fellowship from the NASA Ames Research Center Aviation Systems Division in California. He has also worked as a contractor for NASA and the US Federal Aviation Administration (FAA). He has published widely on air transport systems analysis, including aviation and the environmental, airline operations, airport capacity, and air traffic management.

Outline

- Introduction
- Aviation Integrated Modelling (AIM) project
- Sample problems
  - Airline fleet replacement funded by a global carbon tax
  - Climate-neutrality versus carbon-neutrality for an aviation biofuel policy

Introduction

- Air transport contributes $2.4 trillion to the world economy, or 3.4% of global GDP (ATAG 2014)
- About 2-3% of global anthropogenic CO_2 emissions are from aviation (IEA 2008)



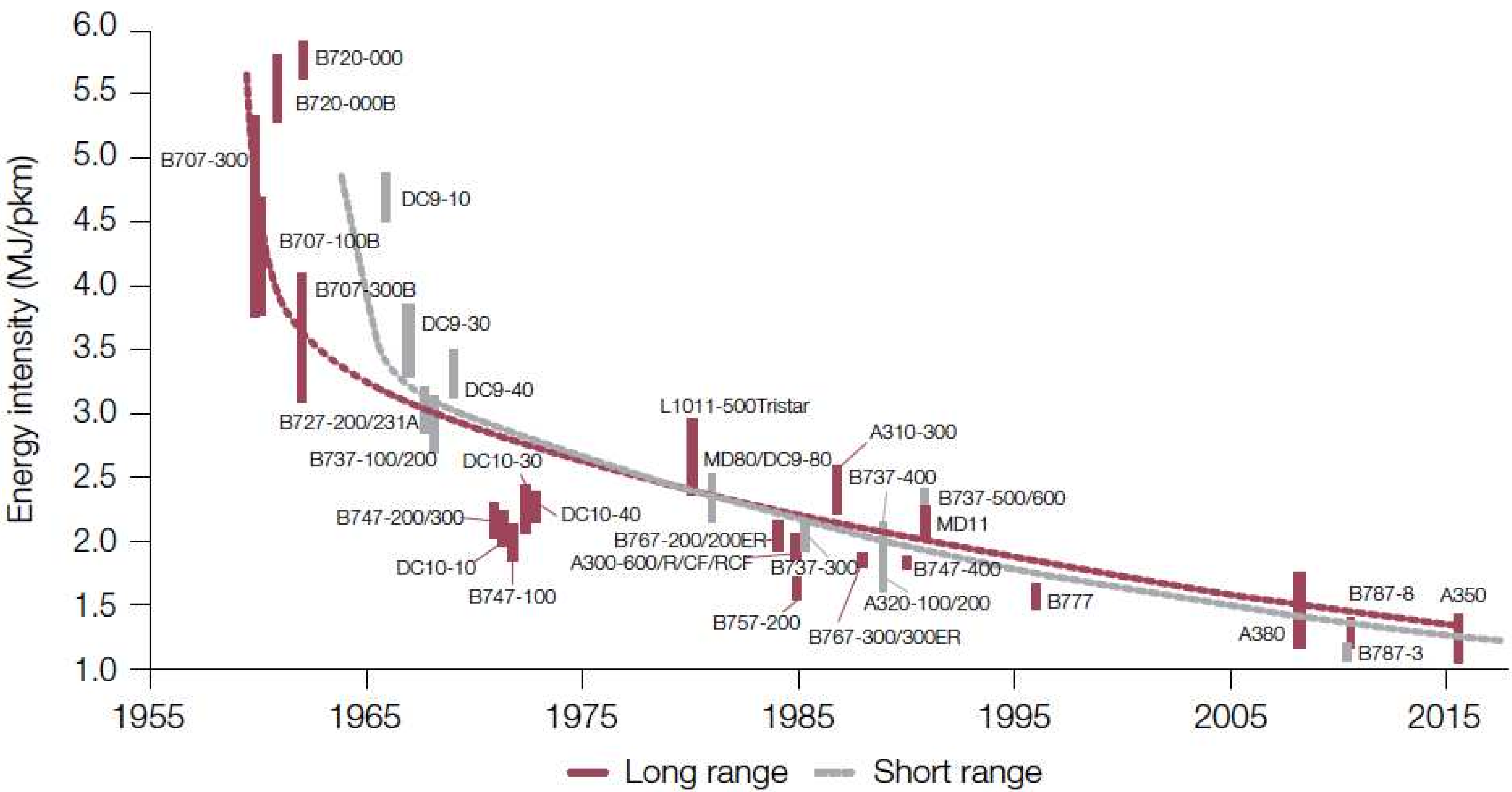
Lee *et al.*, 2010

Introduction

- Air transport contributes $2.4 trillion to the world economy, or 3.4% of global GDP (ATAG 2014)
- About 2-3% of global anthropogenic CO_2 emissions are from aviation (IEA 2008)
  - 3.5% to 4.9% of global anthropogenic radiative forcing (RF) if non-CO_2 effects included (Lee et al. 2010)

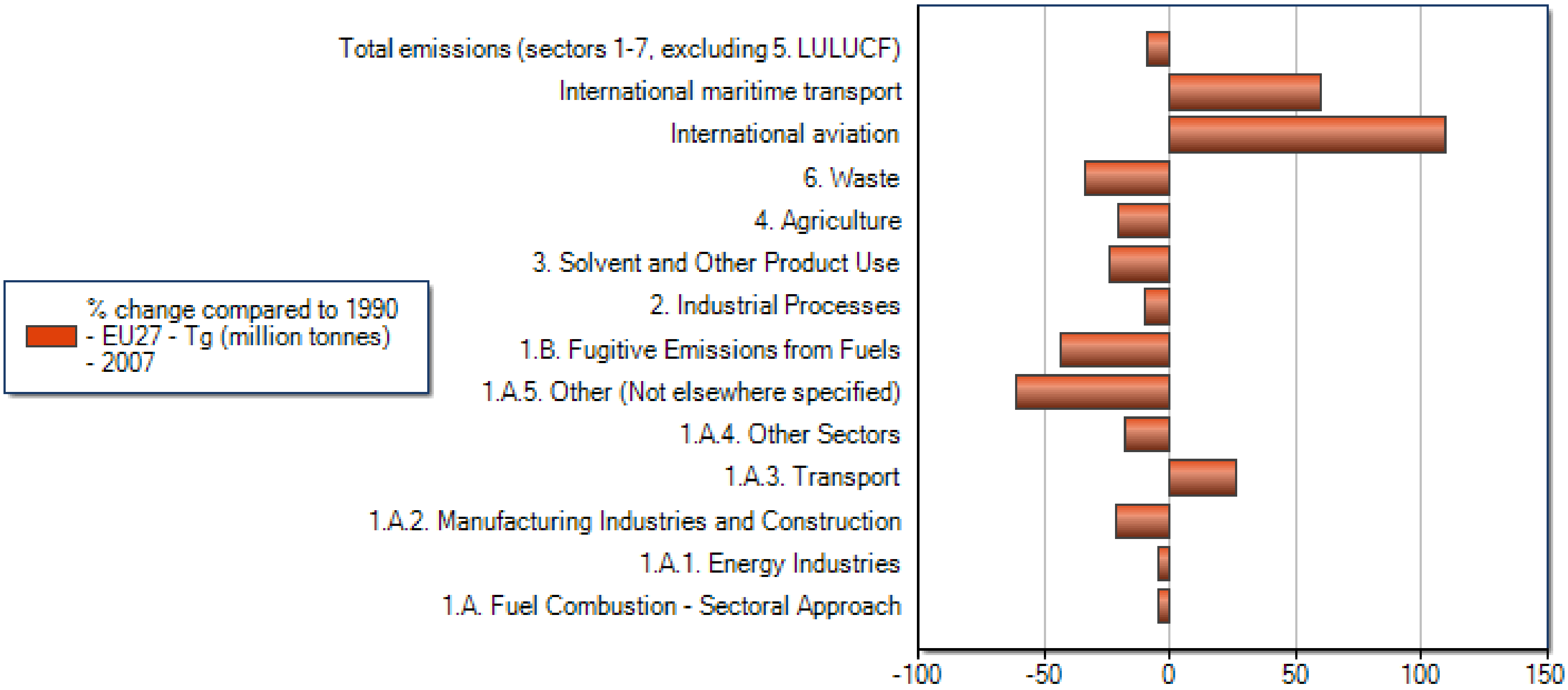
- Global aviation RPK growth of ~5%/year forecast (Airbus, Boeing 2013)
  - But there have been significant advances in aircraft energy intensity

Aircraft Energy Intensity



[Source: IEA]

Change in EU Emissions since 1990



- Emissions from other sectors have been decreasing (in some world regions) but continue to grow strongly in aviation
    - Aviation potentially a target for emissions reduction policies

[Source: EEA]

Mitigation Measures

- Economic – e.g. EU ETS
  - Increase cost to airlines and/or passengers to reduce demand or stimulate other measures
  - Or provide alternatives – e.g. high-speed rail
- Technological
  - Retrofits to existing aircraft – e.g. winglets
  - New aircraft materials and designs (composite materials, open rotor engines, BWBs, ...)
  - Alternative fuels
- Operational
  - Improved air traffic control (CDAs etc.), airline operations (lightweighting, cruise at fuel optimal speeds, etc.)

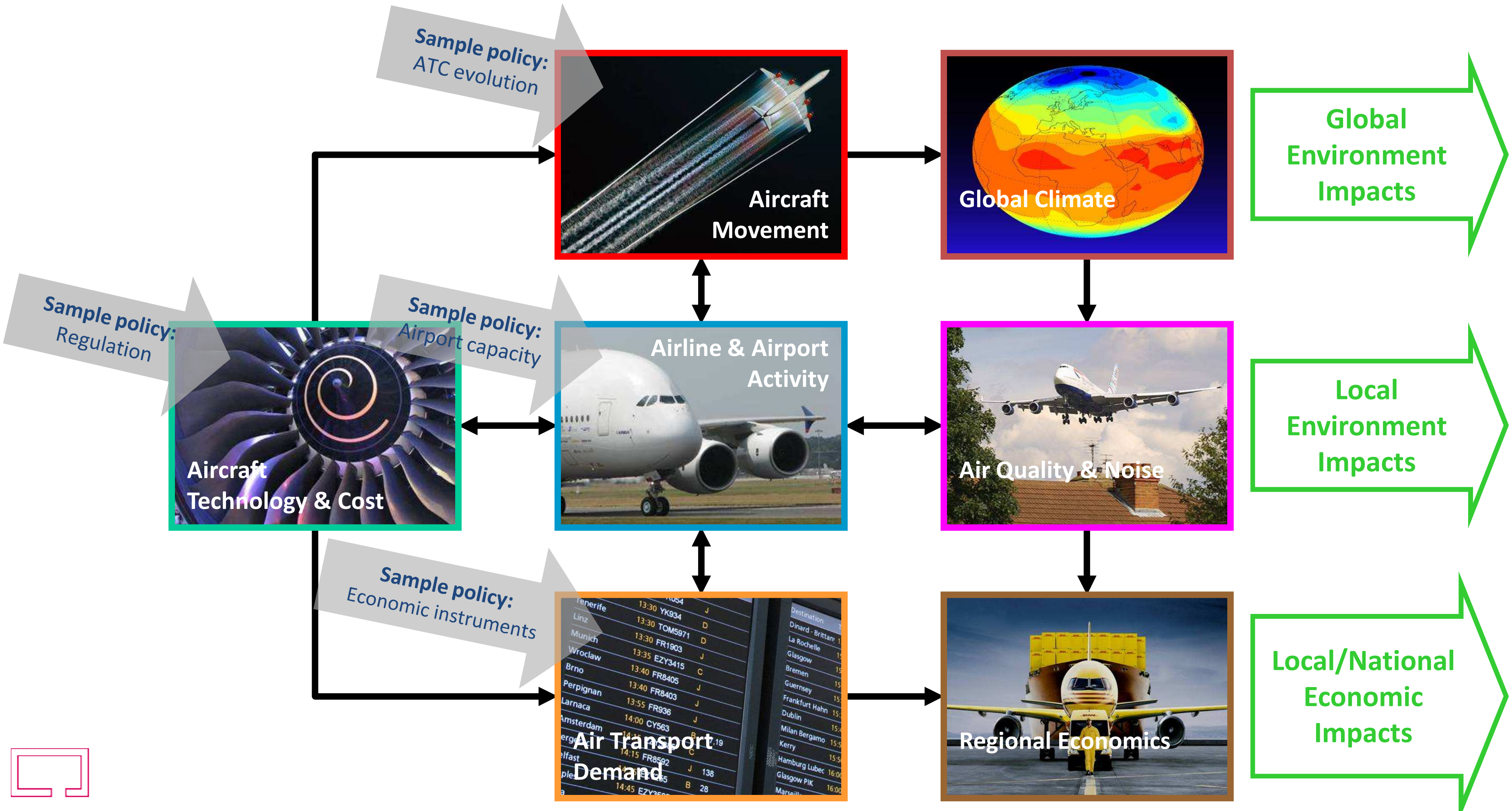
Mitigation Measures

- Best results likely from a combination of measures
- Complicated interactions – not necessarily additive
  - E.g., Applying engine upgrade kit, then re-engining
  - Interventions which improve fuel economy may lead to lower ticket prices and higher demand (rebound effect)
- Trade-offs
  - E.g., Contrail avoidance increases CO_2 emissions
- Range of stakeholders, effects, regions, technologies…
- Effects dependent on future population, income, oil price, carbon price, etc.

→ **need for integrated modelling to assess impacts**

Aviation Integrated Modelling Project

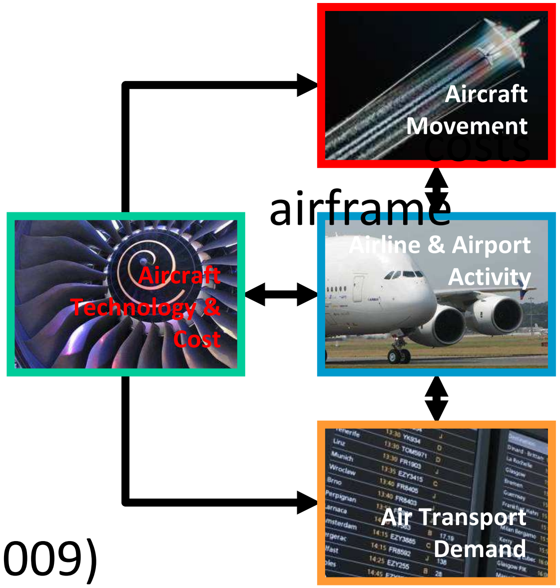
- **Goal:** Develop policy assessment tool for aviation, environment & economic interactions at local & global levels, now and into the future



Aircraft Technology & Cost

Goals

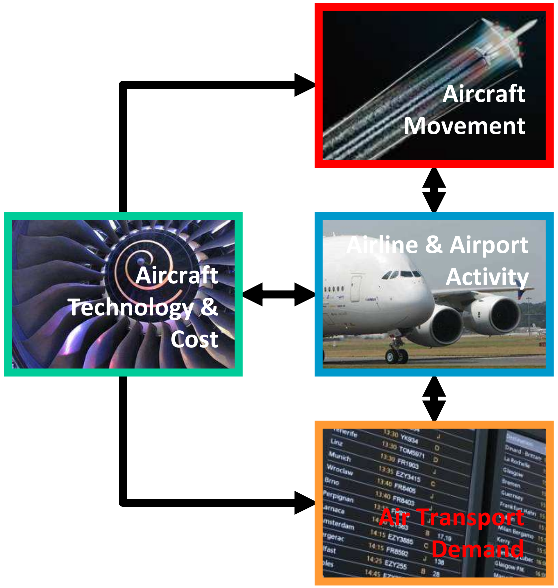
- Simulate fuel burn, emissions and operating costs by stage length and load factor, for airframe and engine technologies to 2050



Methodology

- 3 aircraft size and 2 technology-age categories
- Emissions below 3,000ft from ICAO Exhaust Emission Data, Reference LTO Cycle (ICAO, 2006, 2009)
- Emissions above 3,000ft from Eurocontrol Base of Aircraft Data (Eurocontrol, 2009)
- Operating costs for US airlines (DOT, 2009) adjusted for global differences (ICAO, 2006)
- Fleet turnover based on historical behavior of global fleet
- Simulated airline acquisition of new technology using NPV model

Air Transport Demand



Goals

- Forecast true origin-ultimate destination passenger and freight demand for air travel
- Global set of 700 cities, 95% of scheduled RPKM

Methodology

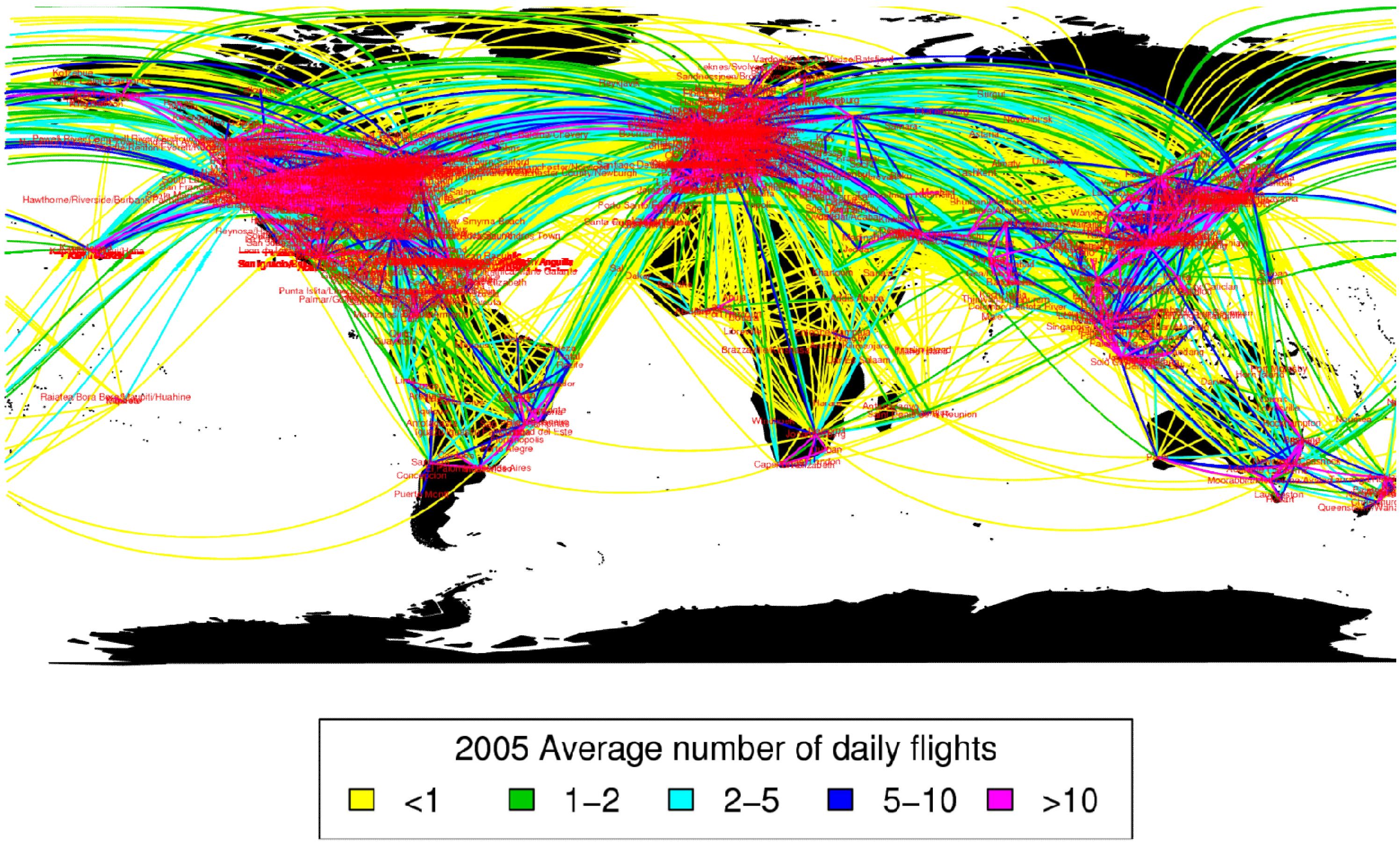
- Simple gravity-type model

$$D_{ij} = K \cdot \left(I_i I_j\right)^{\alpha} \cdot \left(P_i P_j\right)^{\beta} \cdot e^{\delta A_{ij}} \cdot e^{\varepsilon B_{ij}} \cdot e^{\varphi S_{ij}} \cdot e^{\omega DF_{ij}} \cdot e^{\mu R_{ij}} \cdot \left(F_{ij} + VoT \cdot TT_{ij}\right)^{\tau}$$

  - Function of income, population, fare, travel time, flight delays, special city characteristics, road/high-speed rail links, domestic/international
- Estimated separately for short-, medium-, long-haul and different world regions

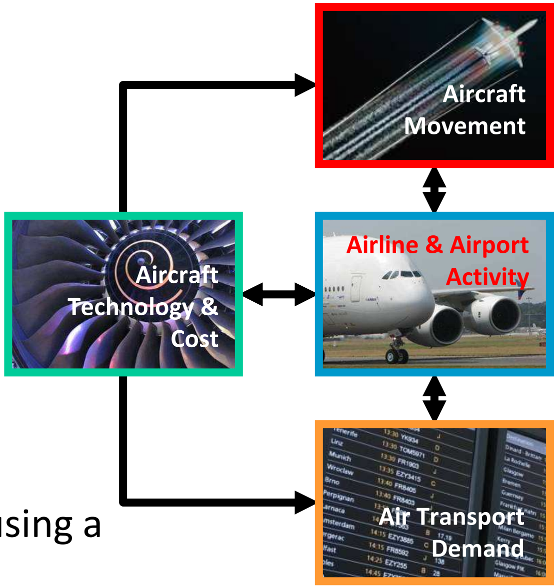
Air Transport Demand

- Geographic Scope: 95% of global scheduled RPK



[Data: OAG(2005)]

Airline & Airport Activity



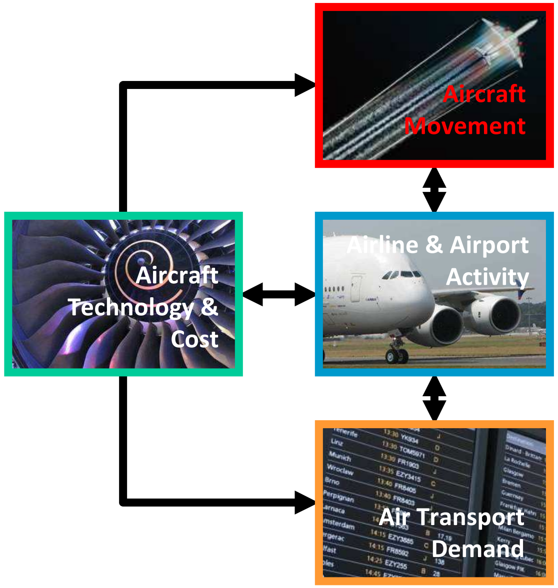
Goals

- Generate flight schedules
- Predict delay and LTO emissions

Methodology

- Flight network and scheduling modeled according to forecast passenger demand
  - Mode 1: Basic model forecasting global traffic
    - Routing network scaled from base year
    - Proportion of flights of each aircraft type estimated using a multinomial logit regression
    - Flight frequencies applying estimated base year load factors
  - Mode 2: High fidelity model simulating airline response to constraints
    - Simulates airline aircraft and network choice to maximize profit
    - Simulates a Nash best-response game between competing airlines to capture effects of frequency competition
- Fares modelled assuming constant rate of return relative to base year
- Flight delay modelled using queuing theory
- LTO emissions estimated according to schedule, delays, and engine emission rates

Aircraft Movement

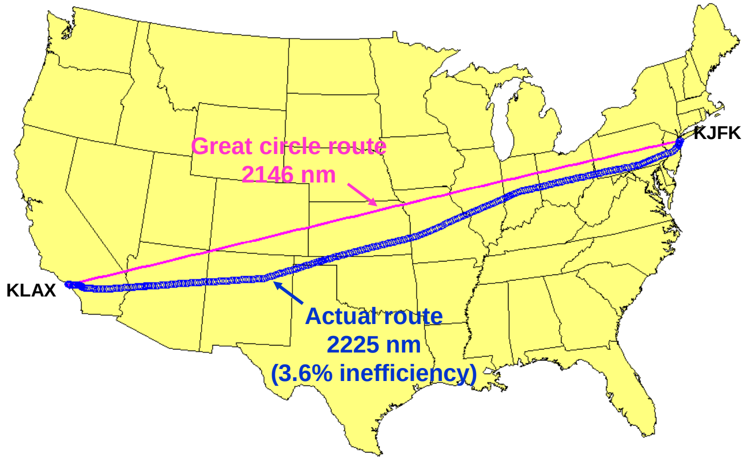


Goals

- Simulate the location of emissions release from aircraft in flight, accounting for ATM inefficiencies

Methodology

- Calculate optimal routes between given city pairs, e.g. great circle
- Add "inefficiency factors" to account air traffic control
- Efficiency factors vary by region and time



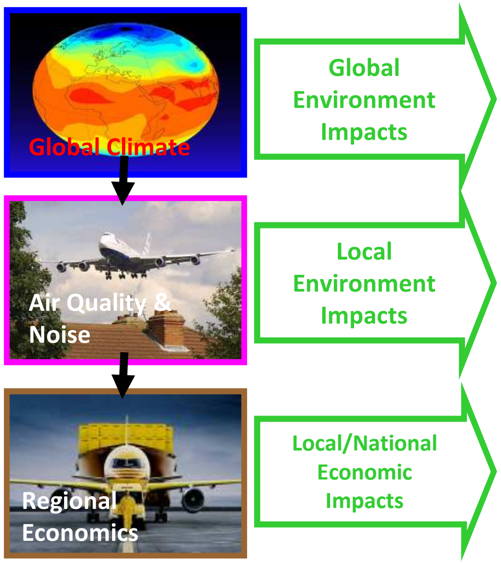
Global Climate Module

Goals

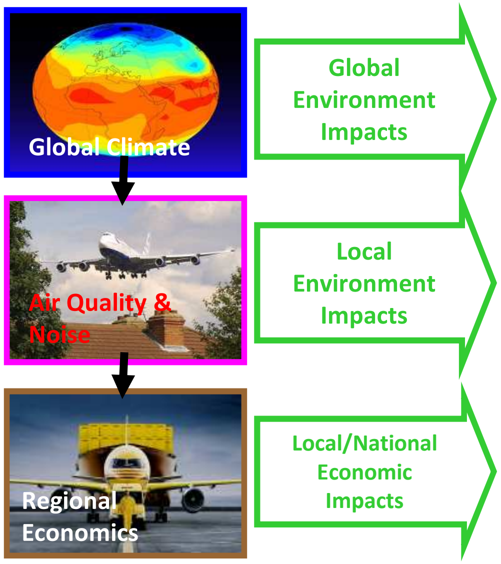
- Determine impact of aircraft emissions on the global climate system (CO_2, NO_x, SO_x, H_2O)

Methodology

- Three configurations
  - Global Climate Model (GCM)
  - Chemistry Transport Model (CTM)
  - Parametric Model based on runs of CTM
- Models account for:
  - Combining emissions, i.e., aircraft, lightning, ground-based
  - Atmospheric dynamics, i.e., advection, convection, diffusion, deposition
  - Atmospheric chemistry, i.e., homogenous, heterogenous and photolytic
  - Atmospheric radiation, i.e., radiative forcing
- Metrics for climate change include Global Warming Potential (GWP) and Global Temperature Potential (GTP)



Local Air Quality & Noise Module



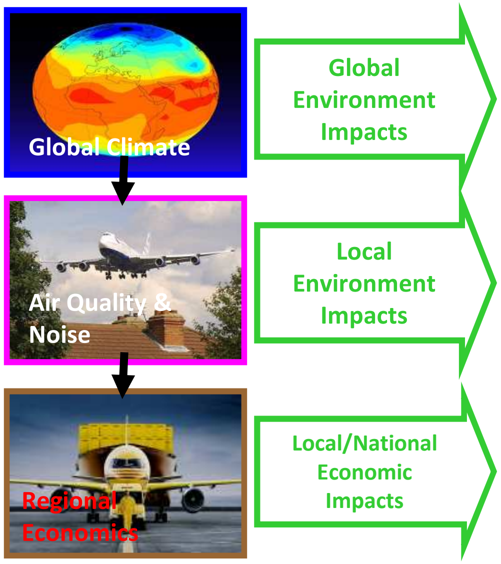
Goal

- Investigate dispersion of critical pollutants (NO_x, PM, O_3) and noise impacts in airport vicinity

Methodology

- Emission dispersion impact parameter estimated using meteorology parameterization
  - LTO time, emissions and path inputs from Airline and Airport Activity Module
- Emissions concentrations estimated using dispersion model
  - Dispersion impact parameter and source parameter (from source pre-processing) inputs
- LAQ contours estimated using atmospheric chemistry model based on emission concentrations
- Noise contours estimated using Industry Noise Model
- Outputs:
  - NO_x, NO_2, PM_{10} & $PM_{2.5}$ concentrations, Noise contours/population impacts for metrics of choice

Regional Economics Module



Goal

- Quantify positive and negative economic effects of air transport activity on surrounding regions

Methodology

- Noise effects estimated based on estimated noise contours using a noise costing model
- LAQ effects estimated based on estimated LAQ contours using a LAQ costing model
- Employment effects estimated based on passenger and freight flows by airport using a local employment model
- Total economic effects estimated accordingly
- 'Conversion factors' taken from literature to convert pollutant concentration or marginal effect of emissions into health effects/economic costs

Sample Applications of AIM

- Assessment of the impact of domestic ***emissions trading schemes*** on the ***US*** and ***Indian*** air transport systems
- An assessment of the potential ***penetration of fuel-saving technologies and lower carbon alternative fuels in Europe*** in response to the EU Emissions Trading Scheme
- Quantifying the **rebound effect** in the aviation sector in the US
- Detailed assessment of **airline operational responses to airport capacity constraints** in the United States
- Comparison of the impact of **airline network change on emissions** in India and the United States
- An assessment of the effects of a ***global emissions trading scheme*** on global air passenger demand and emissions
- An integrated assessment of the carbon reduction potential of ***airline fleet replacement*** in developing economies ***funded by a global carbon tax***.
- An evaluation of whether carbon neutral growth is possible with **aviation biofuel uptake under a global emissions trading scheme**, and the extent to which this corresponds to climate neutral growth

Sample Case Studies

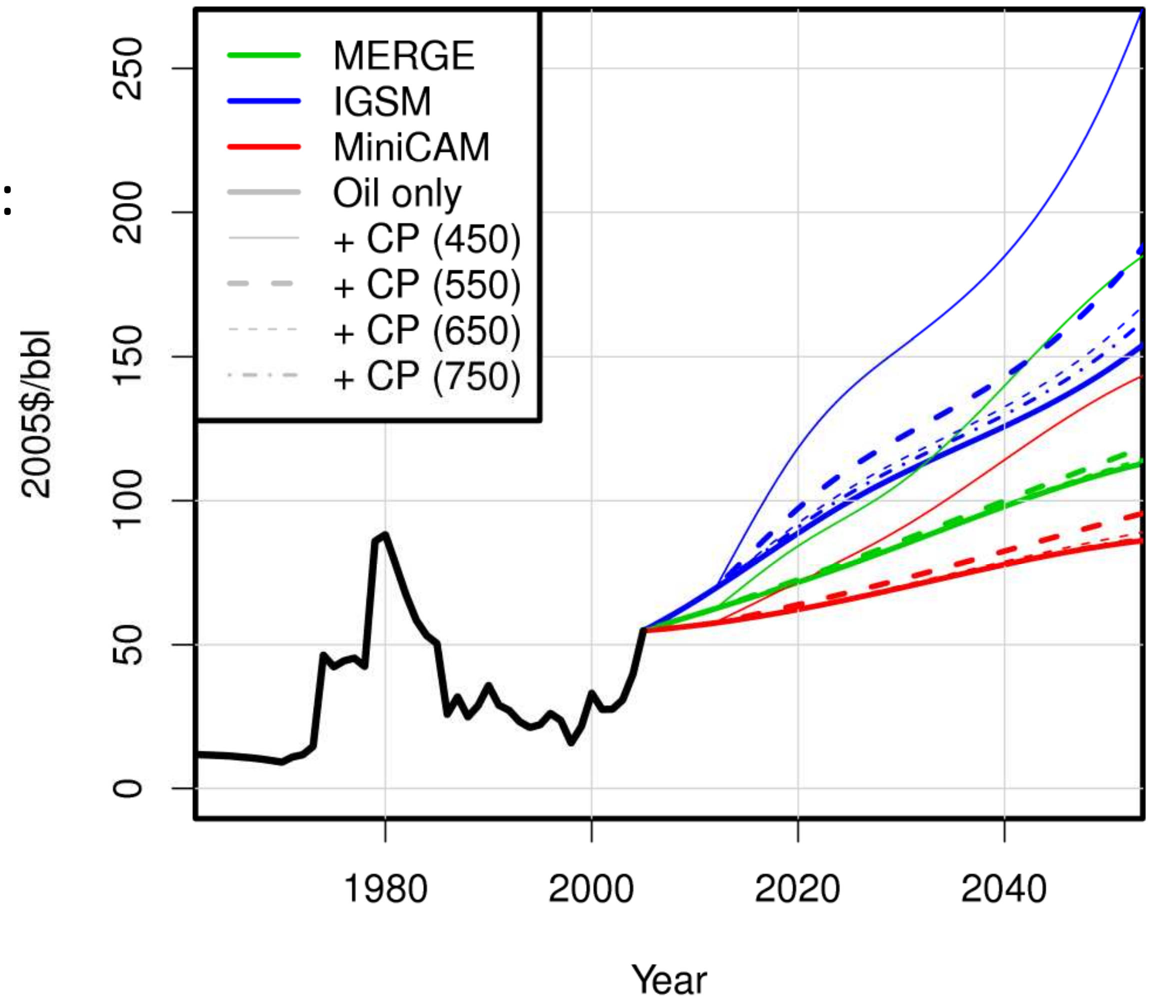
- ***Case Study 1****: Airline fleet replacement funded by a global carbon tax*
- ***Case Study 2***: Climate-neutrality versus carbon-neutrality for an aviation biofuel policy

Policy Description

- Based on two existing concepts for emissions reduction
  - Cap and trade / Emissions trading (e.g., European ETS)
  - Subsidized fleet renewal (e.g. road vehicle "scrappage schemes")
- Apply a global carbon tax to aviation
  - Similar impacts to a global cap and trade scheme in which aviation is a net buyer
- Use revenues from this tax to fund fleet replacement of older aircraft
- Potential effects:
  - Changes in fleet technology composition
  - Reduced fuel costs leading to decreased fares and increased demand
  - Carbon tax leading to increased fares and decreased demand

Future Scenarios

- Use CCSP (2007) scenarios for 2010-2050 development of:
  - Oil & fuel price
  - Carbon price
    - If modelling emissions trading
    - 450 – 750 ppm stabilisation levels
  - GDP
  - Population



[Data: CCSP(2007)]

Scenario Description

- Socioeconomic scenarios
  - Describes growth in population, income, oil price etc.
  - MIT IGSM
    - 5.2%/yr global demand growth; high GDP growth in US and Europe; high oil price
  - Stanford MERGE
    - 4.8%/yr global demand growth; medium oil price
  - Joint Global Change Research Institute's MiniCAM
    - 4.6%/yr global demand growth; high growth in Asia; low oil price
- Carbon Tax assumptions
  - Applied from 2015
    - Initially funds replacement of aircraft over 30 years old
    - Age threshold incrementally reduced to 20 years by 2025
  - Varied over time
    - Carbon tax calculated based on number and types of aircraft over age threshold
    - Applied to raise NPV of new aircraft purchase above that of keeping old aircraft, assuming scrappage value 10% of list price

Scenario Description

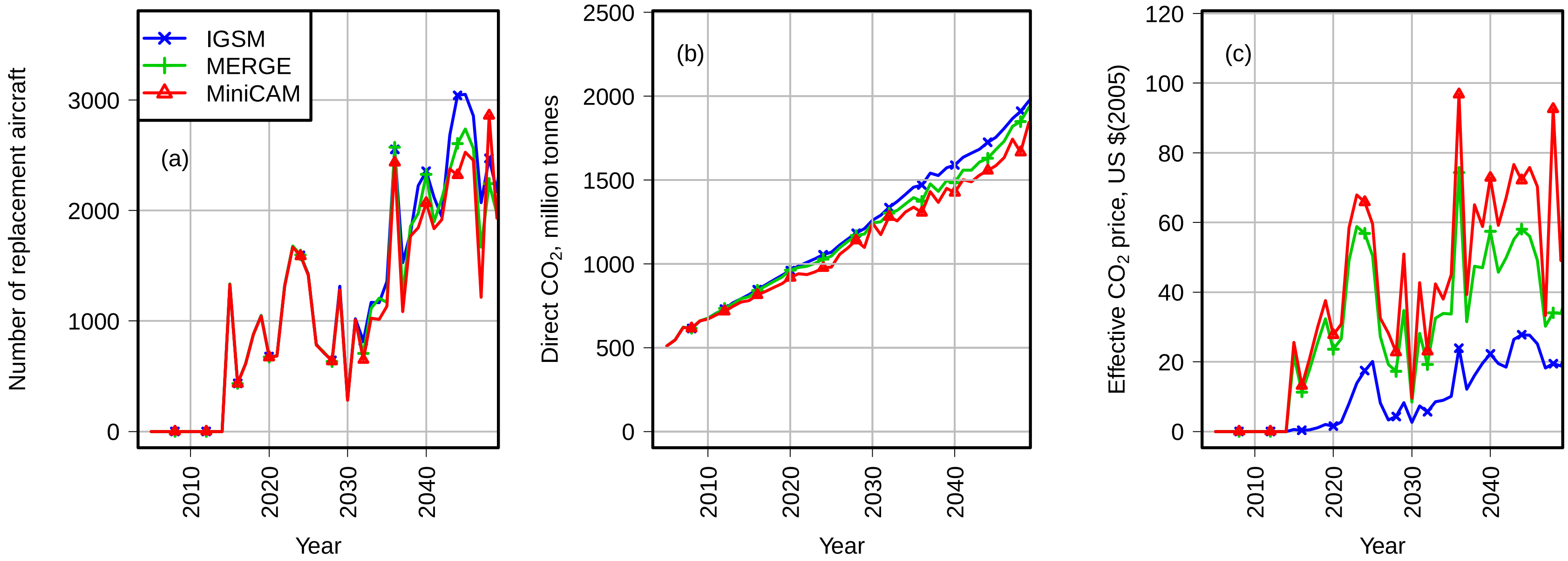
- Technology assumptions
  - Drop-in biofuel blend from cellulosic biomass feedstock assumed to be available by 2020
    - Biofuel production initially limited
    - No more than 20% blend applied
  - ATM improvements in US, Europe and Asia applied from 2015-2025
    - Supply 4% global decrease in fuel burn
  - Fuel burn of new aircraft models improves by 1% per year
  - Specific new technologies also modeled

New Technology	Year of Introduction	% Reduction in Fuel Burn over existing Technology
Composite Evolutionary Replacement Narrowbody	2025	22%
Open Rotor Narrowbody	2025	35%
Optimized Open Rotor Narrowbody	2025	45%
Blended Wing Body Widebody	2037	30%

Comments

- Any global cap and trade or emissions trading scheme is likely to see significant political challenges
- Widespread carbon taxation could face legal challenges under Chicago convention
- Policy could be seen as rewarding airlines with old, inefficient fleets
- Possible counterproductive effects
  - As fleet emissions decrease, tax has to increase to maintain fleet replacement
  - Possible reductions in non-policy technology use
- We do not consider emissions from aircraft construction and disposal
- Questions about whether such a tax should be used to fund fleet renewal in all regions?
  - Could fund fleet renewal only in developing economies

Policy Results

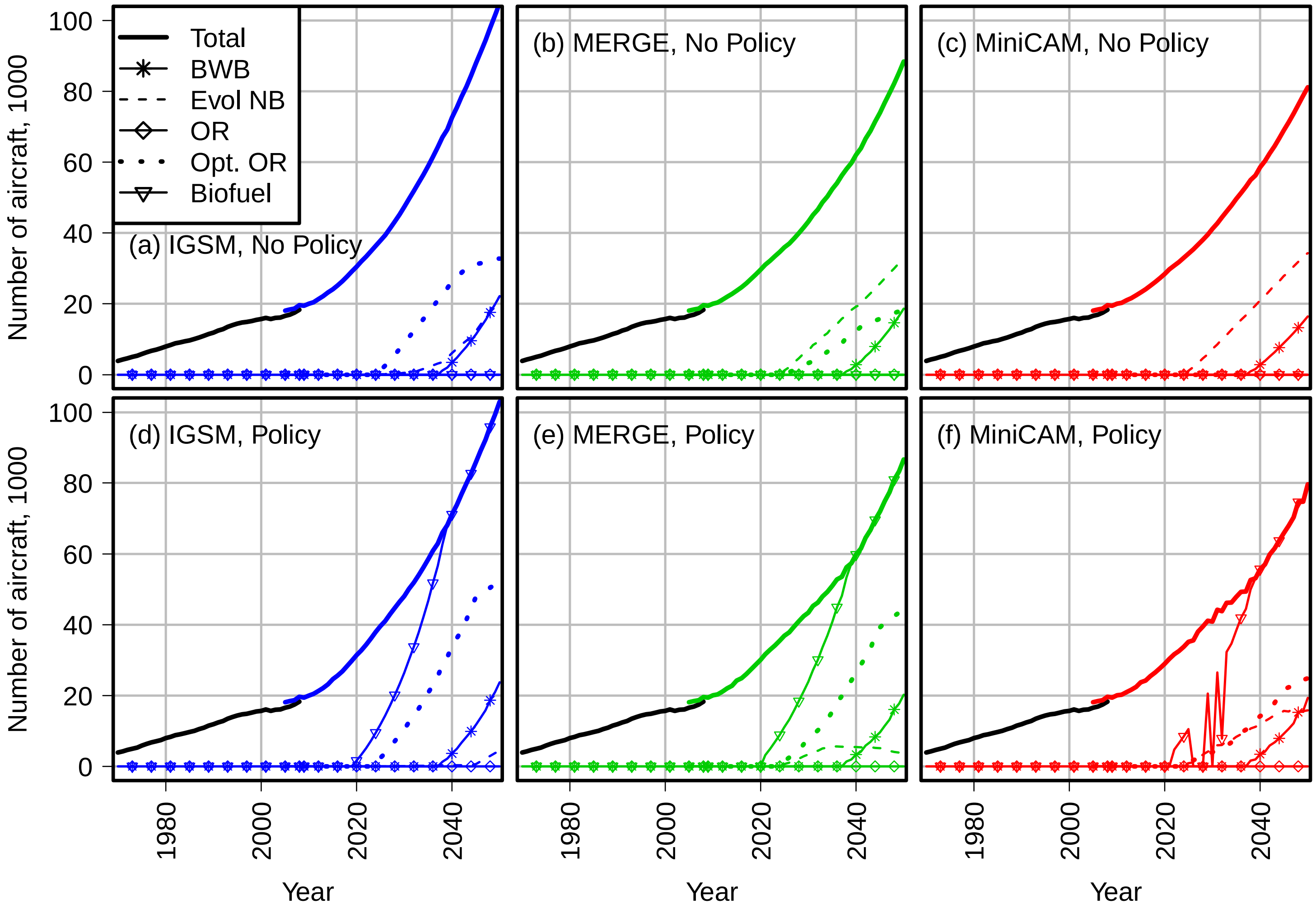


- Number of replacement aircraft highly variable
  - Fleet age structures highly peaked
- Direct emissions totals similar across scenarios
- Effective carbon price also highly variable
  - Within range of projected prices in European ETS
  - IGSM scenario low because of high oil price

Effect on Global Fleet

Reference Case (No Policy)

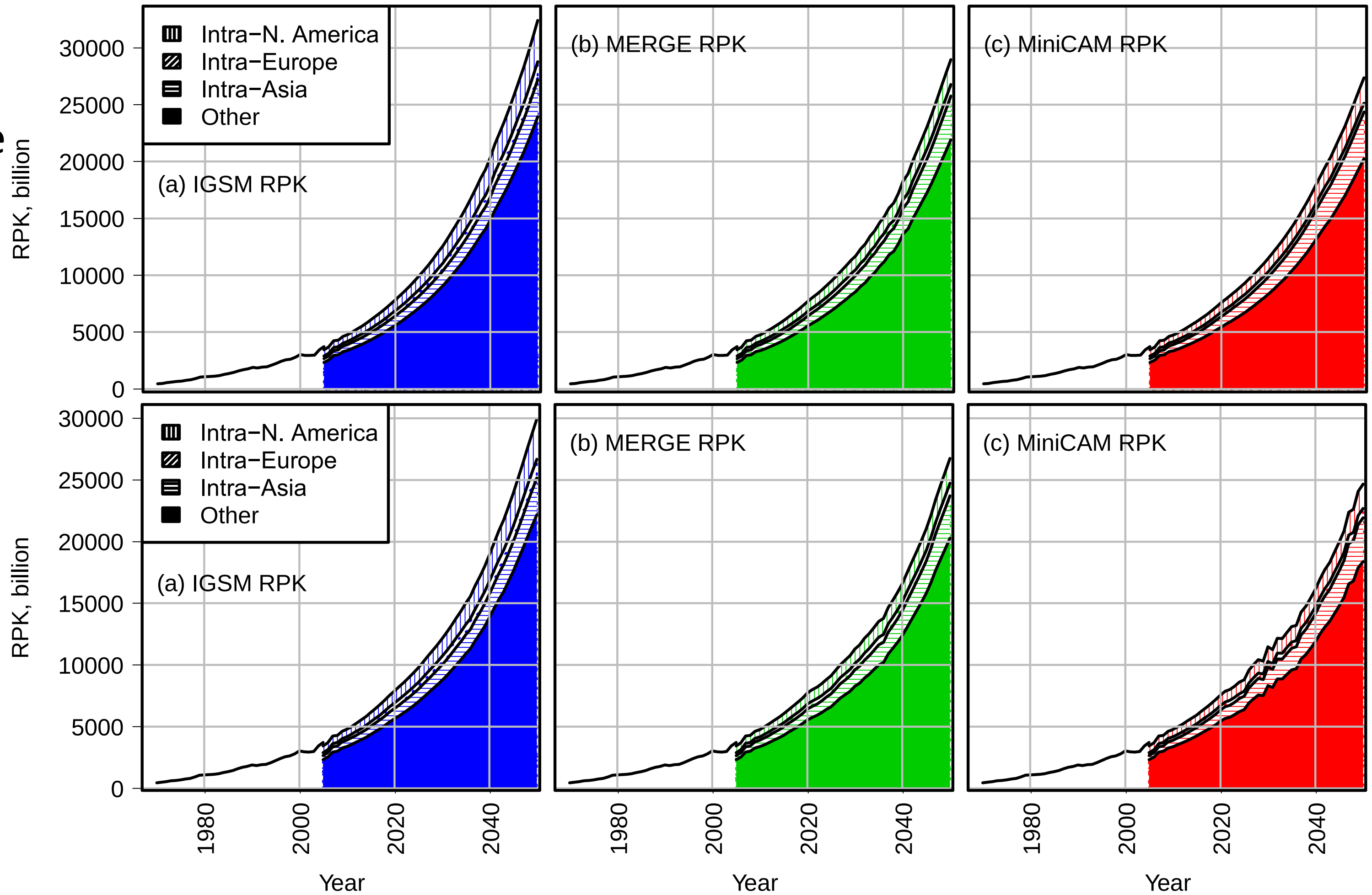
Policy Case



Effect on Global RPK

Reference Case (No Policy)

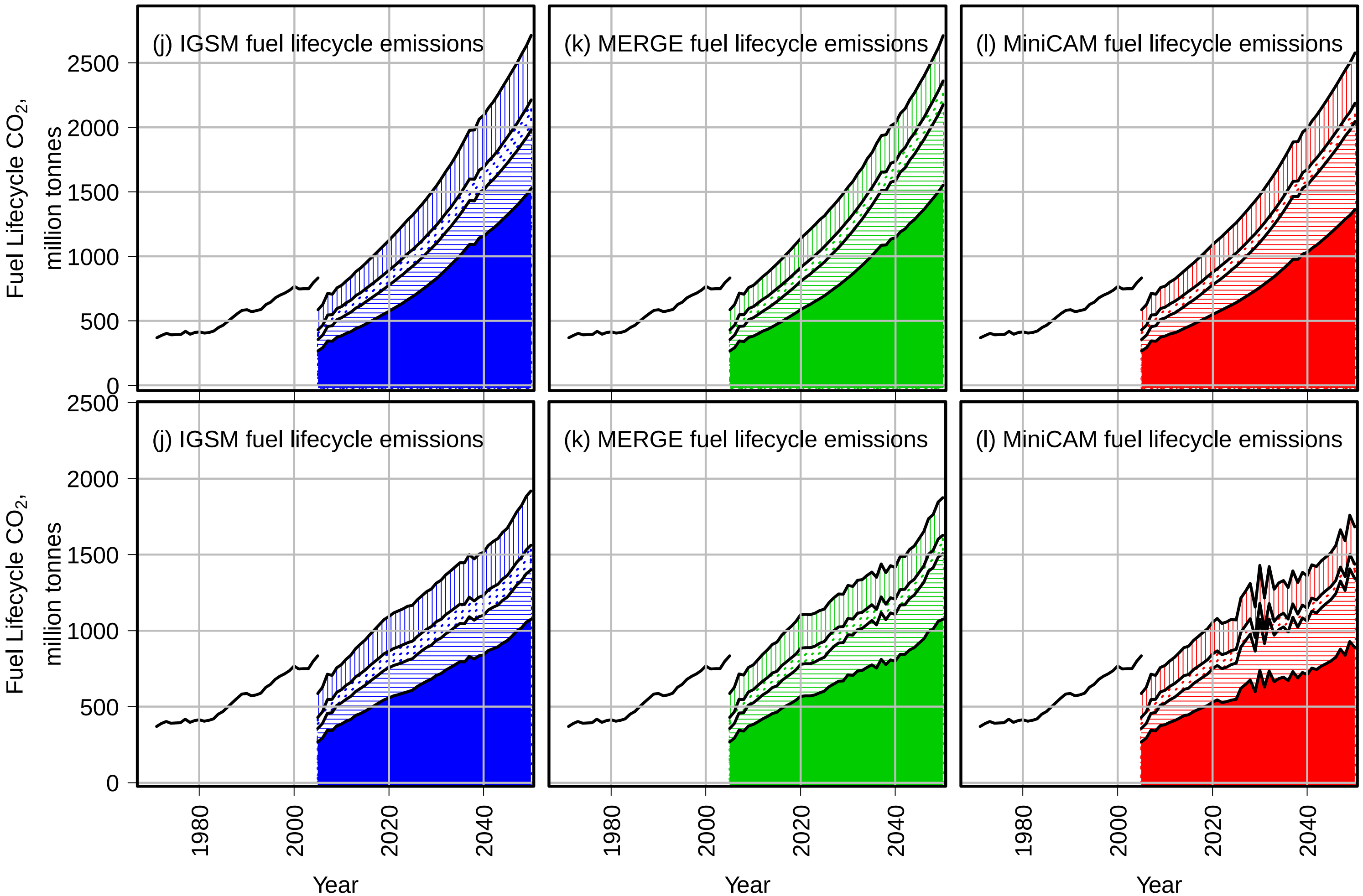
Policy Case



Effect on Global Lifecycle CO_2

Reference Case (No Policy)

Policy Case



Case Study Conclusions

- Airline fleet replacement funded by carbon tax
  - A carbon tax used to fund fleet renewal could reduce lifecycle CO_2 emissions due to aviation by up to 35% relative to a no-policy case
    - ~⅓ due to demand reduction
    - ~⅓ due to increased use of biofuels
    - ~⅓ due to fleet replacement
  - Results are robust across different socioeconomic scenarios
  - There are significant drawbacks
    - Increasing carbon price with reduces emissions
    - High variation in carbon price

Sample Case Studies

- ***Case Study 1**: Airline fleet replacement funded by a global carbon tax*

- ***Case Study 2***: Climate-neutrality versus carbon-neutrality for an aviation biofuel policy

Policy Description

- The EU Emissions Trading Scheme consider aviation biofuel to have zero emissions for the purposes of carbon trading
- However, drop-in biofuels address only aviation CO_2
- Non-CO_2 climate impacts may still be significant
  - NO_x impacts on ozone and methane
  - Contrails and aviation induced cirrus
- We compare estimated total climate impact with and without biofuels
  - Under a future global emissions trading policy
  - Flights using biofuel are exempt

Climate Modelling Assumptions

- Absolute Pulsed GWP estimated
  - A pulse of emissions is total emissions from aviation for one year
  - 100 year time horizon consisdered
- Non-CO_2 climate impacts modelled:
  - NO_x impacts on ozone and methane
    - Calculated by flight level
  - Contrails and contrail induced cirrus
    - Linear scaling with distance flown over altitude
  - (Other non-CO_2 effects neglected)
- Climate conditions, affecting atmospheric background concentrations not assumed to change with time

Scenario Description

- Technology assumptions
  - Drop-in biofuel blend from cellulosic biomass feedstock assumed to available from 2020
    - Biofuel production initially limited
    - No more than 50/50 blend applied
  - ATM improvements in US, Europe and Asia applied from 2015-2025
    - Supply 4% global decrease in fuel burn
  - Fuel burn of new aircraft models improves by 1% per year
  - Specific new technologies also modeled

New Technology	Year of Introduction	% Reduction in Fuel Burn over existing Technology
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Scenario Description

- Socioeconomic scenarios
  - Describes growth in population, income, oil price etc.
  - MIT IGSM 550ppmv
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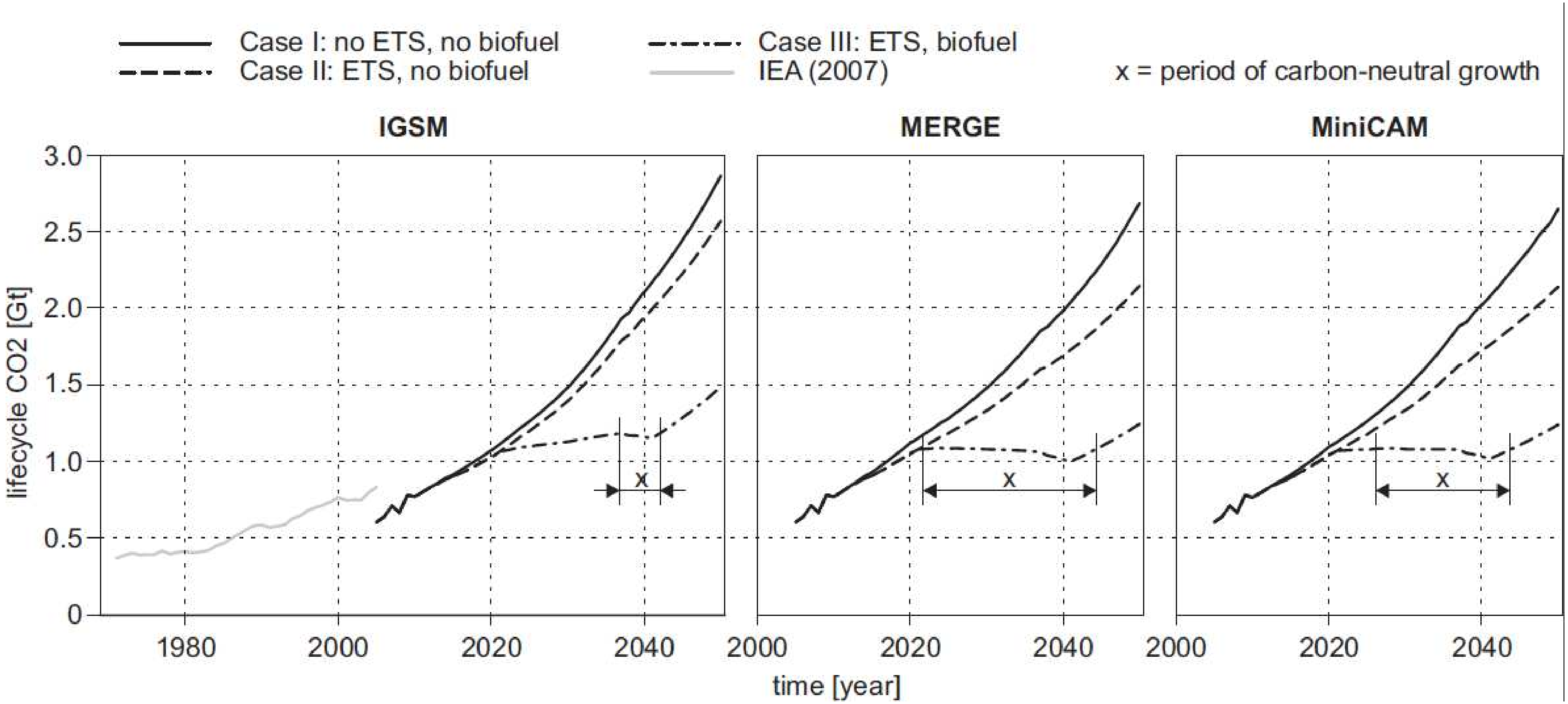
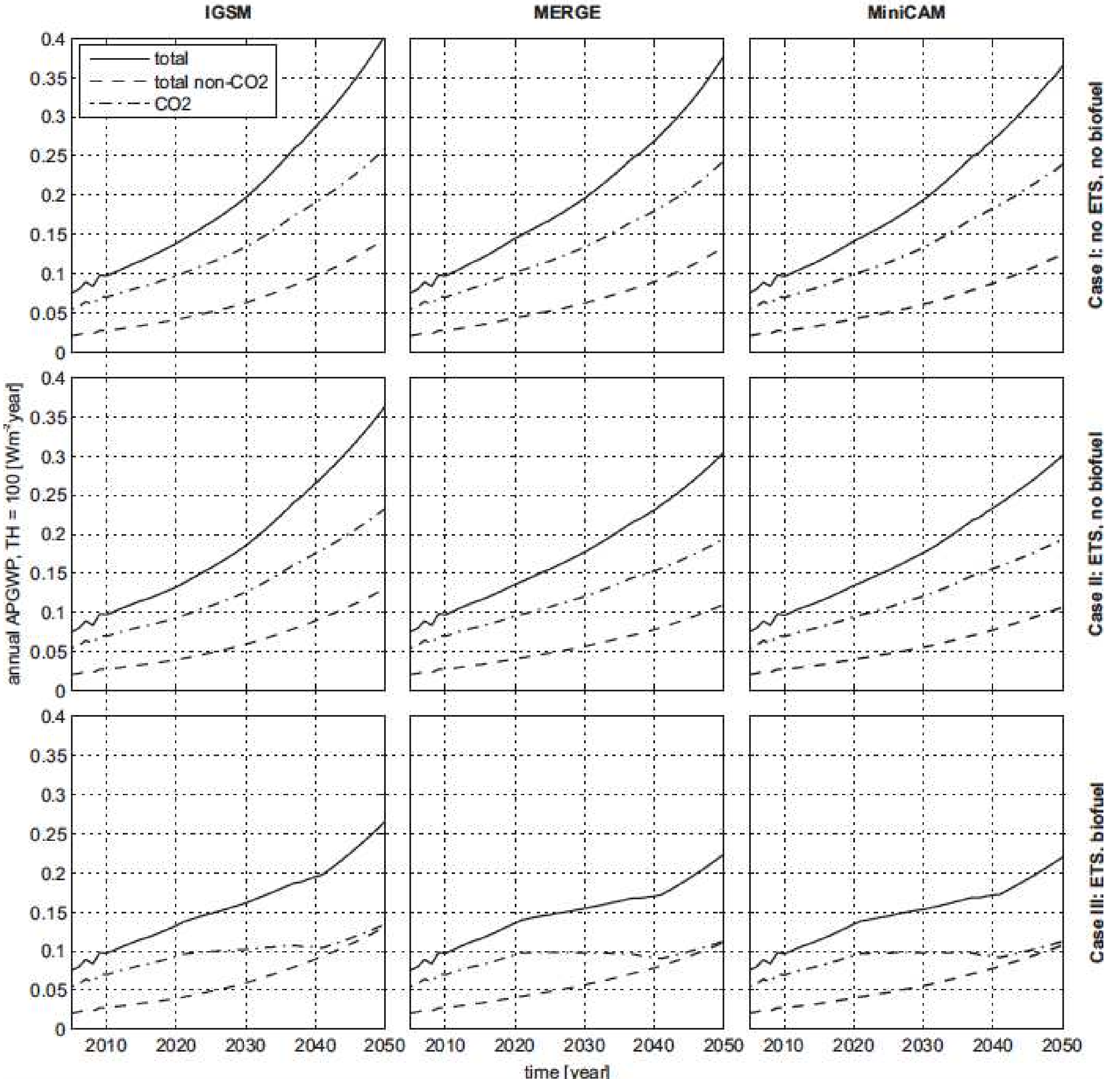
  - Stanford MERGE 450ppmv
    - 4.8%/yr global demand growth; medium oil price
  - Joint Global Change Research Institute's MiniCAM 450ppmv
    - 4.6%/yr global demand growth; high growth in Asia; low oil price
- Emissions trading assumptions
  - Global emissions trading scheme applied as a carbon tax
  - Carbon taxes applied to achieve long-term atmospheric CO_2 concentrations of 550 ppmv and 450 ppmv
  - Socioeconomic inputs internationally consistent with oil and carbon prices
  - Biofuels are exempt

Lifecycle CO_2 Emissions



Source: Krammer et al. , 2011

Global Warming Potential



Source: Krammer et al. , 2011

Case Study Conclusions

- With a 50/50 biofuel blend and emissions trading, 2050 CO_2 emissions can be reduced by ~50%
  - Demand reduction
  - Biofuel uptake
  - Uptake of other mitigation technologies
- A period of carbon-neutral growth is possible, but not sustainable indefinitely
- Reduction in total climate impact (APGWP) significantly lower: ~30% (only 15% with 20 year time horizon)
- Potential for biofuel to provide climate-neutral growth limited
- Emissions trading exemptions for biofuel may not be justified

Conclusions

- Is technology enough?
  - Technology adoption is highly dependent on purchase cost, fuel price, and other competing technology
  - Technology adoption can be faster with policy intervention
  - Carbon neutral growth may be possible, but only under an effective ETS
  - Carbon neutral growth does not mean climate neutral growth

AIM Team

Core team:

- Prof. Andreas Schäfer *(Principal Investigator, UCL)*
- Dr. Lynnette Dray *(Cambridge)*
- Dr. Antony Evans *(UCL)*
- Mr. Philip Krammer *(UCL)*
- Dr. Olivier Dessens *(UCL)*

Co-investigators ***(Cambridge)*****:**

- Prof. Bill Dawes *(Engineering)*
- Dr. Chez Hall *(Engineering)*
- Prof. Peter Haynes *(Applied Maths)*
- Prof. Roderic Jones *(Chemistry)*
- Prof. John Pyle *(Chemistry)*

Affiliated researchers:

- Dr. Steven Barrett *(Air Quality, MIT)*
- Prof. Rex Britter *(Air Quality, MIT)*
- Dr. Marcus Köhler *(Global Climate, University of Birmingham)*
- Dr. Tom Reynolds *(Air Traffic Control/Management, MIT Lincoln Lab)*
- Dr. Zia Wadud *(Regional Economics, University of Leeds)*

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NATURAL ENVIRONMENT RESEARCH COUNCIL

Their support is gratefully acknowledged

Questions?

Future Developments

- The Aviation Integrated Model (AIM) can be applied to regional and global policy assessment
  - Simulates detailed technology entry into the fleet, but subject to assumed availability and cost
  - Captures feedback between key elements of the air transport system
- Future developments include:
  - Base year update
  - Greater integration of the high fidelity airline response model into AIM
  - Capturing passenger choice effects in inter-continental connecting traffic
  - Simulating system response to airport capacity constraints