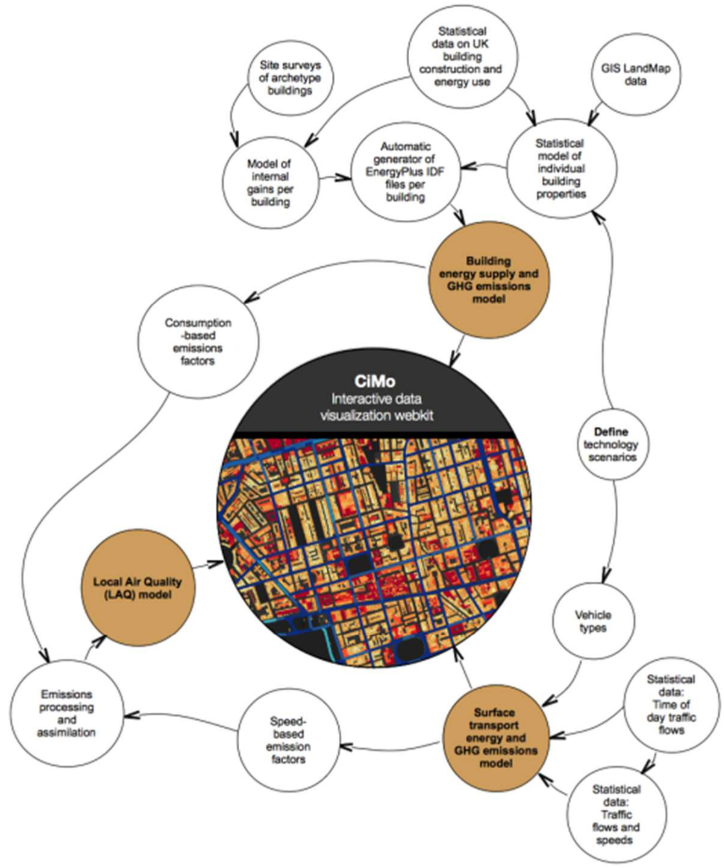


Energy Efficient Cities initiative

EECi

Initiative Objectives

i. Build a critical mass of researchers;
ii. Synthesize approach to buildings, transport and de-centralised power generation research;
iii. Develop novel energy efficiency technologies;
iv. Develop a cohort of researchers moving to academic and industrial positions;
v. Educate undergraduate and post-graduate students about low-energy design
vi. Enhance professional practice through fostering links between industry and researchers
vii. Contribute to the national dialogue about energy generation and use.

Capacity Building (Objectives i, iv & v)

The initiative's contribution in capacity-building for industry and academia has been substantial. Three lecturers, 15 research associates, 19 PhD students and 15 Master's students have been involved in the initiative.

Lecturers (3)

Dr Adam Boies
Dr Ruchi Choudhary
Dr Ying Jin

Research Associates (4)

Dr Justin Bishop
Dr Adam Rysanek
Dr Marc Stettler
Rebecca Ward

Current PhD Students (12)

Pankaj Arora, Debbie B. Deng, Carlos A. Gonzalez, Hsin-tzu Ho, Kaveh Jahanshahi, Xihe Jiao, Yohei Kiguchi, Mingfei Ma, Niall Martin, Adnan Mortada, Xiao Rong and Li Wan.

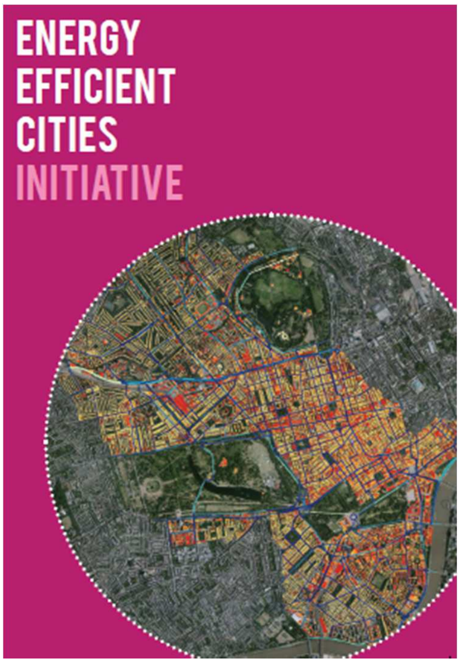
Alumni (12 Lecturers/Professors, 22 Industry/Research) – *not counting MPhil cohorts*:

Steven Barrett, Assistant Professor, MIT; **Steve Denman**, Senior Research Associate, University of Cambridge; **Alex Hagen-Zanker**, Lecturer, University of Surrey; **Yeonsook Heo**, Lecturer, University of Cambridge; **Kiril Stanilov**, Senior Research Associate, University of Cambridge; **Jacob Swanson**, Assistant Professor, Minnesota State University; **Wei Tan**, Lecturer, Tianjin University of Science and Technology; **Peng Wu**, Associate Professor, Sichuan University; **Xiaoyu Yan**, Lecturer, University of Exeter; **Steve Yim**, Assistant Professor, The Chinese University of Hong Kong, **Xin Zhang**, Associate Professor, Tsinghua University; **Liang Zhao**, Associate Professor, Tsinghua University. **Adam Booth,** Socialist Appeal; **Uven Chong**, Research Fellow, Millenium Challenge Corporation; **Denis Garber**, Geotechnical Engineer, WorleyParsons; **Akomeno Omu**, Research Scientist, IBM Research Africa; **Juan José Sarralde**, Lecturer, Universidad Austral de Chile; **Ye Zhang**, Assistant Professor, National University of Singapore; **Jie Zhu**, Senior Consultant, Mott MacDonald UK.

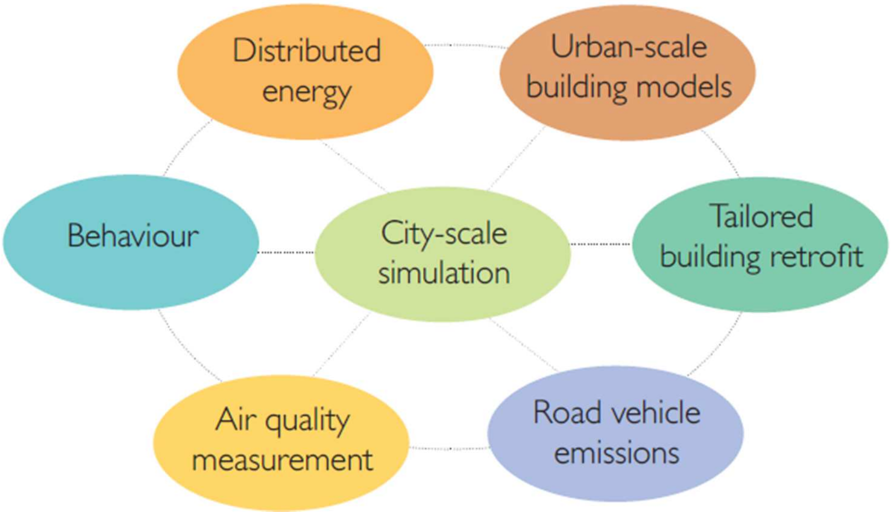
Publications (Objectives ii, iii, vii)

- Built Environment (14 pubs), e.g.
  Decision Making under Uncertainty in the Retrofit Analysis of the UK Housing Stock: Implications for the Green Deal, Energy & Buildings, 64, 292-308, 2013.
- Transport (11 pubs), e.g.
  Global Civil Aviation Black Carbon Emissions. Stettler, M. E.J.; Boies, A. M.; Petzold, A.; and Barrett, S. R.H. *Environmental Science & Technology*, 47(18):10397-10404. 2013.
- Urban planning (14 pubs), e.g.
  A New Method of Adaptive Zoning for Spatial Interaction Models. Hagen-Zanker, A.; and Jin, Y. *Geographical Analysis*, 44(4):281–301. 2012.
- Energy Supply (3 pubs), e.g.
  Distributed energy resource system optimisation using mixed integer linear programming. Omu, A.; Choudhary, R.; and Boies, A. *Energy Policy*, 61:249-266. October 2013.

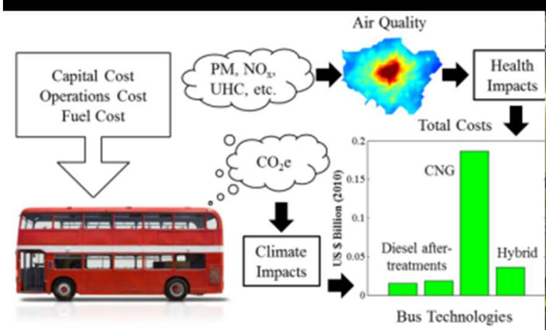
Public Dissemination Pamphlet

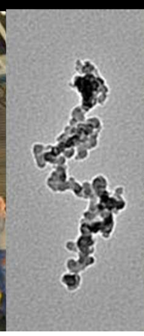
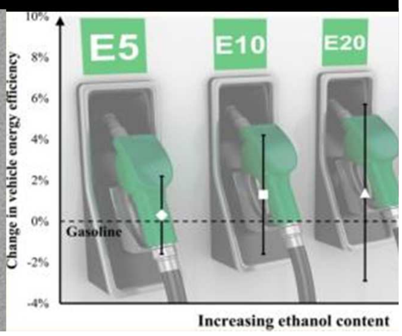


We needed to dig deeper before we got there!



Urban Transport: Energy Use and Impacts



Transportation Models

Goal: Reduce energy use of transportation

Hypothesis: Energy use is problematic to the extent that it causes climate change, impacts air quality or has financial cost.

Road Fleet Modelling

1. London Bus Emissions
2. Bottom-Up UK Transport Model

Lifecycle Analysis of Fuels and Power Generation

1. UK Transport Fuels – Ethanol
2. Electricity Generation with Biomass – Tilbury

Emissions Measurement

1. Gas Turbine Measurement – SAMPLE III
2. Ambient Air Quality – Paddington Trains
3. Dual Fuel (Diesel/Natural Gas)

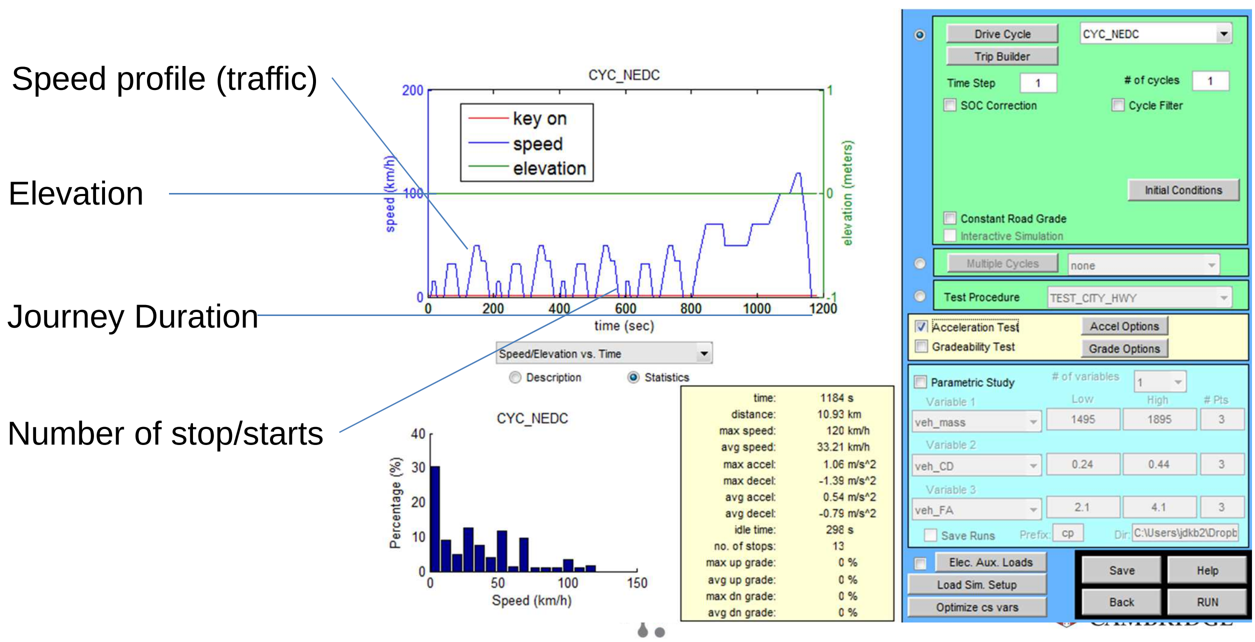
Emissions Modelling

1. Airports
2. Trains
3. UK Light-Duty Vehicle Fleet

Bottom-Up Vehicle Analysis

Quantify WTW CO_2 cost-effectiveness of novel vehicle powertrains
Account for differences in vehicle size and performance

ADVISOR



Performance Fuel Economy Index (PFI)

Quantification of tradeoff between acceleration and fuel economy

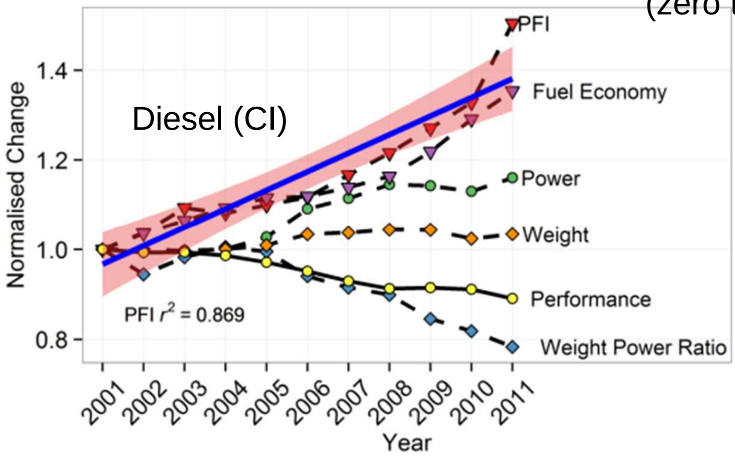
$$PFI = \frac{P}{m} \cdot FE = t_{z-62} \cdot FE$$

P - Power

m - mass

FE – fuel economy

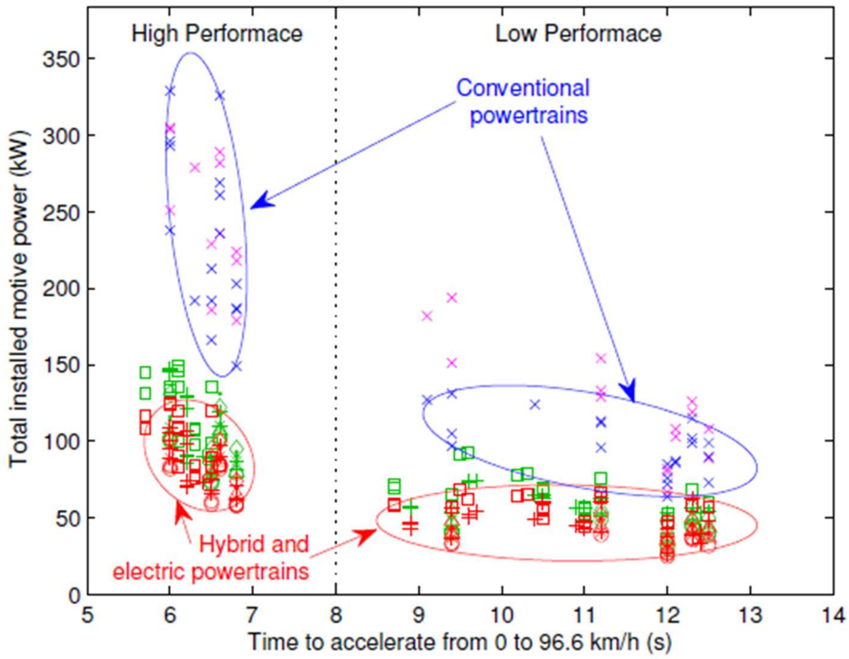
t_{z-62} – acceleration time (zero to 62 mph)



Technological advancements increasing at 4.7%/year for Petrol (SI) vehicles and 5.0%/year for Diesel (CI) vehicles.

Increasing fuel economy is largely responsible for PFI growth though available power and acceleration times have increased and decreased by approximately 10% each.

Installed motive power versus acceleration time



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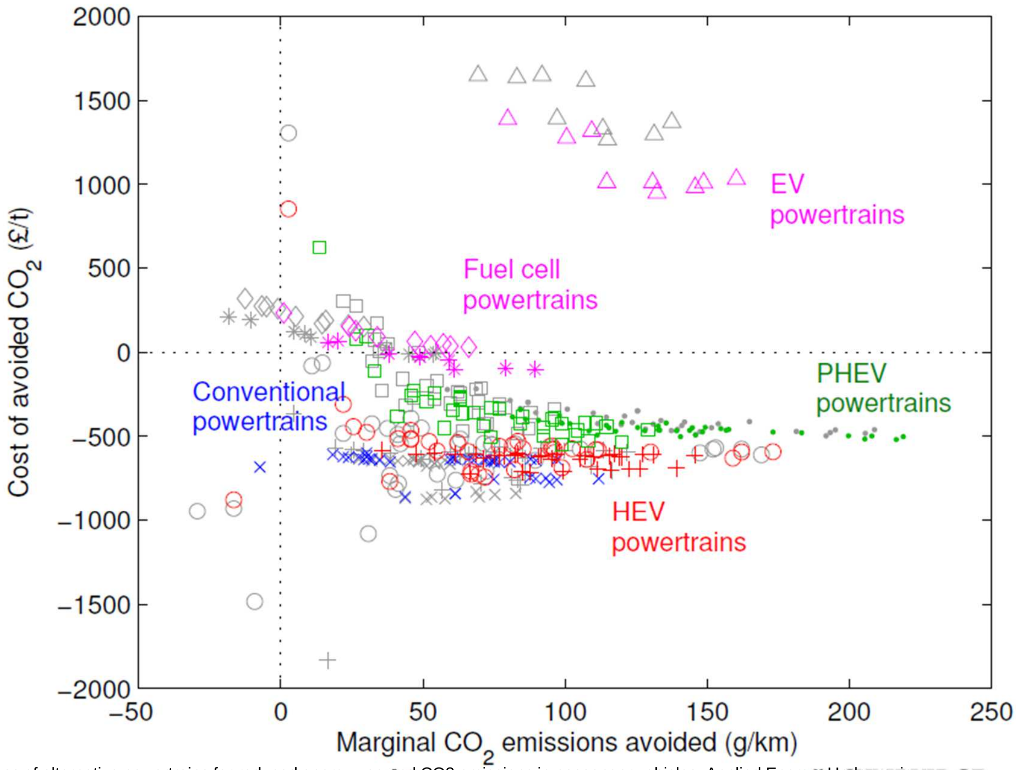
Vehicle Cost Effectiveness

Results

Most Cost Effective: Conventional Powertrains and HEVs

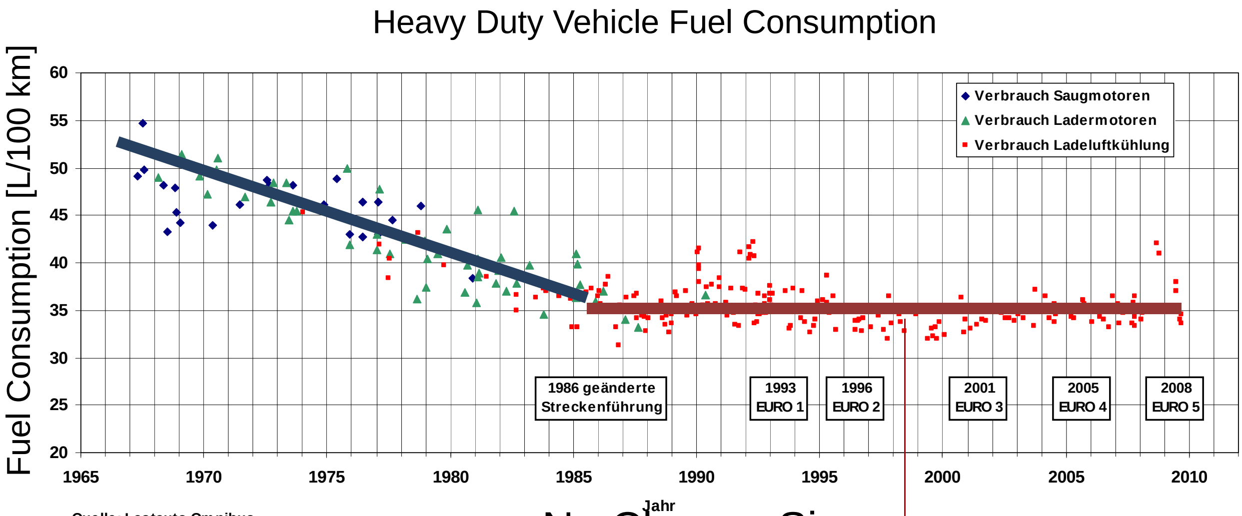
Least Cost Effective: Fuel cells and EV powertrains



JDK Bishop et al (2013). Cost-effectiveness of alternative powertrains for reduced energy use and CO2 emissions in passenger vehicles. Applied Energy, Under review.

London Bus Technologies

“Lastauto-Omnibus” Data Courtesy Daimler



No Change Since 1986!!!

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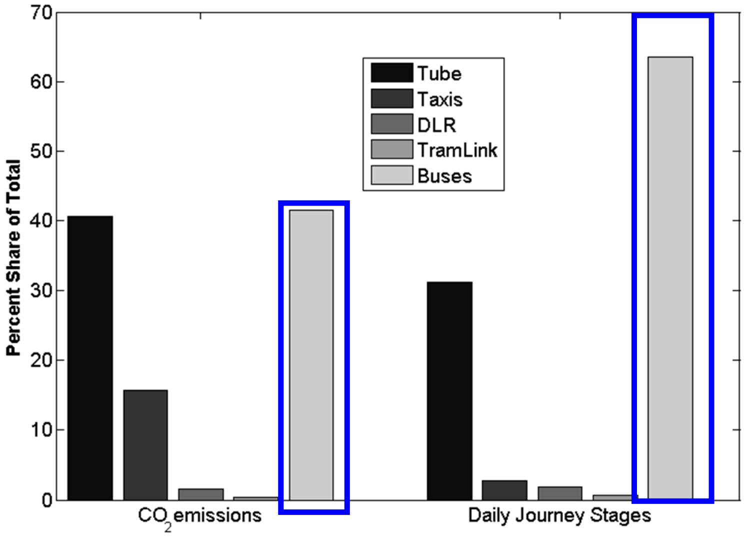
Example: London Buses



SOURCE: TfL Environment Report 2009

Atmospheric London Bus Emissions Resource Tool (ALBERT)

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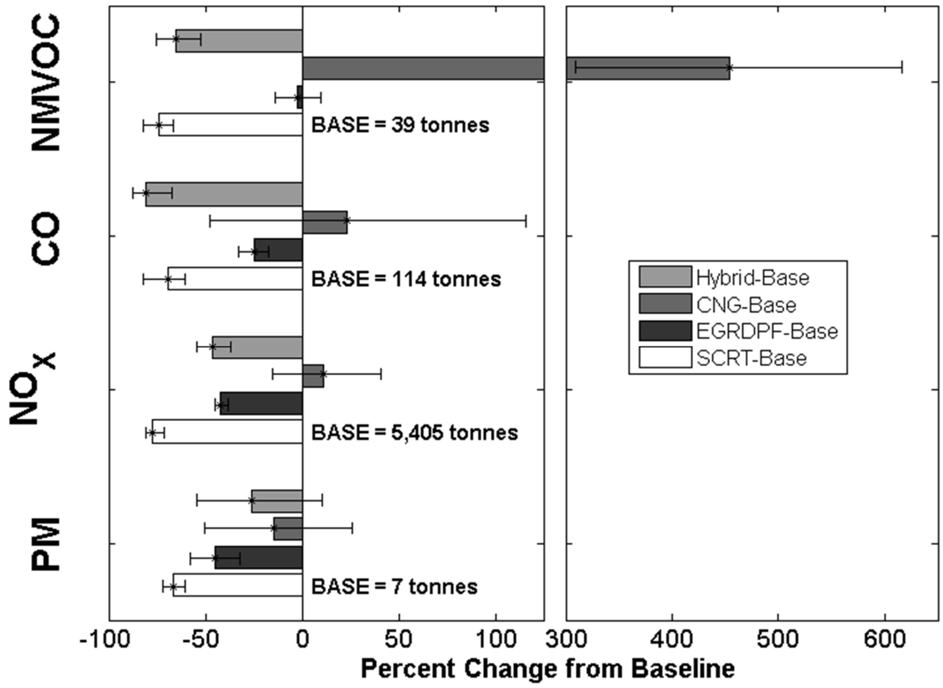
Application

Exhaust Retrofits	Propulsion Technology
Continuously Regenerating Trap (CRT)	Compressed Natural Gas (CNG)
Selective Catalytic Reduction (SCR)	Diesel – Electric Hybrid
Exhaust Gas Recirculation (EGR)	

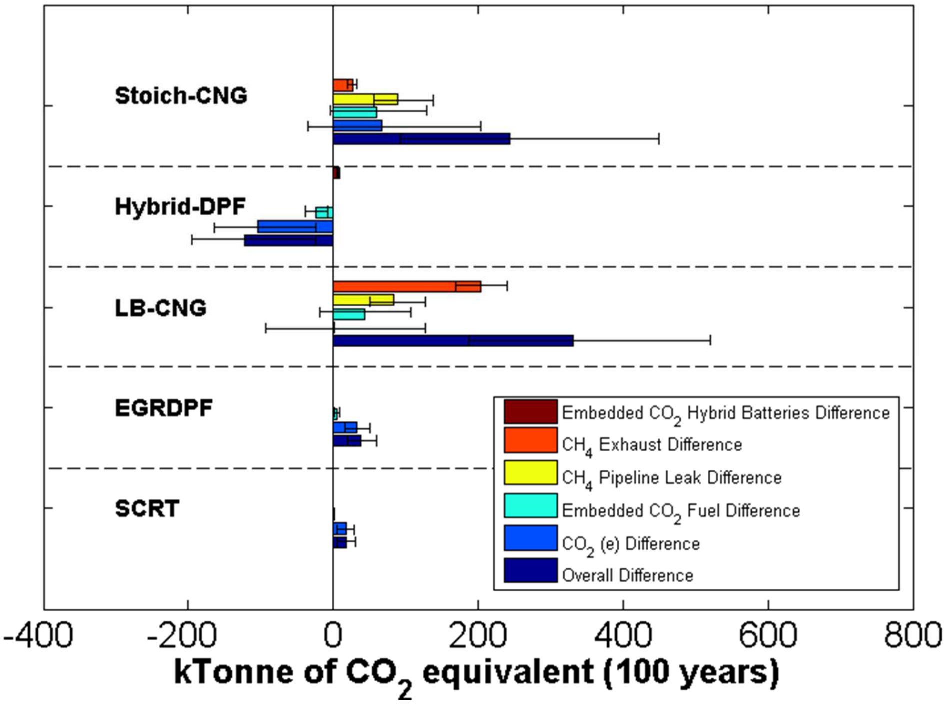
Base Engine Level	EURO Level Composition	Baseline Scenario Exhaust Treatment	SCRT Scenario Exhaust Treatment	EGR DPF Scenario Exhaust Treatment	Hybrid or CNG Scenario
EURO II	25%	CRT	CRT + *SCR*	CRT + *EGR*	
EURO III	50%	CRT	CRT + *SCR*	CRT + *EGR*	*100% CNG or*
EURO IV	20%	SCR	SCR + *CRT*	SCR + *CRT*	*100% Hybrid*
EURO V	5%	None	None	None	

Bus Emissions Results



Almost all scenarios result in noxious emissions reductions

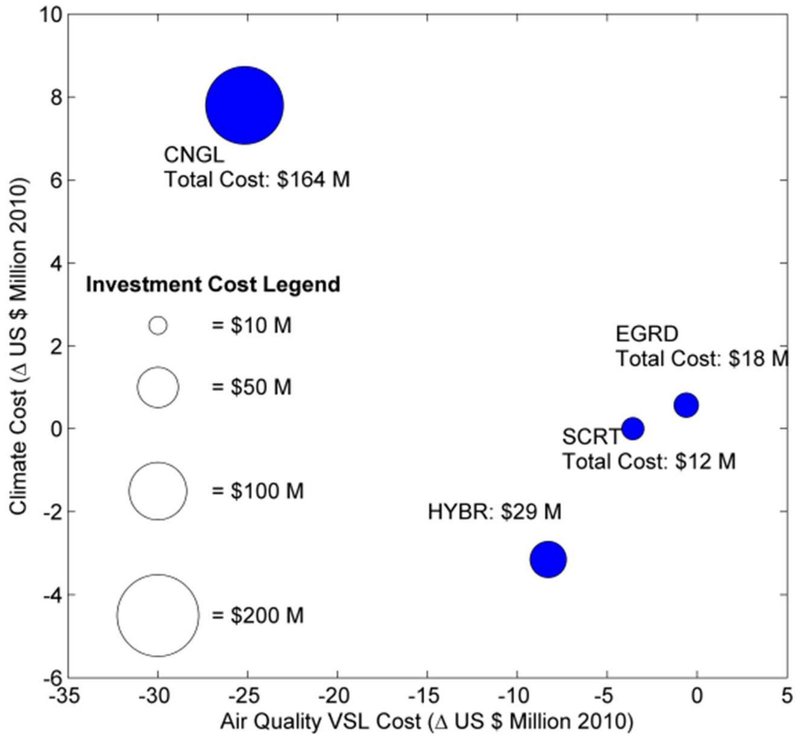
Bus Climate Results



Generally, all scenarios (except Hybrid-DPF), the retrofit causes a net positive warming effect.

Reductions in noxious emissions increase GHG emissions

Monetized Bus Costs



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Paddington Train Station

Motivation

Paddington Station

- 8th Busiest train station in Great Britain (ORR 2010)
- Terminus of the longest non-electrified train line in the UK (DfT 2009)

Emissions Regulations

- No regulatory authority has jurisdiction over air quality within the station

Is air quality within the station a concern?

Paddington Station

Emission Sources

- Food cooking
- Cigarette smoking
- Trains
  - o Electric
  - o Diesel locomotive: propels unpowered railcars that carry passengers.
  - o Diesel railcar: self-propelled cars carrying passengers

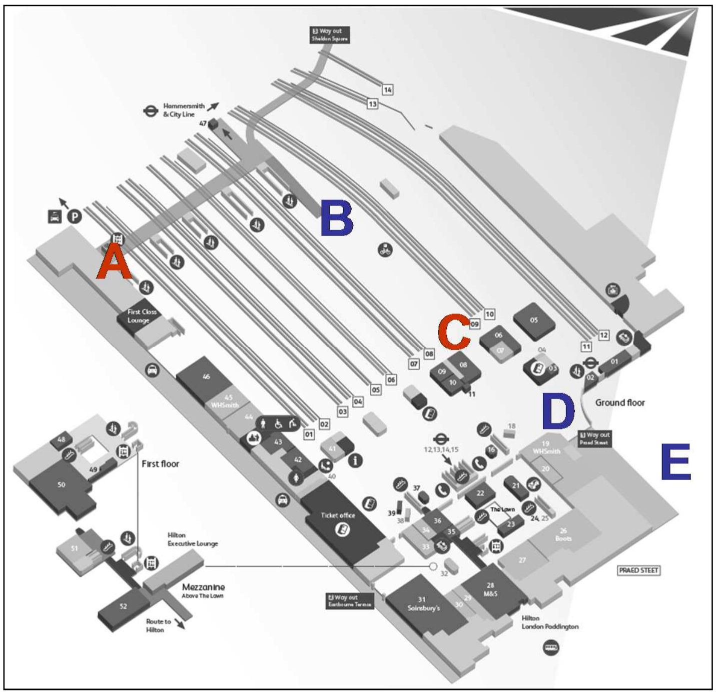

Photo: Mark Beton


Photo: Much Ramblings

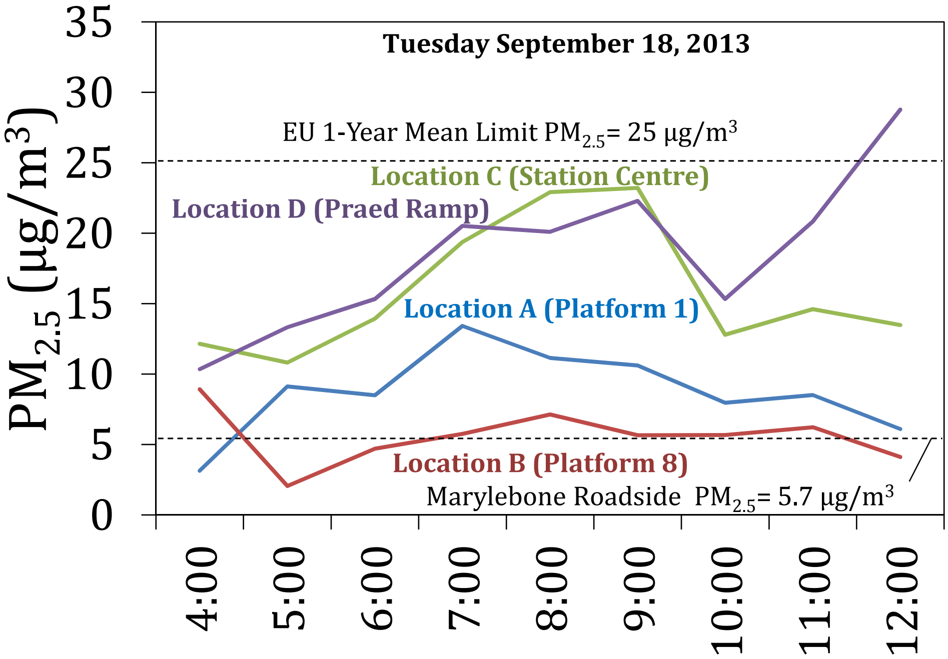
Measurement Methodology

	Description
A	Platform 1 (Class 43 locomotives)
B	Platform 8 (Class 165 multi-unit)
C	Station Centre (Cooking)
D	Praed Ramp entrance (Smoking)
E	Outside station (Roadside ambient)

Species	Equipment Used
$PM_{0.8}$ mass	AM510 + Dorr Oliver cyclone
PM number	SMPS and Catalytic Stripper
SO_2	UV Fluorescence Analyser
NO_X	Chemiluminescence Analyser
OC/EC Ratio	Pump + Quartz Filters
Metals	Pump + Cellulose Filters
Anions	Pump + PTFE Filters



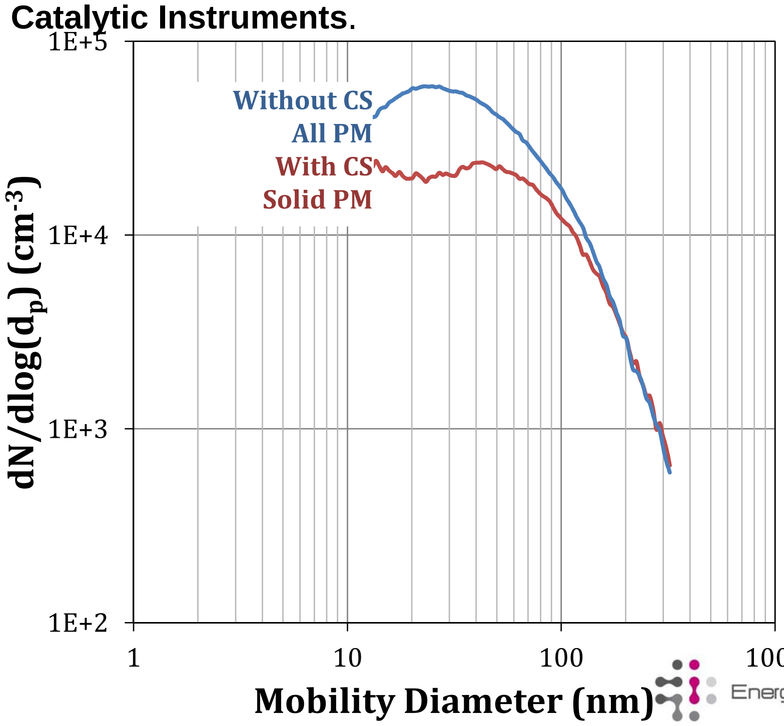
PM Mass Concentration



- $PM_{2.5}$ at Station Centre and Praed Ramp approach EU $PM_{2.5}$ limits at peaks.
- $PM_{0.8}$ at all locations are greater than London Marylebone roadside concentrations.

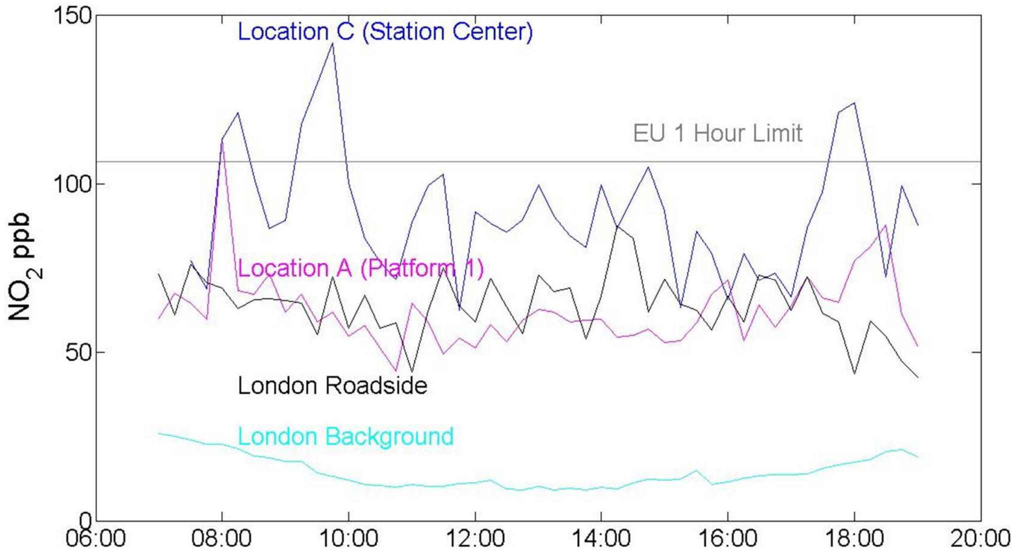
Solid vs. Wet (Semi-Volatile) PM

Applied “new” technique for measuring solid particles. Resulted in a new company **Catalytic Instruments**.



- Impacts of solid black carbon particles are known to adversely impact health, but semi-volatile (liquid) particles are not understood.
- Catalytic stripper allows removal of the semi-volatile fraction to detect solid particles.
- Majority (in terms of number) of particles are semi-volatile
- Solid and semi-volatile particles have the same general size – unusual.

NO_2 Concentration



- NO_2 is highest next to Location C (Station Centr).
- NO_2 EU 1 hour averaged limits were exceeded 5 times during the week (only18 exceedances allowed per year).
- The average NO_2/NO_X ratio was 0.19.

Summary

Road Fleet Modelling
1. London Bus Emissions
2. Bottom-Up UK Transport Model

Lifecycle Analysis of Fuels and Power Generation
1. UK Transport Fuels – Ethanol
2. Electricity Generation with Biomass – Tilbury

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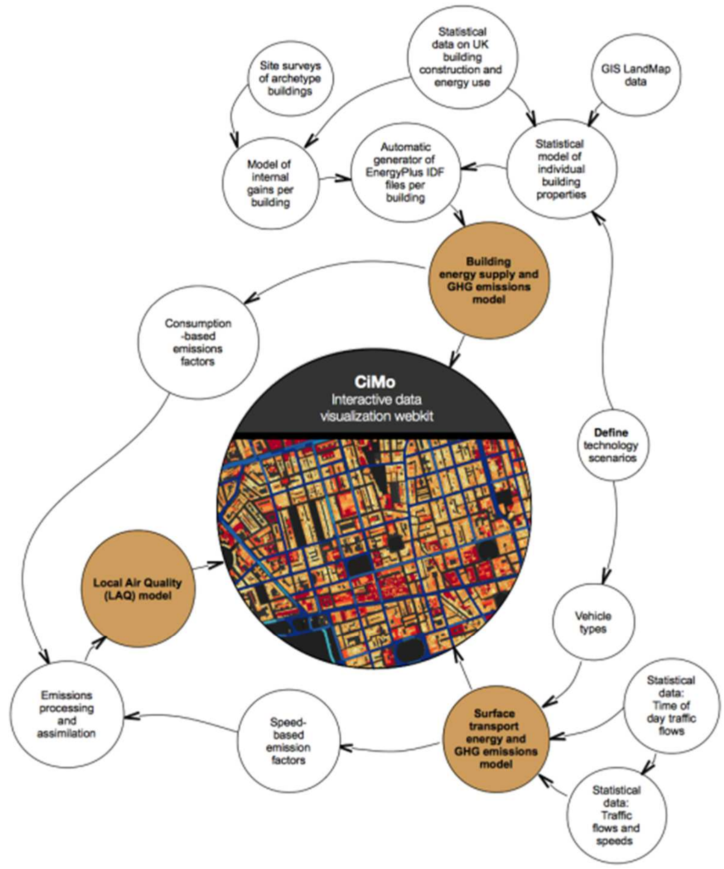
1. Gas Turbine Measurement – SAMPLE III
2. Ambient Air Quality – Paddington Trains
3. Dual Fuel (Diesel/Natural Gas)

Emissions Modelling
1. Airports
2. Trains
3. UK Light-Duty Vehicle Fleet

Individual models provide insight into specific questions and phenomena

Broader impacts come from combination of models within the urban environment

Westminster Study

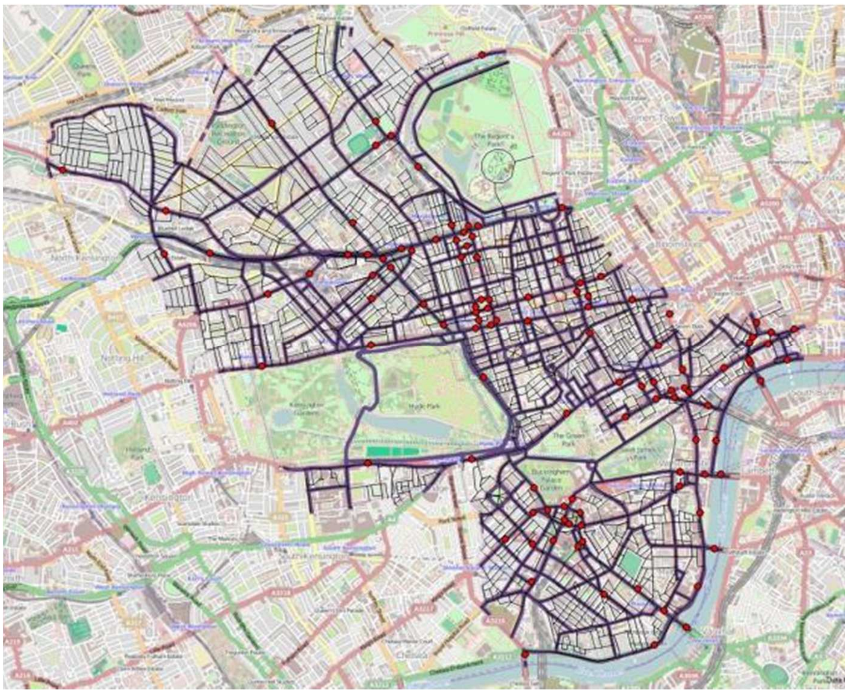


CiMo

City of Westminster Analysis

Web Tool

Automatic traffic counters



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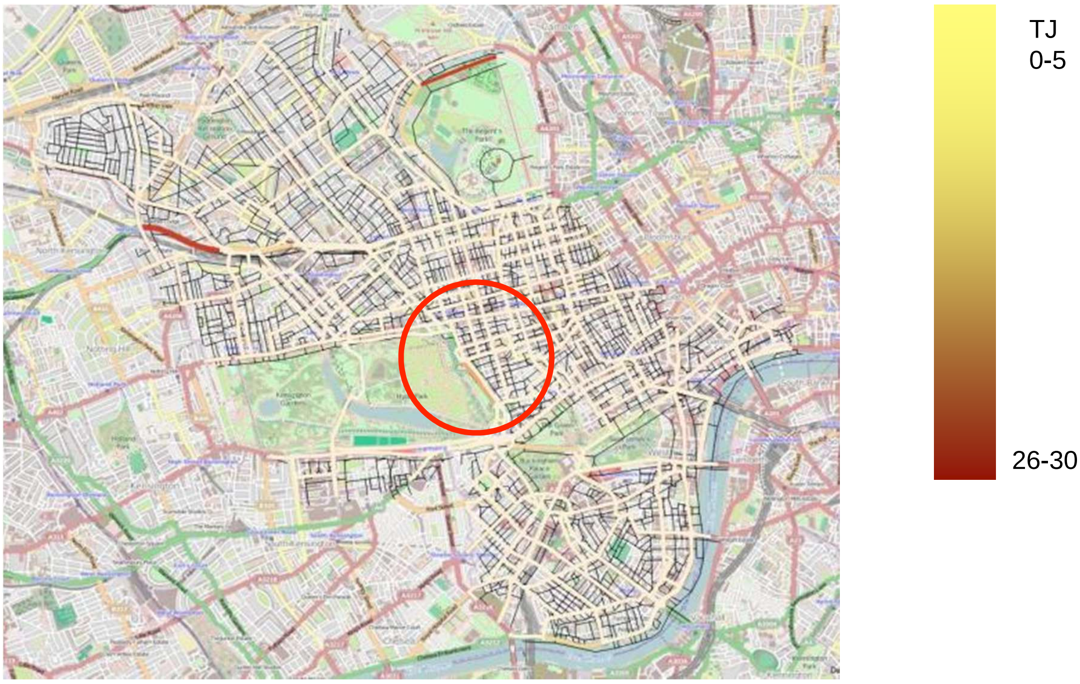
Passenger vehicle energy use



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Dynamic Building Energy Simulation:

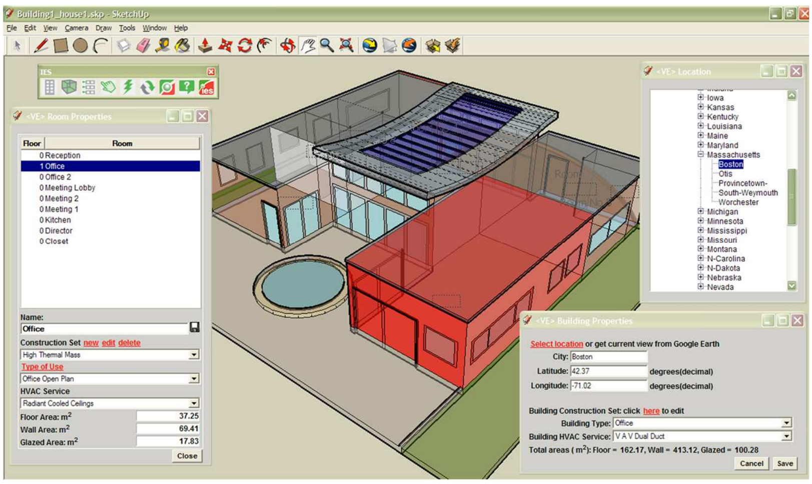
The “state-of-the-art” in building energy performance modelling

Characteristics:

- 3-dimensional representation of building form and heat transfer
- Solution of energy balance equations at small intervals (e.g., hourly) over an entire year

Caveats:

- Requires 3D building geometry data
- Requires sensible inputs for hourly energy services demand



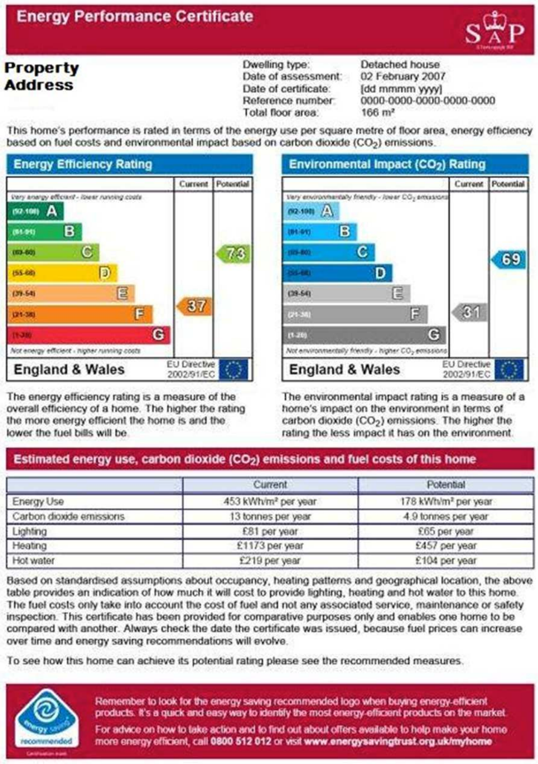
Westminster EPC Register

Summary (Domestic sector)

- Coverage for ~64,000 dwellings
- Includes building construction information (wall type, window type, etc.)
- Includes heating system type

Summary (Non-domestic sector)

- Coverage for ~8,500 premises
- Does not include construction information
- However, includes retrofit recommendations per premises (e.g., “replace glazing”)


Energy Performance Certificate

SAP

Property Address

Dwelling type: Detached house
Date of assessment: 02 February 2007
Date of certificate: [dd mmmm yyyy]
Reference number: 0000-0000-0000-0000-0000
Total floor area: 166 m²

This home's performance is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO_2) emissions.

Energy Efficiency Rating — Current: 37 (F); Potential: 73 (C)
Very energy efficient - lower running costs
(92-100) A; (81-91) B; (69-80) C; (55-68) D; (39-54) E; (21-38) F; (1-20) G
Not energy efficient - higher running costs
England & Wales — EU Directive 2002/91/EC

Environmental Impact (CO_2) Rating — Current: 31 (F); Potential: 69 (C)
Very environmentally friendly - lower CO_2 emissions
(92-100) A; (81-91) B; (69-80) C; (55-68) D; (39-54) E; (21-38) F; (1-20) G
Not environmentally friendly - higher CO_2 emissions
England & Wales — EU Directive 2002/91/EC

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills will be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.

Estimated energy use, carbon dioxide (CO_2) emissions and fuel costs of this home

	Current	Potential
Energy Use	453 kWh/m² per year	178 kWh/m² per year
Carbon dioxide emissions	13 tonnes per year	4.9 tonnes per year
Lighting	£81 per year	£65 per year
Heating	£1173 per year	£457 per year
Hot water	£219 per year	£104 per year

Based on standardised assumptions about occupancy, heating patterns and geographical location, the above table provides an indication of how much it will cost to provide lighting, heating and hot water to this home. The fuel costs only take into account the cost of fuel and not any associated service, maintenance or safety inspection. This certificate has been provided for comparative purposes only and enables one home to be compared with another. Always check the date the certificate was issued, because fuel prices can increase over time and energy saving recommendations will evolve.

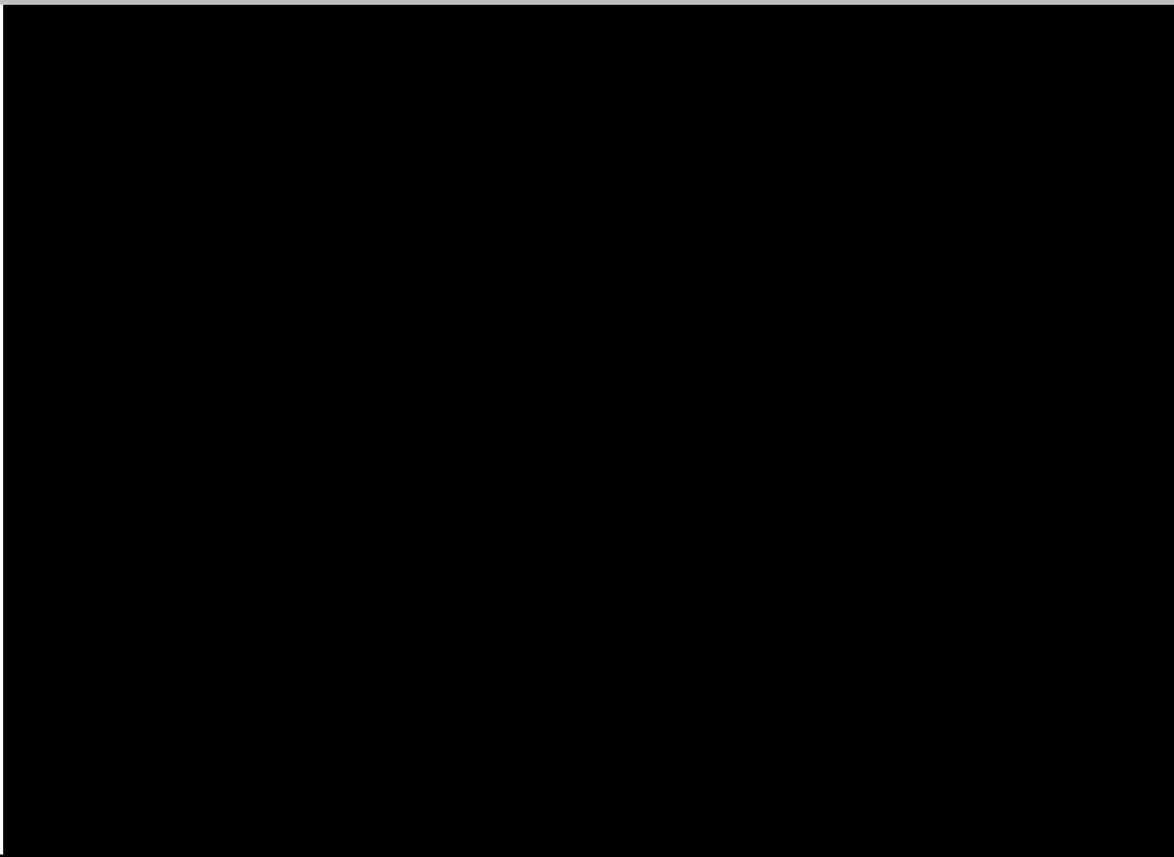
To see how this home can achieve its potential rating please see the recommended measures.

Remember to look for the energy saving recommended logo when buying energy-efficient products. It's a quick and easy way to identify the most energy-efficient products on the market.

For advice on how to take action and to find out about offers available to help make your home more energy efficient, call **0800 512 012** or visit **www.energysavingtrust.org.uk/myhome**

1. What are the relative contributions of buildings and transport to energy use, CO_2 emissions and pollutant concentrations in Westminster?
2. Do pollutant emissions in Westminster lead to exceedances of regulatory limits on air quality on their own?
3. What are future air quality impacts?

Overview of Results – Buildings (Colour) Transport (Spheres)



Key questions for environmental impacts

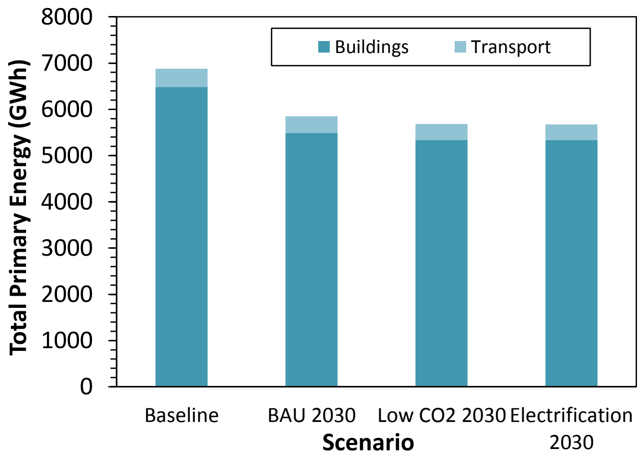
1. What are the relative contributions of buildings and transport to energy use, CO_2 emissions and pollutant concentrations in Westminster?

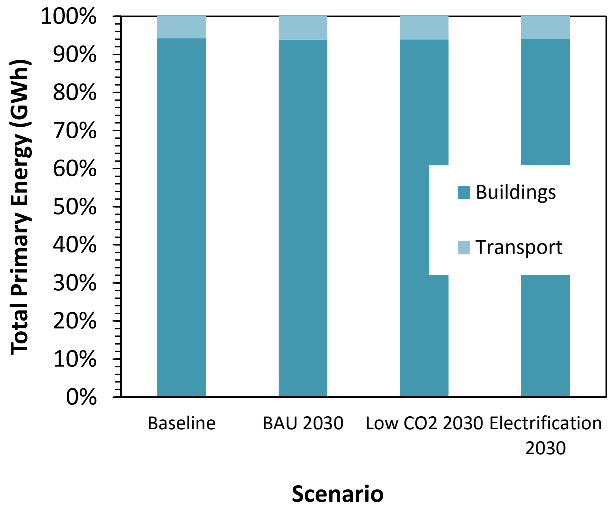
2. Do pollutant emissions in Westminster lead to exceedances of regulatory limits on air quality on their own?

3. What are future air quality impacts?

Total primary energy use

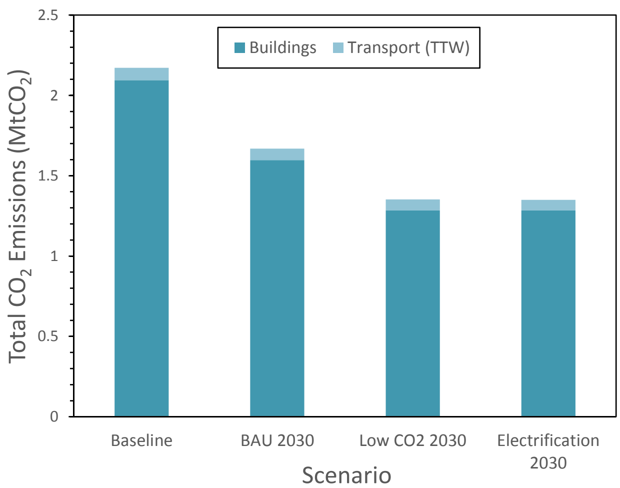
- Buildings (~95%)
- Transport (~5%)
  - c.f. ~20% in Paddington Study, more land area for transport

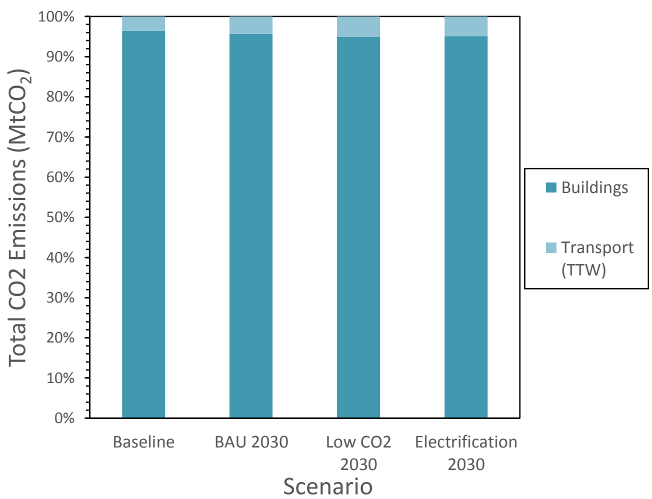




Relative contribution to CO_2 emissions

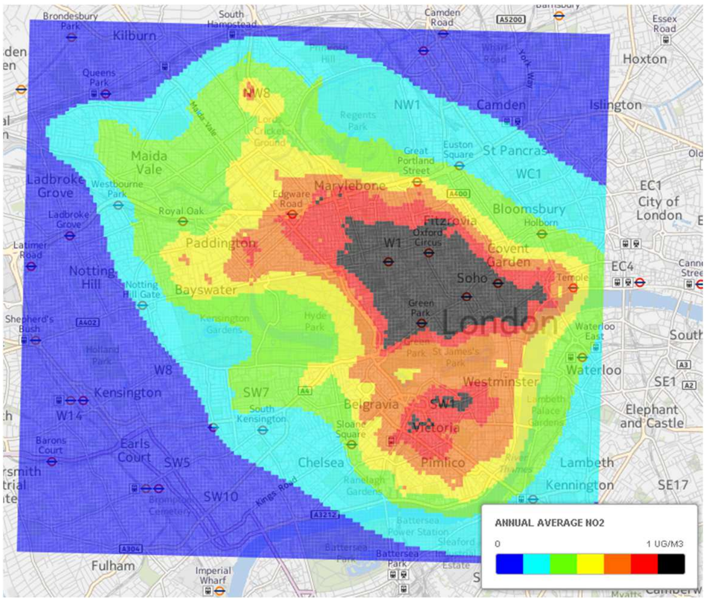
- Buildings (~95%)
- Transport (~5%)
  - c.f. ~20-40% in Paddington Study, very ambitious building technology penetration and decarbonisation





Relative contribution to AQ impacts

- Pollutant concentrations due to buildings emissions are at least an order of magnitude lower than those due to transport



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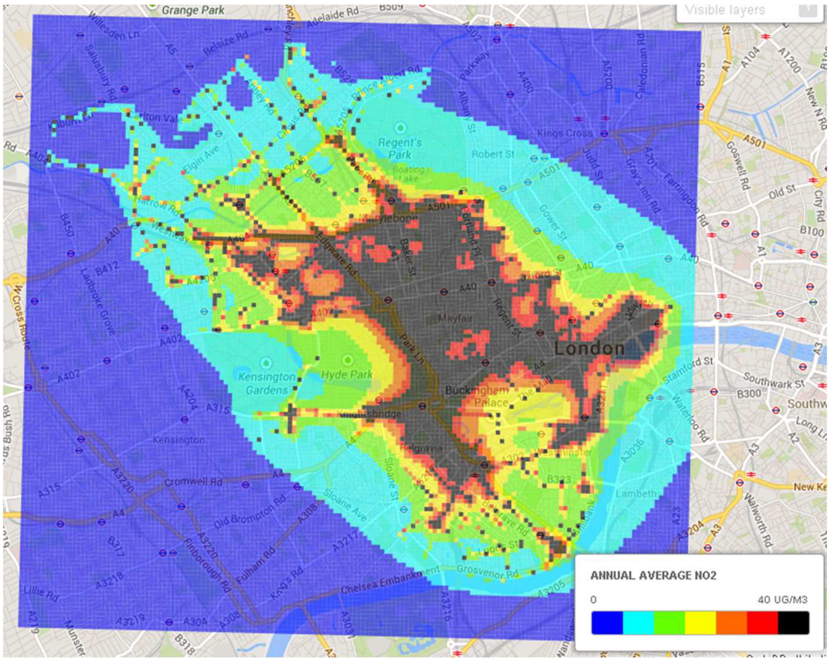
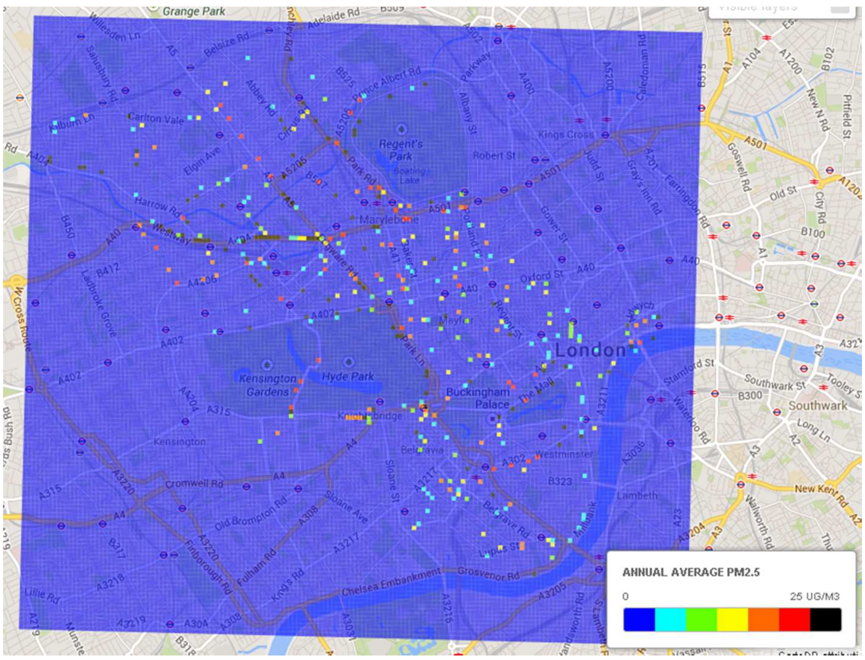
Present day exceedances – NO_2

- Emissions from Westminster currently lead to widespread exceedances of NO_2 regulation



Present day exceedances – $PM_{2.5}$

- Emissions from Westminster currently lead to isolated exceedances of $PM_{2.5}$ regulation



Key questions for environmental impacts

1. What are the relative contributions of buildings and transport to energy use, CO_2 emissions and pollutant concentrations in Westminster?
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Spatial plots of future pollutant concentrations

- NO_2
  - Concentrations decrease in all future scenarios relative to present day
  - Transport emissions are reduced due to increasing proportion of newer cars with lower NO_x emissions and engine exhaust after-treatment
  - Electrification scenario has lowest NO_2 concentrations as buses are also electrified
- $PM_{2.5}$
  - Concentrations decrease in most future scenarios relative to present day
  - Engine exhaust after-treatment (particle filters) becomes more common
    - Scenario with high IC engines ≈ high electrification
    - Future regulatory standards are based on particle number

Conclusions

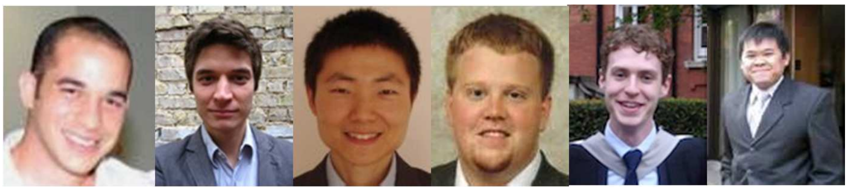
Discover CiMo through our City of Westminster project.

CiMo allows relative impacts to be considered from transport and urban infrastructure.

Generally:
Investments in transportation reduce noxious air pollution.

Investments in buildings reduce greenhouse gas emissions.

Thank You



PhD Students (current)
Hu, K., Hocker, C., Chong, U., Martin, N., Arora, P.
Post-Doctoral Researchers (current)
Stettler, M., (Previously PhD Student) Black carbon emissions from airplane turbines
Smail, F., High throughput carbon nanotube synthesis measurement
Bishop, J., Energy and emissions modeling of light-duty vehicle fleet
Past Students and Researchers
Swanson, J. (Asst. Prof. Minnesota State University), Emissions measurement
Yan, X. (Asst. Prof. Exeter University), Lifecycle analysis
Alam, N. (Industrial Engineer), Nanostructured materials
Harris, G. (Engineering Consultant), Vehicle drive cycles
Pillari, L. (Petroleum Engineer), Anaerobic biogas production
Brakely, N. (Energy Engineer), Hydraulic hybrid analysis
Ritchie, J., (Australian Government Engineer), Impact assessment
Pithoud, F., (Graduate Student, France), Impact of Vehicle Electrification on Emissions

EPSRC Engineering and Physical Sciences Research Council
JM Johnson Matthey
Q-FLO
THE ROYAL SOCIETY