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Near zero greenhouse gas emission energy systems and air pollution – some linkage

presentation to TFIAM 22 April 2020, Cyberworld

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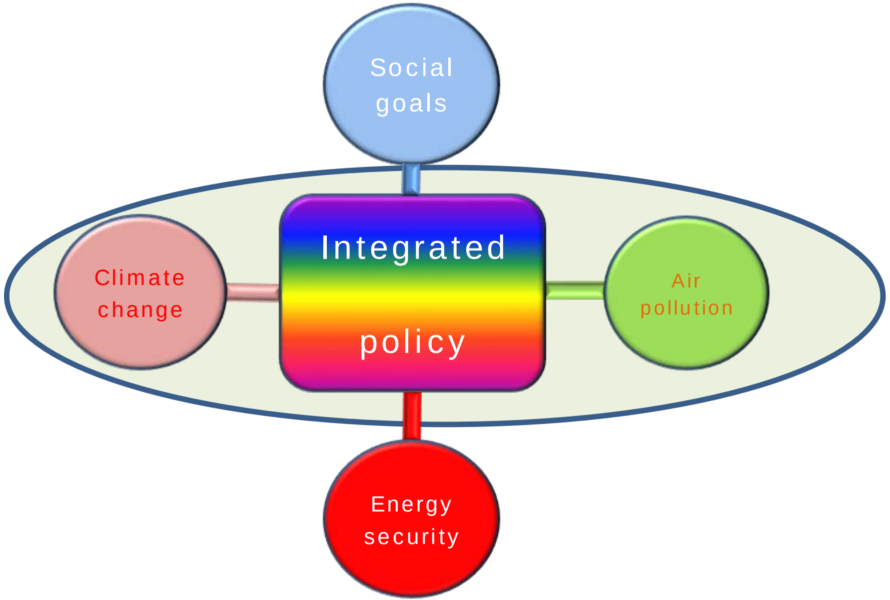
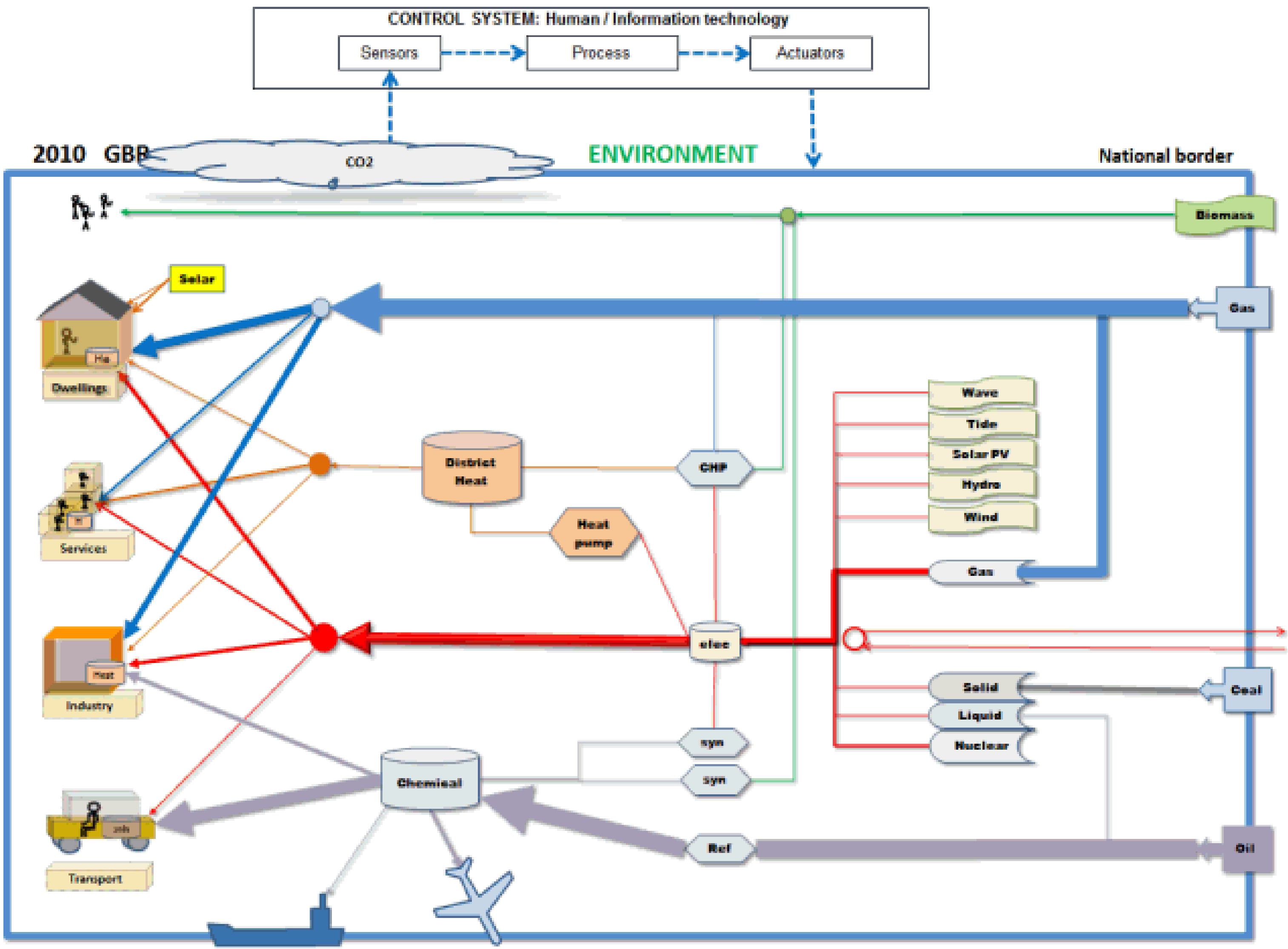
EnergySpaceTime group



CREDS
CENTRE FOR RESEARCH INTO ENERGY DEMAND SOLUTIONS

ESTIMO – system modelled



Near Zero GHG emission energy system
– main elements in ESTIMO design

Primary energy
- renewable electricity and some nuclear
- biomass waste – limited, variegated and diffuse
- biocrops - global warming, ecosystems and land use competition for food and sequestration.

Secondary fuels
- electrofuels - hydrogen and ammonia for storage and ships - made with electricity, water and air
- kerosene for aircraft made from biomass with additional hydrogen and carbon

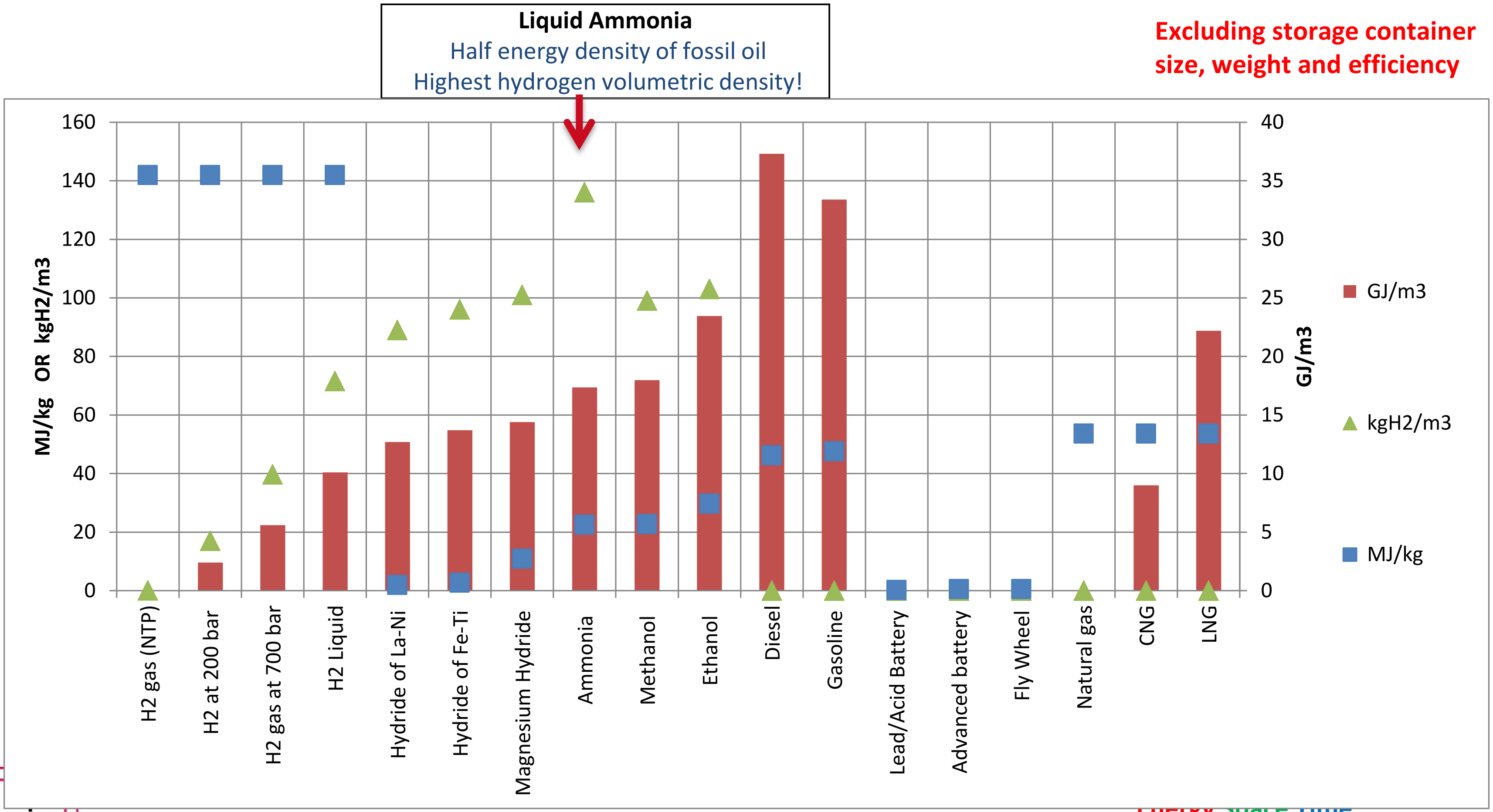
Demand
- electrification of heat and road and rail transport
- electrofuels for ships – H2, NH3
- renewable kerosene for aircraft
- iron and cement

Carbon absorption for synfuels and sequestration to balance residual emissions
- direct air capture DAC?
- [afforestation?]
- [BECCS – problematic because of biomass constraints]

Fuel characteristics

Superiority of hydrocarbons in terms of volumetric and gravimetric density

Excluding storage container size, weight and efficiency

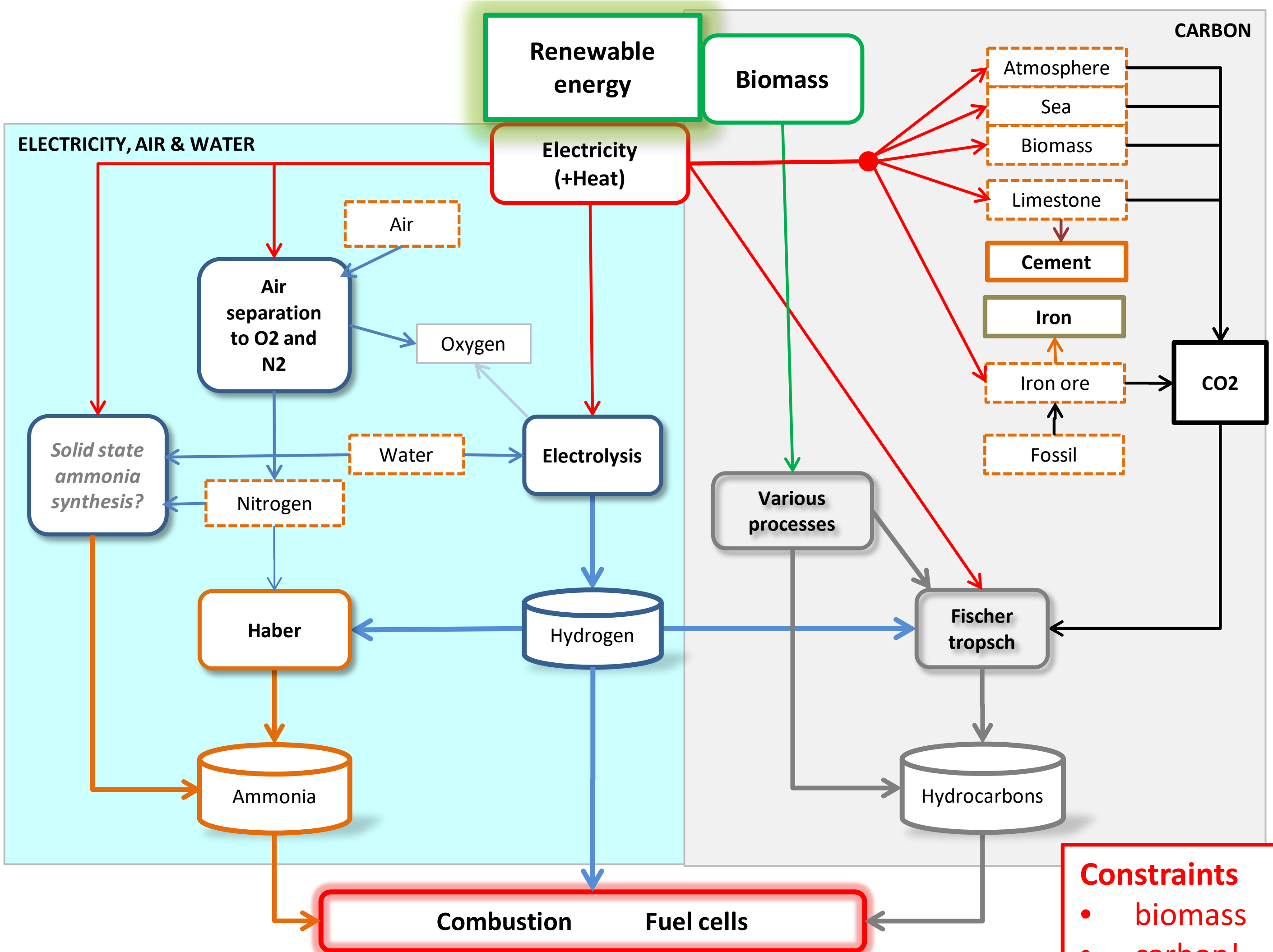


Renewable fuel pathways

Renewable input
- electricity
- biomass
- heat

Feedstocks
- air
- water
- carbon
- biomass

Products
- hydrogen
- ammonia
- hydrocarbons



Constraints
- biomass
- carbon!

Processes and air pollution

Biomass Highly variegated and GHG and air pollution emissions range widely

- waste – wood, straw, manure, sewage etc – CH_4, PM….
- biocrops - inputs (fertiliser, agricultural fuels etc.), land use
- processing for bio-kerosene and for input to Ficher Tropsch etc. – CH_4, NH_3…
- BECCS?

Electrolytic hydrogen

- Negligible emissions?

Synthetic kerosene

- production from biomass, carbon and hydrogen.
- in use will cause some global warming during high altitude flying and air pollution emission (NO_x, PM, secondary O_3, etc.) will be similar to fossil kerosene

Ammonia system emissions

- Haber Bosch synthesis – NH_3?
- storage – NH_3?
- use in engines or fuel cells – NH_3, NO_x?

Industry

- Iron production using hydrogen and electric heating – emissions depend on unproven process details - PM
- Cement - non-limestone feedstocks coupled with electric heating, and carbon capture

Direct Air Capture of CO_2

- CO_2 concentration very low so huge absorber areas needed
- Use liquid (KOH, NaOH, $Ca(OH)_2$ and solid solvents.
- Water

Aviation fuel from biomass – illustrative calculation

1. 12.3 Mt UK aviation fuel use in 2018
2. 463 PJ waste biomass Table 6.1 UK DUKES. This is physically and chemically variegated, geographically diffuse so problematic.
3. Assumptions for energy content (GJ/t) to calculate waste mass (t)
4. Assumptions as to % waste suitable for collection and processing.
5. Assumptions as to carbon content (% waste biomass mass) and total available carbon in the waste.
6. Calculate maximum kerosene that can be produced from biomass carbon (15.5 Mt).
7. Assume % of maximum can be practically produced in Fischer Tropsch process, and thence practical maximum
8. Assume 0.75 ?? kWh electricity per kWh of kerosene for additional hydrogen, transport and processing
9. Waste biomass carbon might produce 60% of total 2018 demand?
10. Further kerosene production would require additional carbon from UK biocrops or biomass imports, or carbon from DAC, and hydrogen.

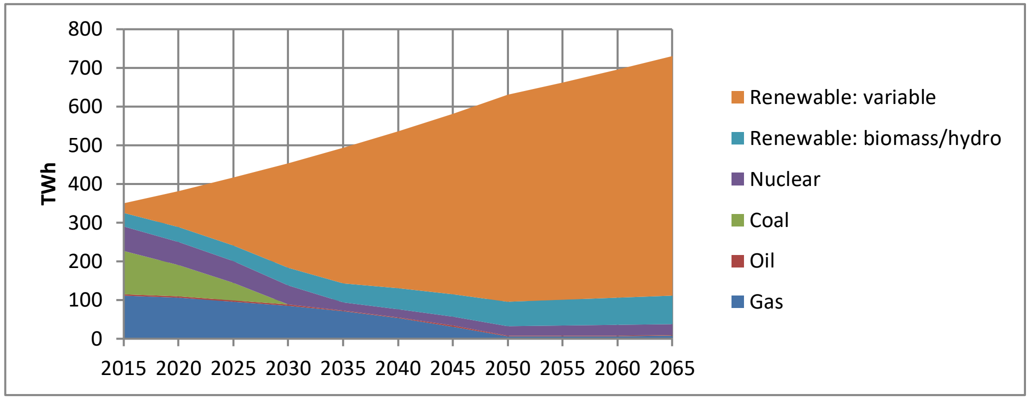
	Energy		Mass	Carbon		Max	Suitable		Practical		Ker	Renewable elec	
	PJ	GJ/t	Mt	%	MtC	Mt (Ker)	%	MtC	FT prod	Mt (Ker)	PJ	PJ	TWh
Waste wood	17	17	1.0	40%	0.4	0.5	80%	0.3	80%	0.3	12	9	3
Wood	86	17	5.0	40%	2.0	2.4	80%	1.6	80%	1.5	64	48	13.3
Animal biomass a	67	17	3.9	40%	1.6	1.9	30%	0.5	80%	0.4	19	14	3.9
Plant biomass	109	12	9.1	40%	3.6	4.3	80%	2.9	80%	2.7	115	86	24.0
Sewage gas	15	50	0.3	75%	0.2	0.3	90%	0.2	80%	0.2	8	6	1.6
Landfill gas	60	50	1.2	75%	0.9	1.1	90%	0.8	80%	0.8	32	24	6.6
Waste	111	10	11.1	40%	4.4	5.2	30%	1.3	80%	1.3	53	39	11.0
TOTAL	**463**		**31.6**		**13.2**	**15.5**		**7.6**		**7.2**	**302**	**226**	**63**
% UK consumption						**126%**				**59%**			

A sample national scenario context

Electricity and emissions

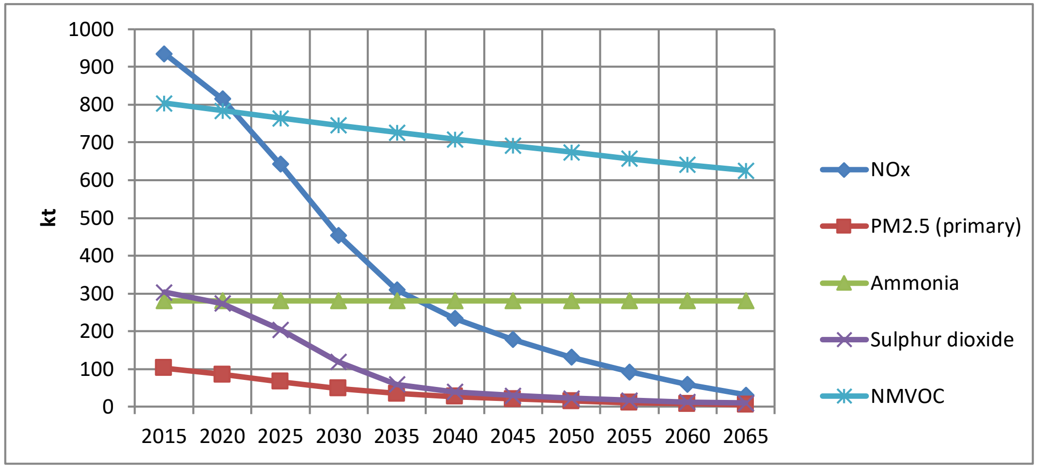
Electricity

- replace fossil with renewable or nuclear
- CO2 and air pollution emissions per kWh fall
- calculate costs per kWh



Emissions (anthropogenic)

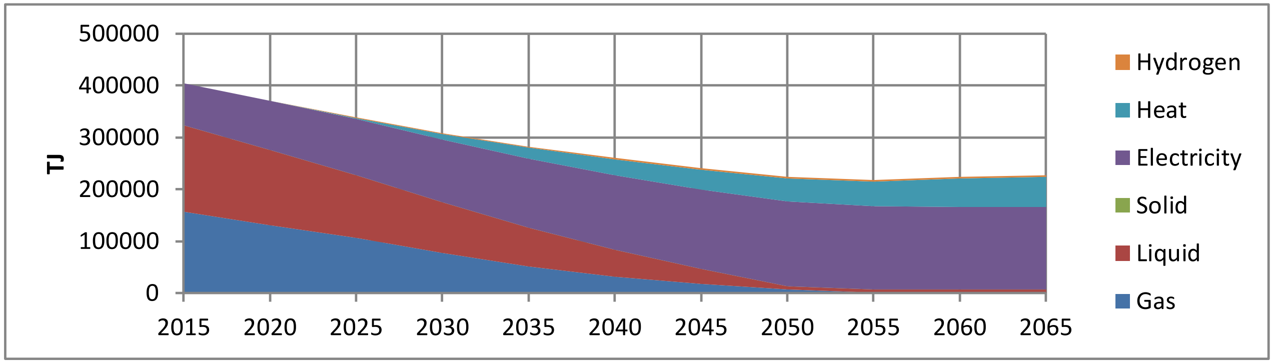
- **Energy** related from energy scenario
- **Other** emissions (e.g. ammonia) from Defra projections & extensions
- Note importance of ~constant ammonia emission for secondary PM2.5



City model: Scenario (London)– demand and supply

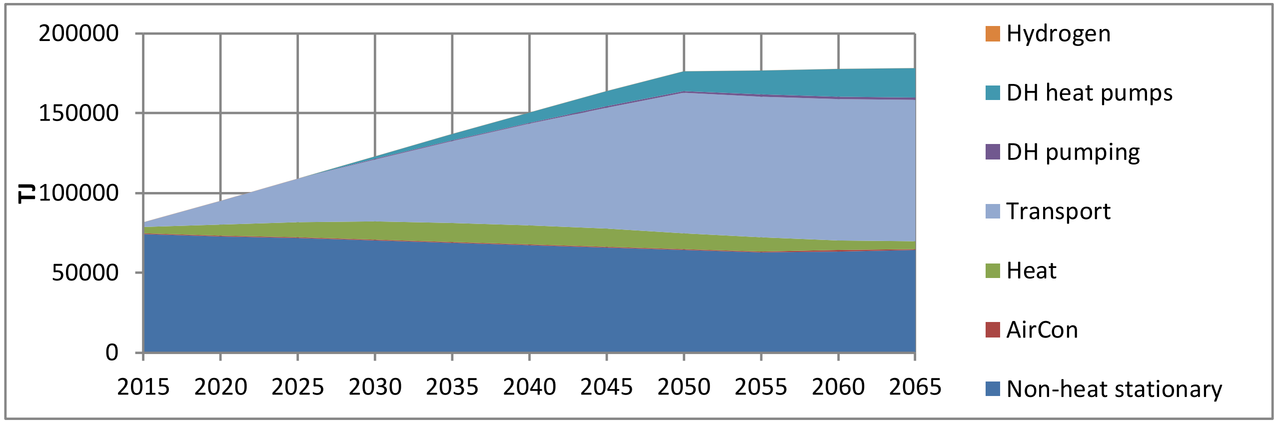
Deliveries

Shift from fossil gas and oil to electricity and DH



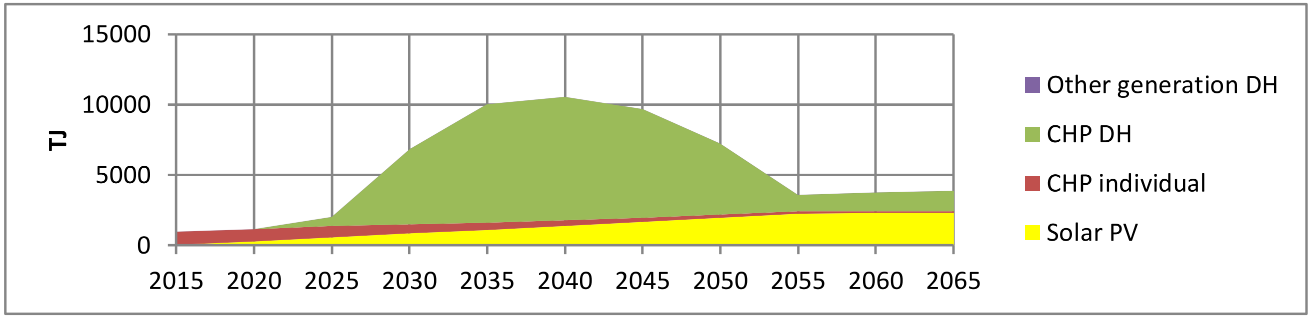
Electricity consumption

Increase for heating and transport



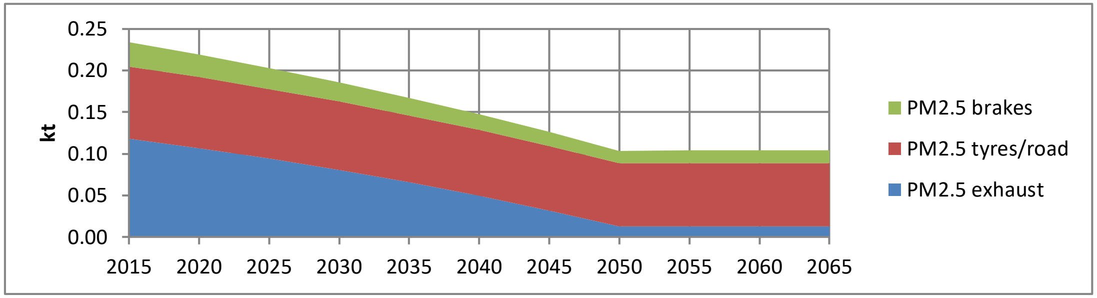
Electricity generation

Steady increase in solar PV and increase then decline in CHP

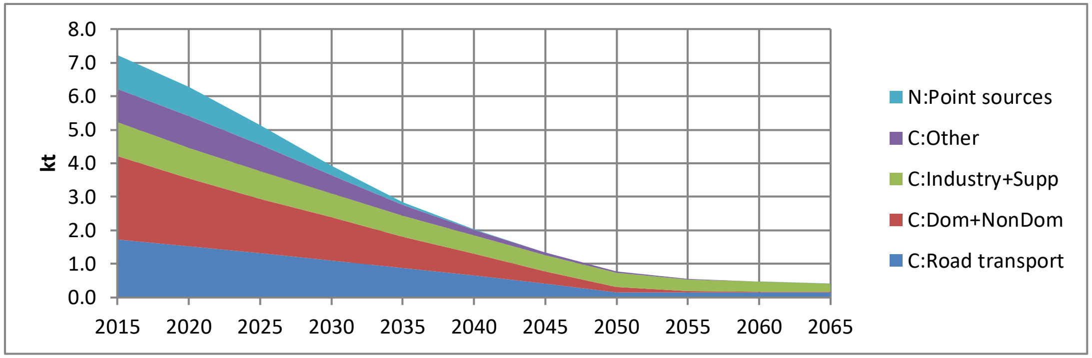


City model: City emissions air pollution and CO_2

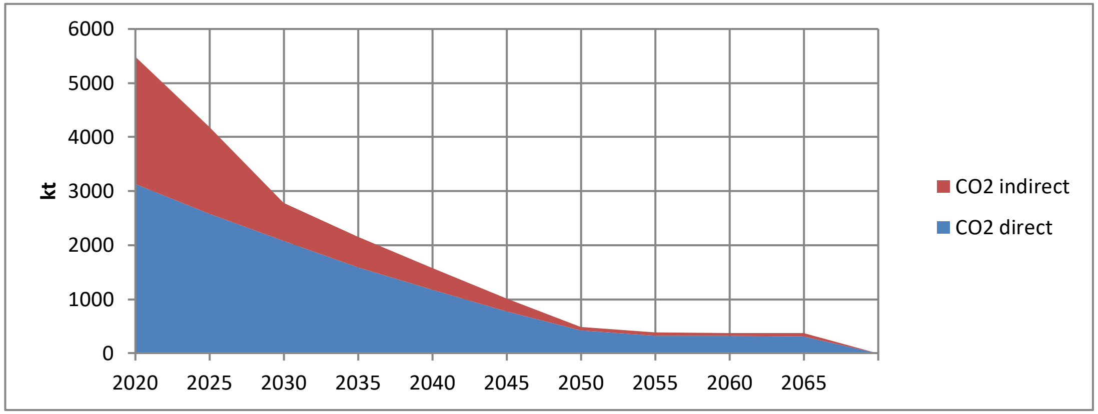
PM2.5
Excluding dust resuspension



NOx



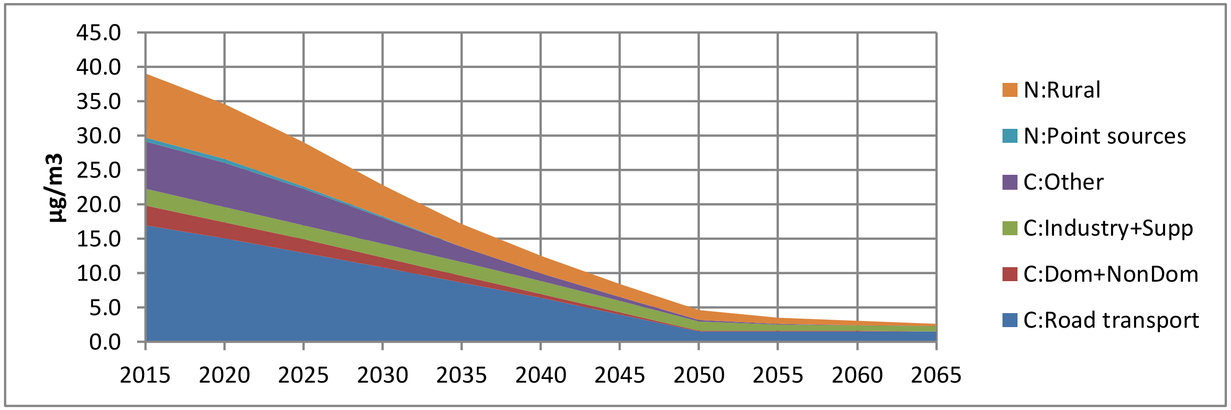
CO2



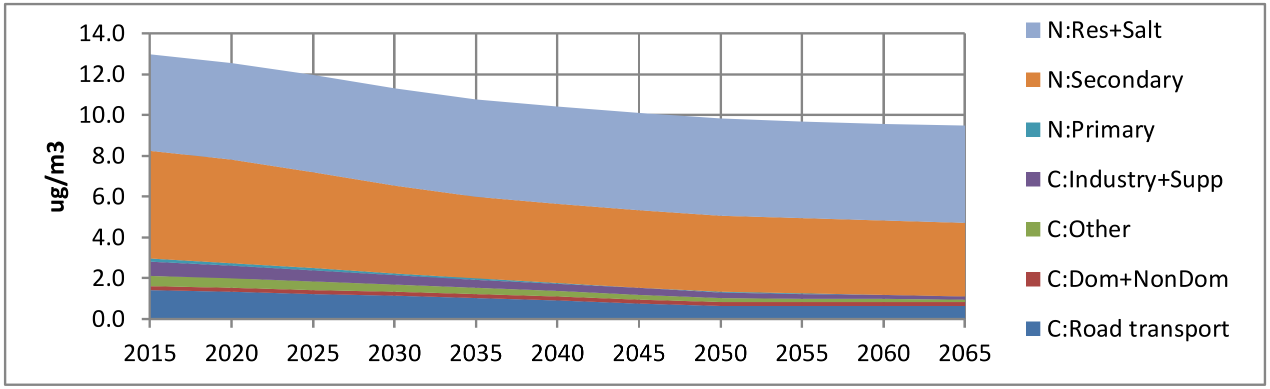
City model: Air pollution emission and concentration projections

NOx

(NO2 similar change)



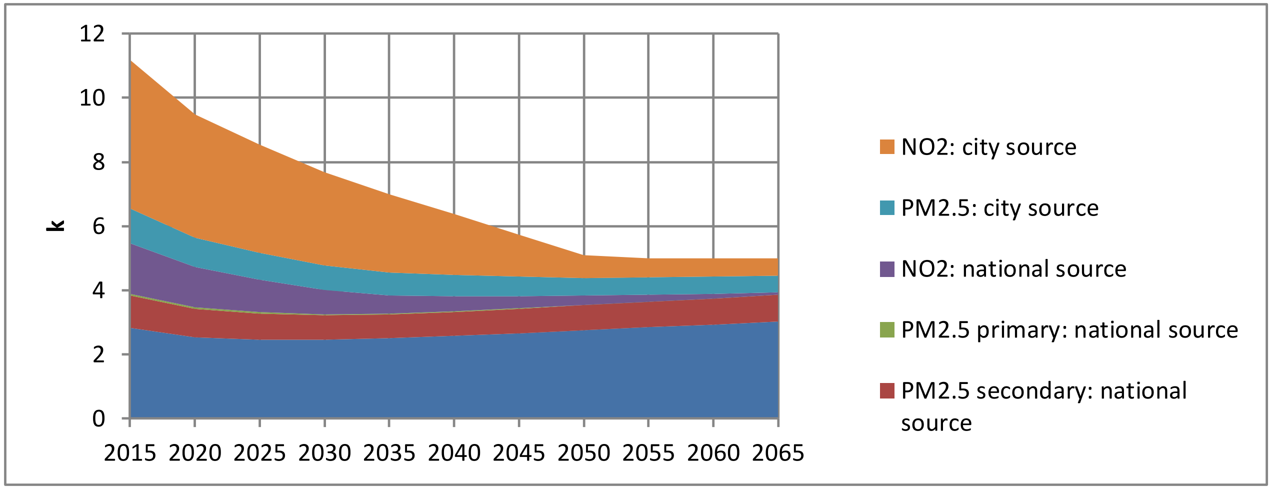
PM2.5



City model: Air pollution health impacts: Birmingham

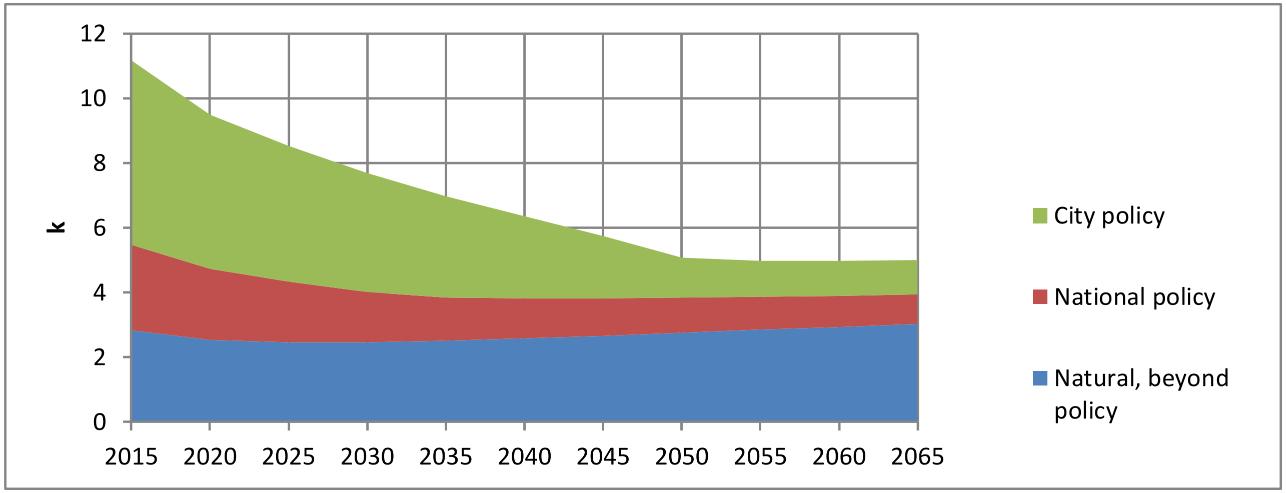
(any increasing trends are due to increasing population)

Premature deaths by pollutant and source



NB: assumption that natural sources have health impacts

Premature deaths affected by policy



Conclusions

Main results

- Net zero GHG energy systems have lower air pollution in general
- Emissions of PM will persist - EV tyres, train wheels, processes (iron, cement)…
- Secondary PM, depending on precursors, and natural PM will remain

New major energy processes possible:

- biomass, hydrogen, ammonia, hydrocarbon synthesis and use
- steel production using hydrogen
- cement with CC and alternative
- carbon capture and sequestration: Direct Air Capture, BECCS

Need for knowledge:

1. What are the process emission factors?
2. How much of the different air pollutants will be emitted given energy flows in scenarios?
3. Where and when will emissions occur?
4. What will be the impact on air pollution concentrations?

Perhaps ESTIMO scenario energy flows and emissions could be input to IAMs and city models*?

Note - ESTIMO includes:

- hourly social activity patterns which might be inputs to exposure models.
- meteorology which can include climate change, heat stress with health AP synergies
- heating and cooling of buildings and effect of climate change

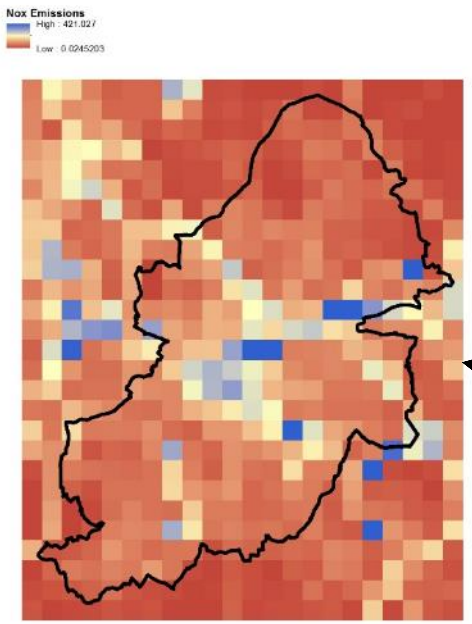
*[*Please ask mark.barrett@ucl.ac.uk if you'd like a ppt on the SEEcity model.]*

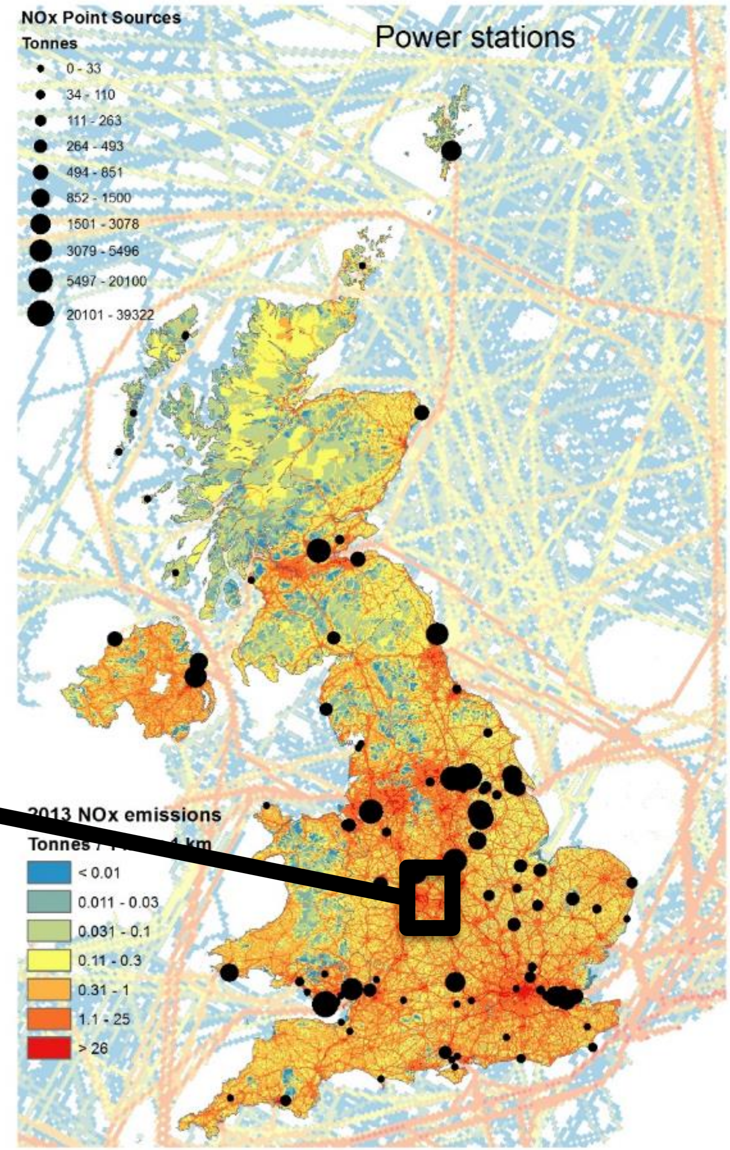
Thanks for listening

Extra material

Air pollution data:

- Emissions available by source
- Contribution to concentration as per algorithm below
- Concentration isolated by Local authority
- External sources contribute





Integration of fuel production into energy system

Biomass availability will be constrained and other uses – e.g. for heat and electricity production with CHP plant

Electricity and heat is required for various processes

- Biomass processing
- Hydrogen — Electrolysis
- Hydrocarbon synthesis — Fischer Tropsch
- Ammonia — Haber Bosch
- Direct Air Capture
- Carbon sequestration

Electricity and heat will predominantly come from variable renewable and nuclear sources.

- Demands and storage for
- Renewable electricity recycles air and water via ammonia that is a near zero greenhouse gas and potentially low air pollution emit
- Assessment of motors and fuel cells using ammonia

- Detailed technical, environmental & economic model of production, distribution and use pathways – particularly issue of ammonia leakage and secondary particles

- Analysis of technical/economic integration of synthesis into national system, including use of hydrogen and ammonia for energy storage

Main emission processes

Operational emissions mainly comprise:

- Methane from hydro reservoirs
- GHG and air pollutants from biomass production and processing
- Air pollutants from ammonia production and use?
- GHG and air pollutants from aircraft kerosene use
- Emissions from machines e.g. EVs

			GHG	PM	NOx	NH3
Primary production	Wind, solar		10			
	Nuclear		10			
	Hydropower		8			
	Biowaste		8	8	10	10
	Biocrops		7	7	7	7
Secondary	Ammonia					9
	Hydrogen					
	Kerosene			9	10	10
Consumer	Electrical equipment					
	Heat pumps and district heating					
	NH3 CHP		10	9	9	8
	Electric vehicles			7		
	Ships	Ammonia			9	8
		Hydrogen			9	
	Aircraft kerosene		7	9	8	

Atmospheric emissions from whole fuel cycle

Emissions depend in complex ways on:

- Fuel production systems: land use change, technologies, inputs, feedstocks
- Fuel utilisation systems in vehicles and stationary plant
  - internal/external combustion or fuel cells
  - emission control
- Stationary plant can reduce emission greatly with control technologies because less weight and space penalty, and economies of scale

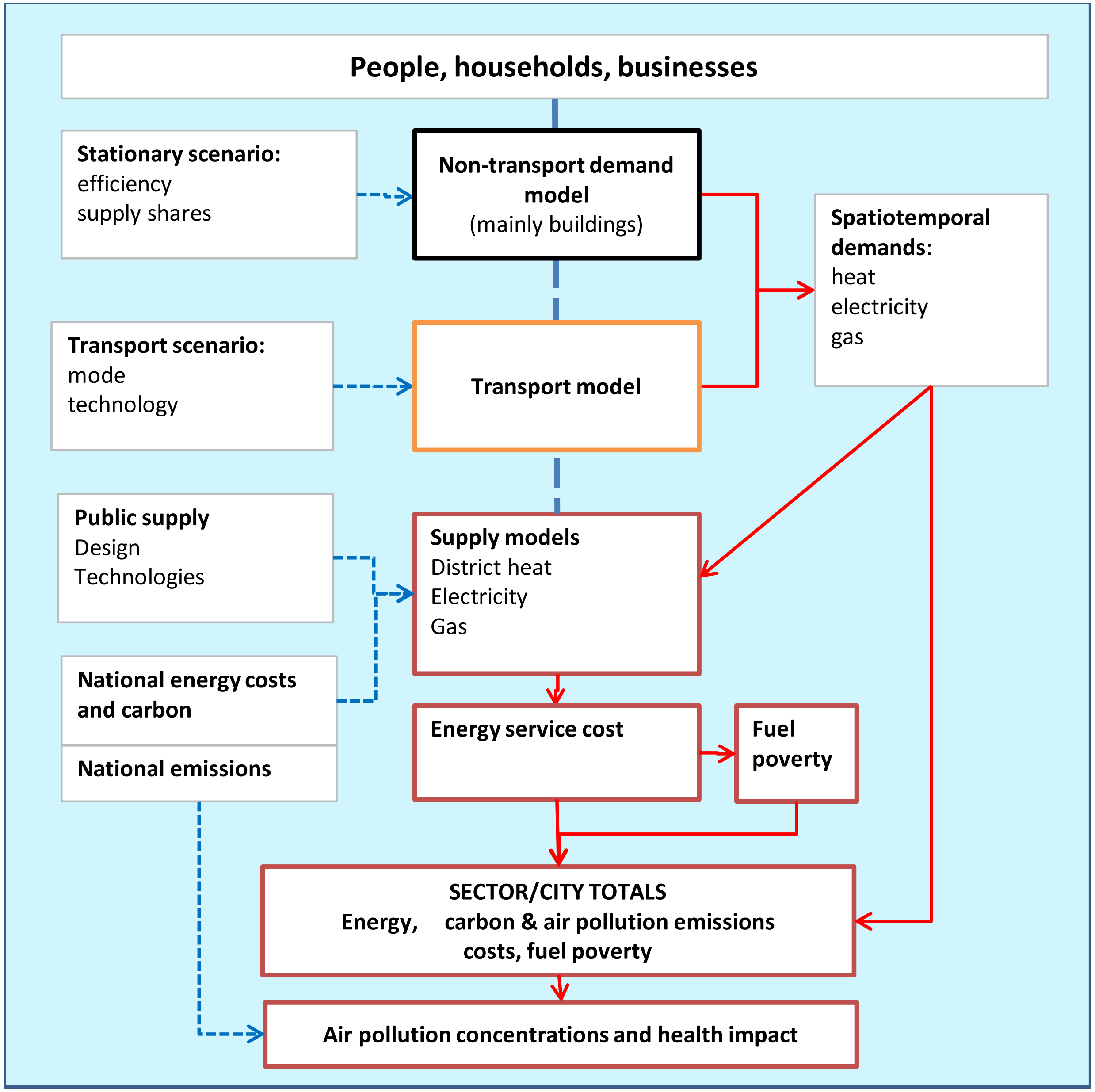
Lack of information about some existing fuel and technology combinations, but particularly new combinations.

TENTATIVE INDICATORS – relative to fossil oil

		GHG	**Air pollution**							
		CO2, N2O. Land use	Nitrogen dioxide		Particulate matter	Hydrocarbons	Carbon monoxide	Acetaldehyde	Ozone	Ammonia
		CO2	Primary	Thermal	PM	HC	CO		O3	NH3
Biofuels	Diesel	- 15-90%	?	0% ?	- x%	?		+%		
	Ethanol	- 15-90%		0% ?	- x%	?			+% ?	
Renewable	Ammonia	- 100%	- 100%	?	- 100%	- 100%	- 100%	- 100%	- 100%	+% ?
(Wind etc.)	Hydrogen	- 100%	- 100%	?	- 100%	- 100%	- 100%	- 100%	- 100%	- 100%

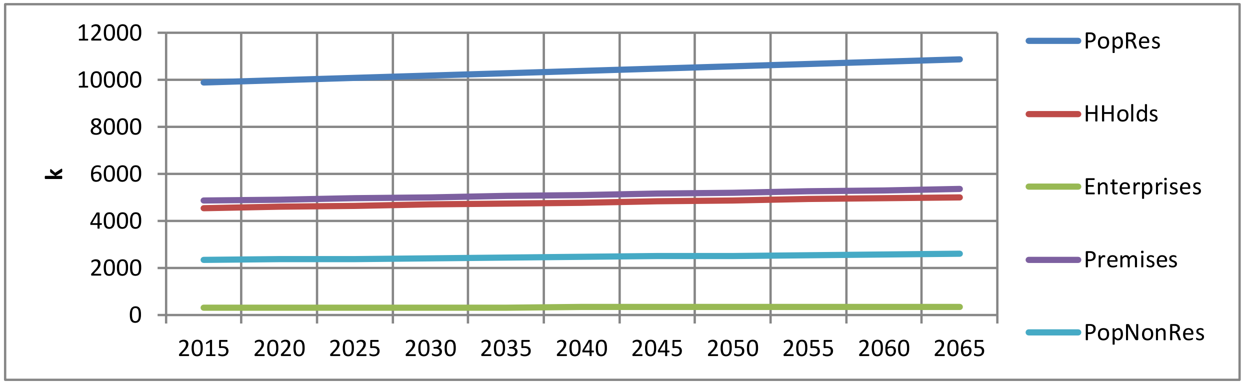
Partly based on: Air quality expert group, 2011, *Road transport biofuels: impact on UK air quality*

City model and data flow

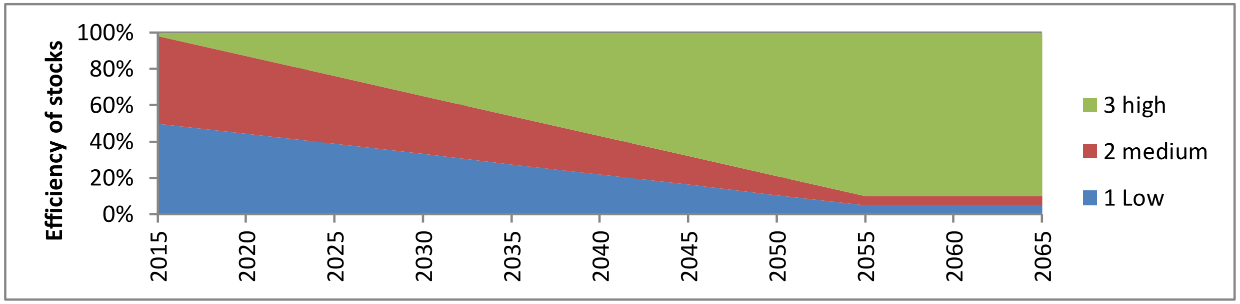


Scenario (London) – demand

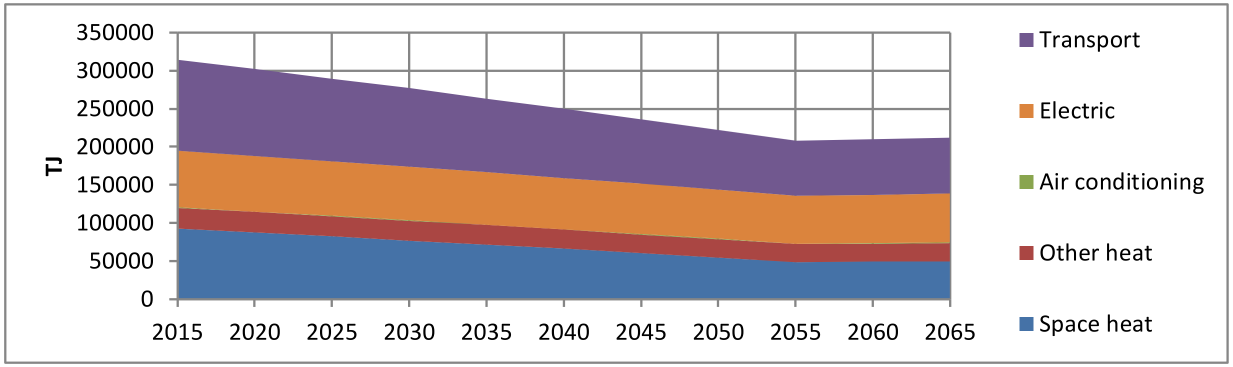
Drivers



Building efficiency

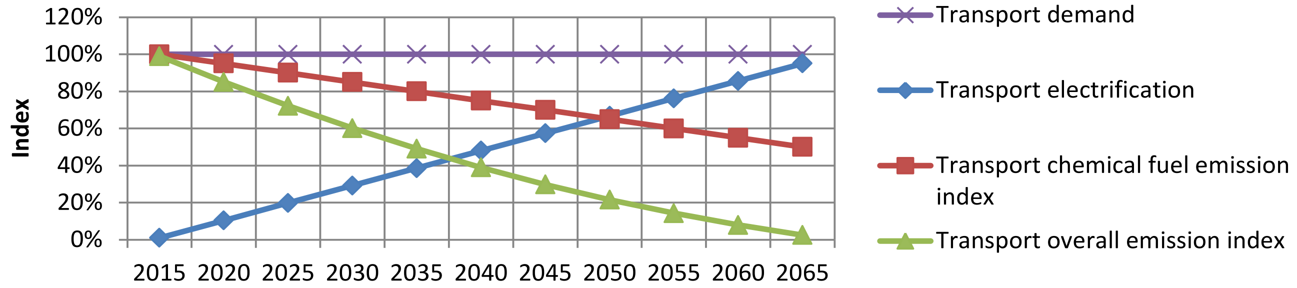


Services

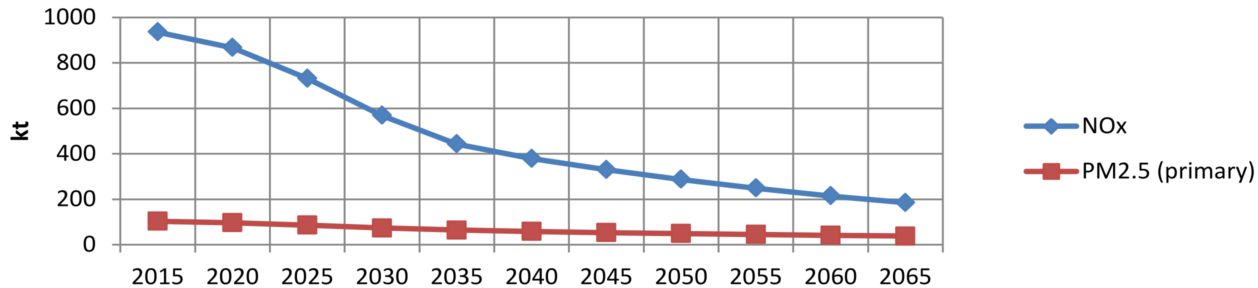


Air pollution projections - national

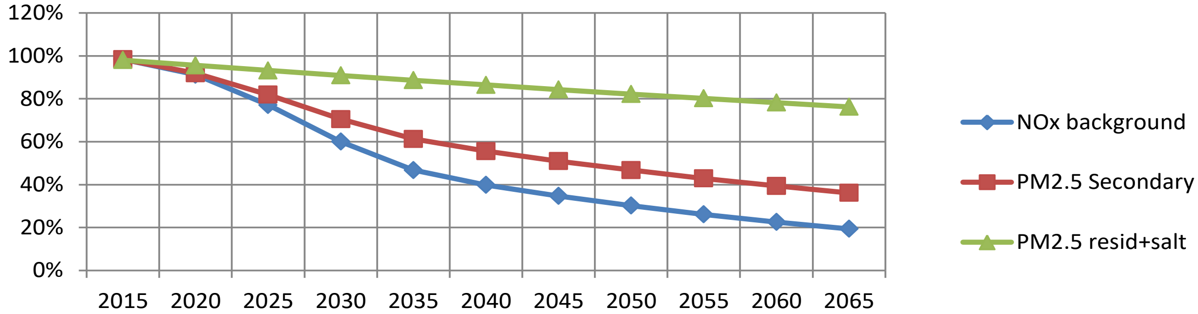
Transport



National primary emissions

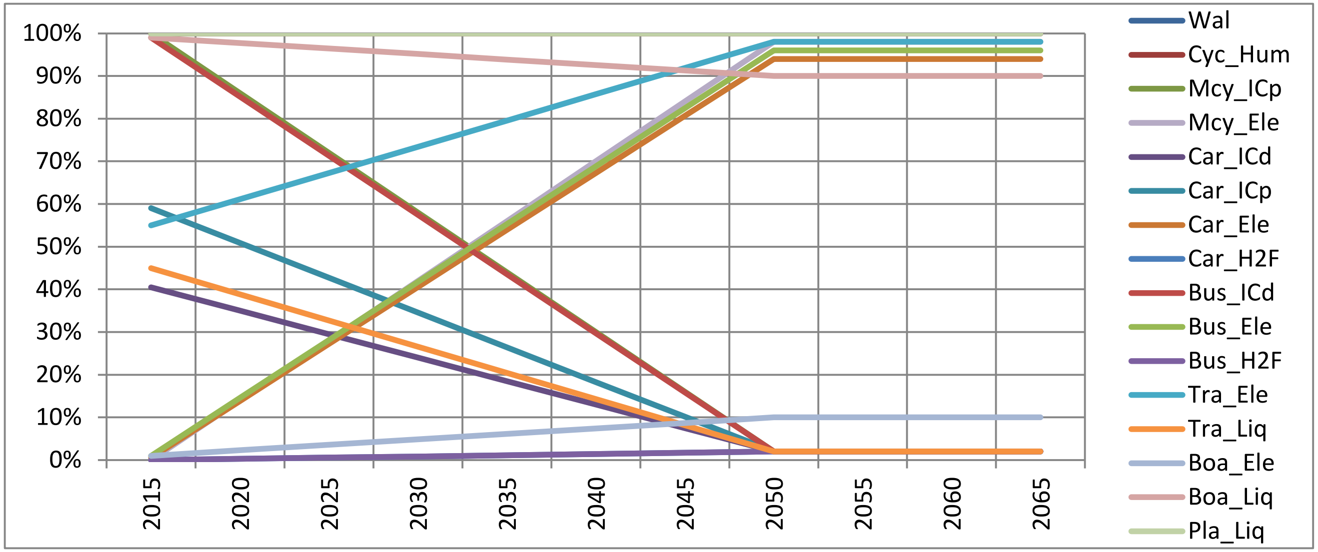


Background concentration indices

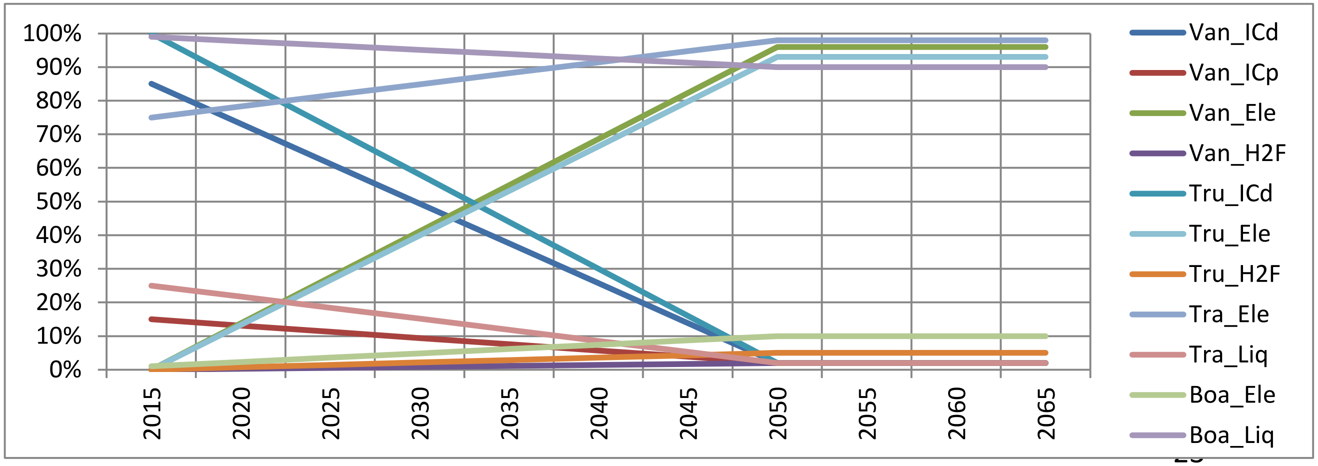


Scenario: transport technology share - shift to electricity

Passenger

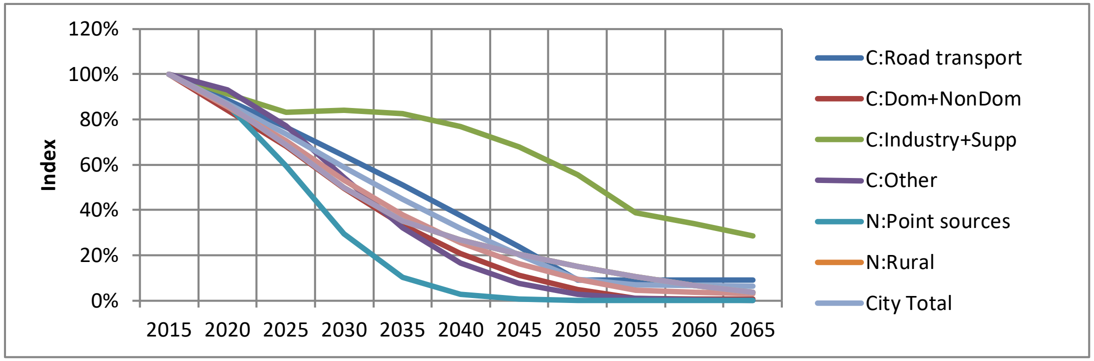


Freight

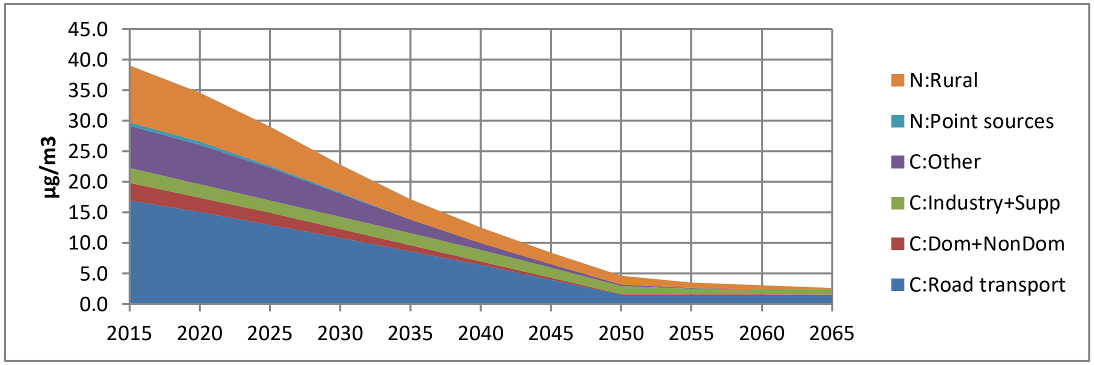


Air pollution emission and city concentration projections

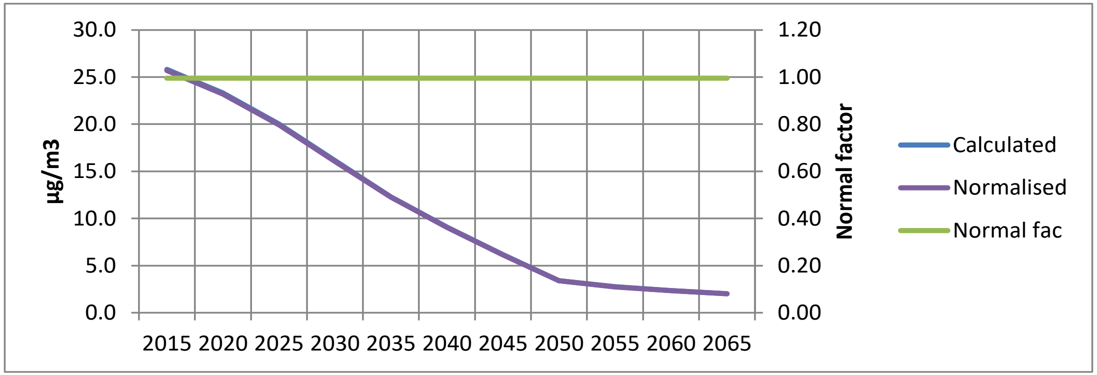
NOx emission indices



City NOx concentration



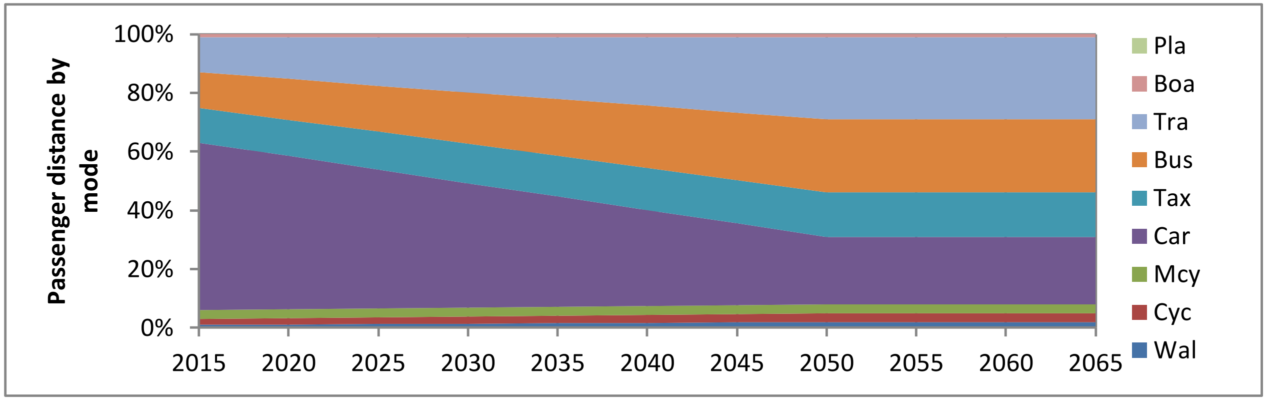
City NO2 calculated concentration



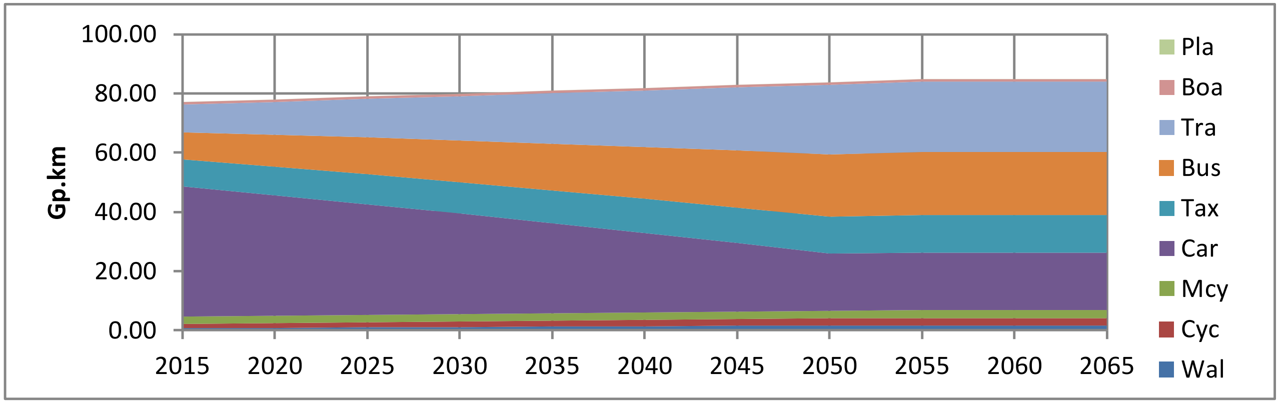
Scenario: transport passenger

Demand by mode

Shift from car to non-mechanised, bus, train

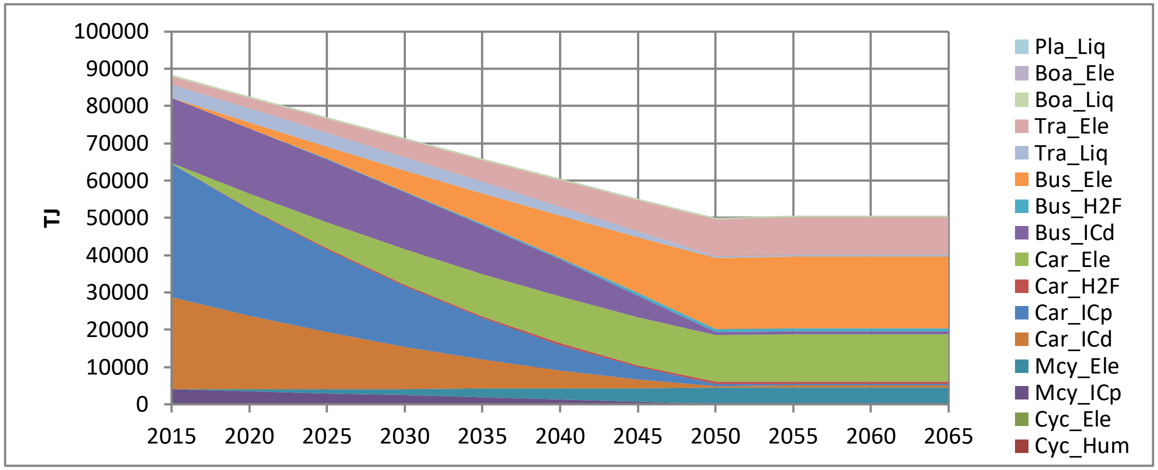


Passenger distance by mode

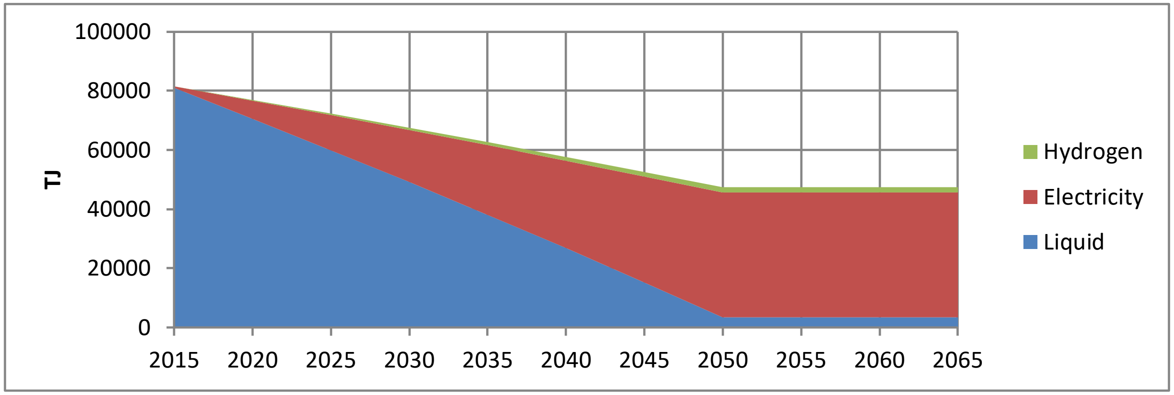


Scenario (London): transport energy

Passenger energy by technology



Energy for passenger and freight



Air pollution

Air pollution calculation

1. Collate base year concentrations by source for city

2. Project city and national emissions

3. Project concentrations using:
   a. changes in emissions from sources
   b. NOx oxidation
   c. Secondary PM formation

4. Calculate premature deaths and years of lost life

NOx to NO2

For base and future year:

1. Estimate city and national (and European?) NOx emissions (kt) from different sectors – transport, electricity etc.

2. Estimate fraction f(NO2) of city and national NOx from these sources that is emitted as nitrogen dioxide (NO2), with the rest being nitric oxide (NO)

3. Estimate oxidation of city and national NO to NO2 using oxidation equation with NO2 and ozone oxidants

4. Normalise calculated NO2 to Defra base year value.

5. Result is city and rural (or background) concentration indices; $Ic_{NO2(c)}$ and $Ic_{NO2(r)}$ (µg/m3)

Emission to concentration model

Multiply base year concentrations Cb for each source by the ratio of future emission/formation index (Icf) which is the calculated future year NO2 (primary and 'rural') and PM2.5 (primary and secondary) divided by the calculated base year index (Icb) to obtain future concentrations Cf.

For each source:

Cf = Cb Icf / Icb µg/m3

The proposed methods for calculating the NOx and PM2.5 indices are on the next 2 slides.

Secondary PM2.5

For base and future year:

1. Assume UK (and Europe) emissions of:
    - Primary PM2.5
    - PM2.5 precursors: nitrate, sulphate and ammonium

2. Estimate formation of secondary PM2.5 to obtain background concentration index for each city with a linear equation:

   $Ic_{PM2.5}$ = k1 NOx + k2 SO2 + *(k3 NH3 assumed constant)*

3. Add national primary and secondary PM2.5 to give PM2.5 (rural/background) concentration index for city; $Ic_{PM2.5(r)}$

Health model

The relative risk RR (a fraction) is the concentration response factor CRF raised to the power ((change in concentration dC)/10):

$$RR = CRF^{(dC/10)}$$

The attributable fraction AF due to air pollution is calculated:

$$AF = (RR-1)/RR$$

The premature deaths PD per year is the population over 30 yrs old Pop30 times the baseline mortality rate Mb times the attributable fraction AF:

$$PD = Pop30\ Mb\ AF$$

The years of life lost (years) YLL is the premature deaths PD times the years of life per premature death YLLd (assumed to be 12 years)

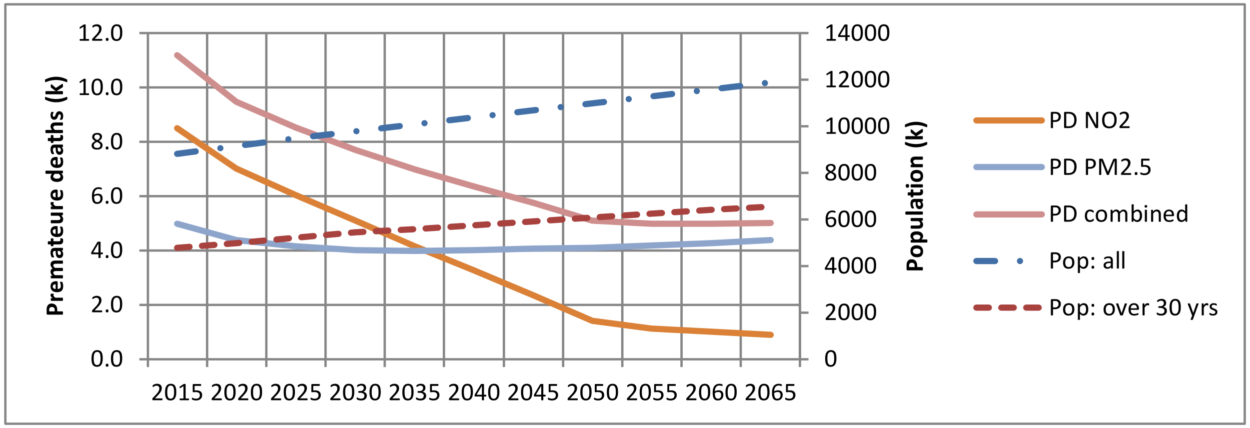
$$YLL = PD\ YLLd$$

Notes:

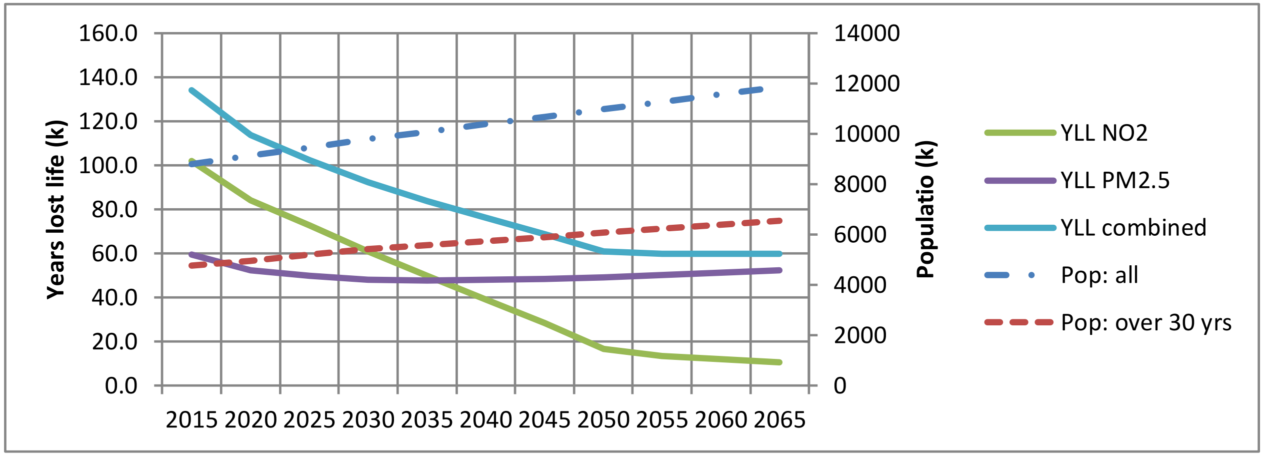
- It is conventionally assumed that the combined impact of several pollutants is less than the sum of the individual impacts.
- Currently natural particulate pollutants (dust, salt etc.) are assumed to have the same impacts as anthropogenic pollutants

Air pollution health impacts

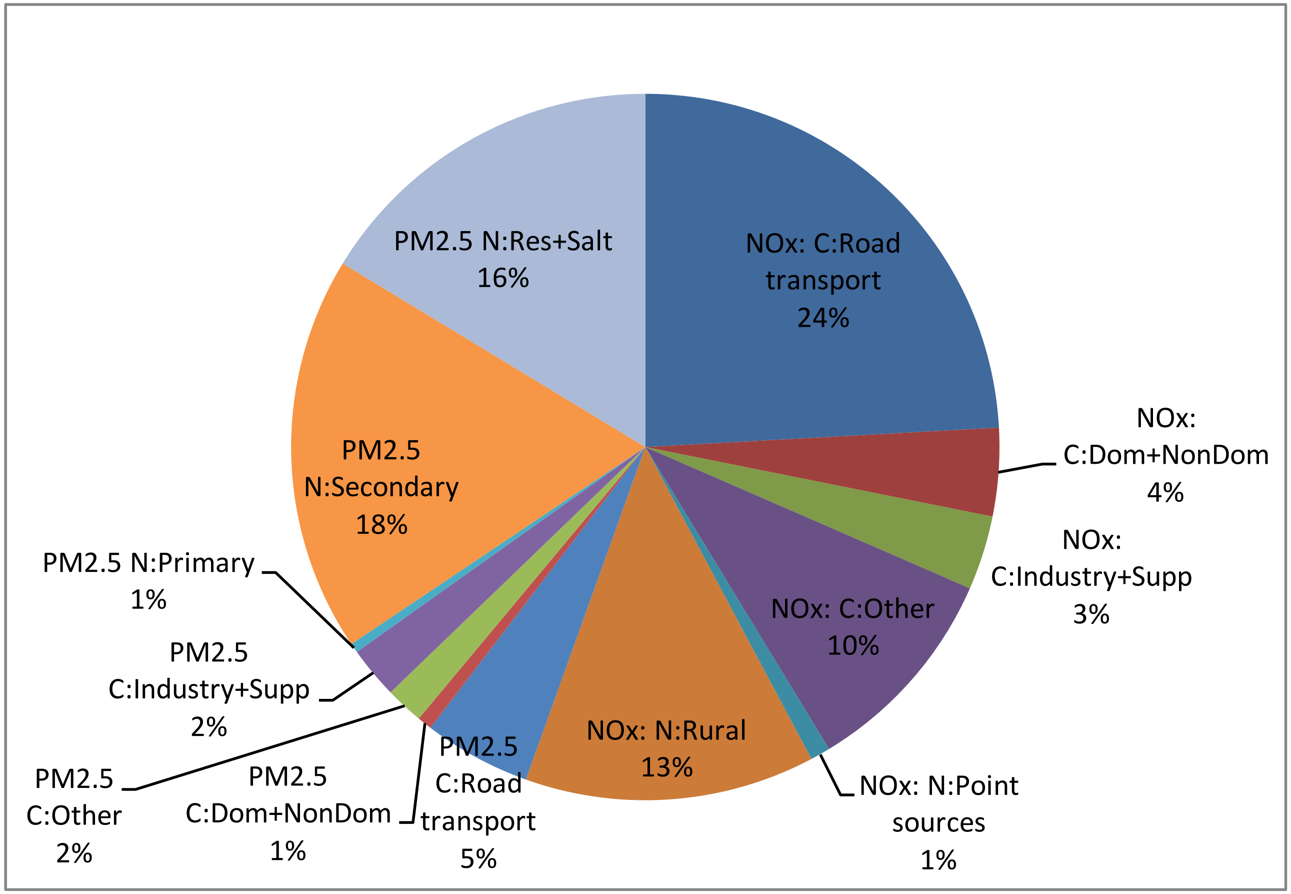
Premature deaths



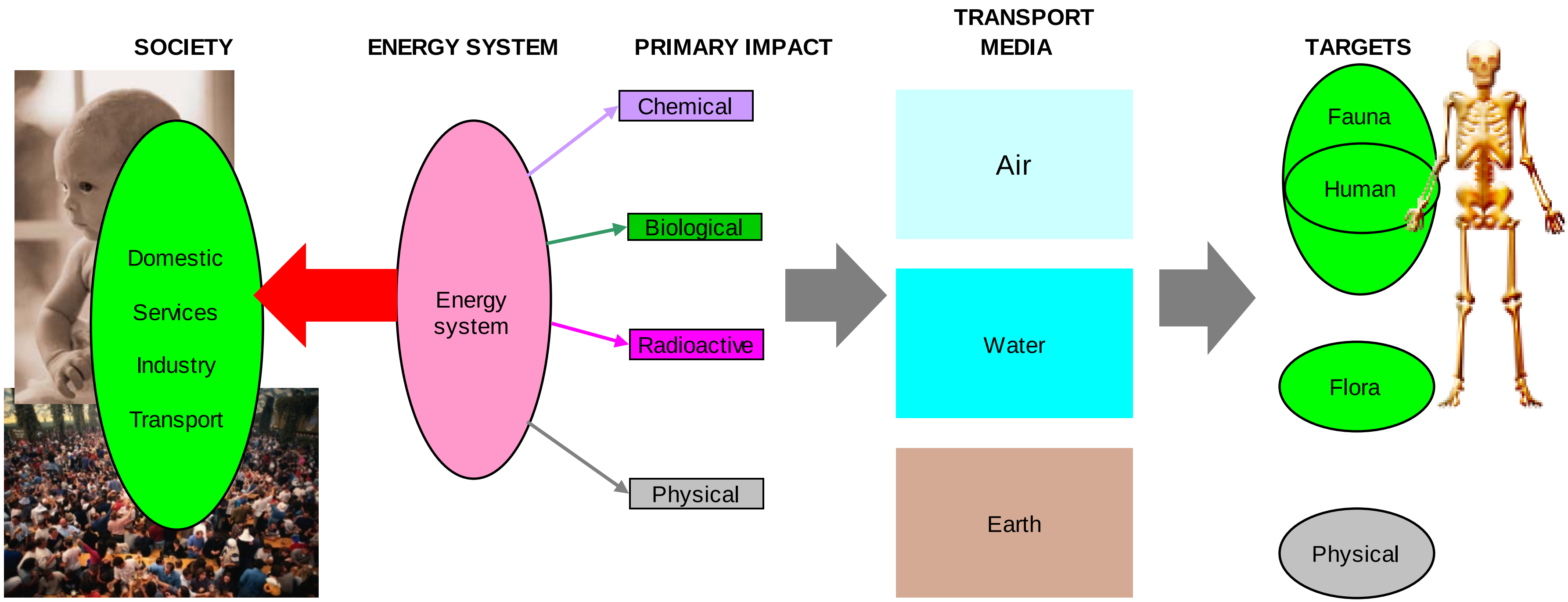
Years of lost life



Air pollution premature deaths



Introduction



Introduction

	Renewables									Nuclear	Fossil Carbon CCS
	Solar	Wind On	Wind Off	Hydro river	Hydro dam	Biowaste	Biocrop	Tidal dam	Wave Tidal flow		
Climate change mitigation	10	10	10	9	7	10	5	8	10	10	7
Air pollution	10	10	10	10	10	10	8	10		9	9
Ecosystem	9	9	9	4	3	9	3	3	9	1	8
Visual	7	2	8	4	1	9	5	3	10	5	2
Potential impact outside UK	10	10	10	10	10	10	10	10	10	0	5
Consumption global resources	10	10	10	10	10	10	5	10	10	5	7
International political impact	10	10	10	10	10	10	10	10	10	0	8
Political security	10	10	10	10	10	10	8	10	10	0	9
Transparency	10	10	10	10	8	10	7	10	10	0	5
Reversibility	10	10	10	5	3	10	5	1	10	0	0
Risk	10	10	10	8	5	10	5	3	10	0	2
Certainty costs and performance	10	10	10		6	10	7	4	3	0	2