Scenario analysis in the UK

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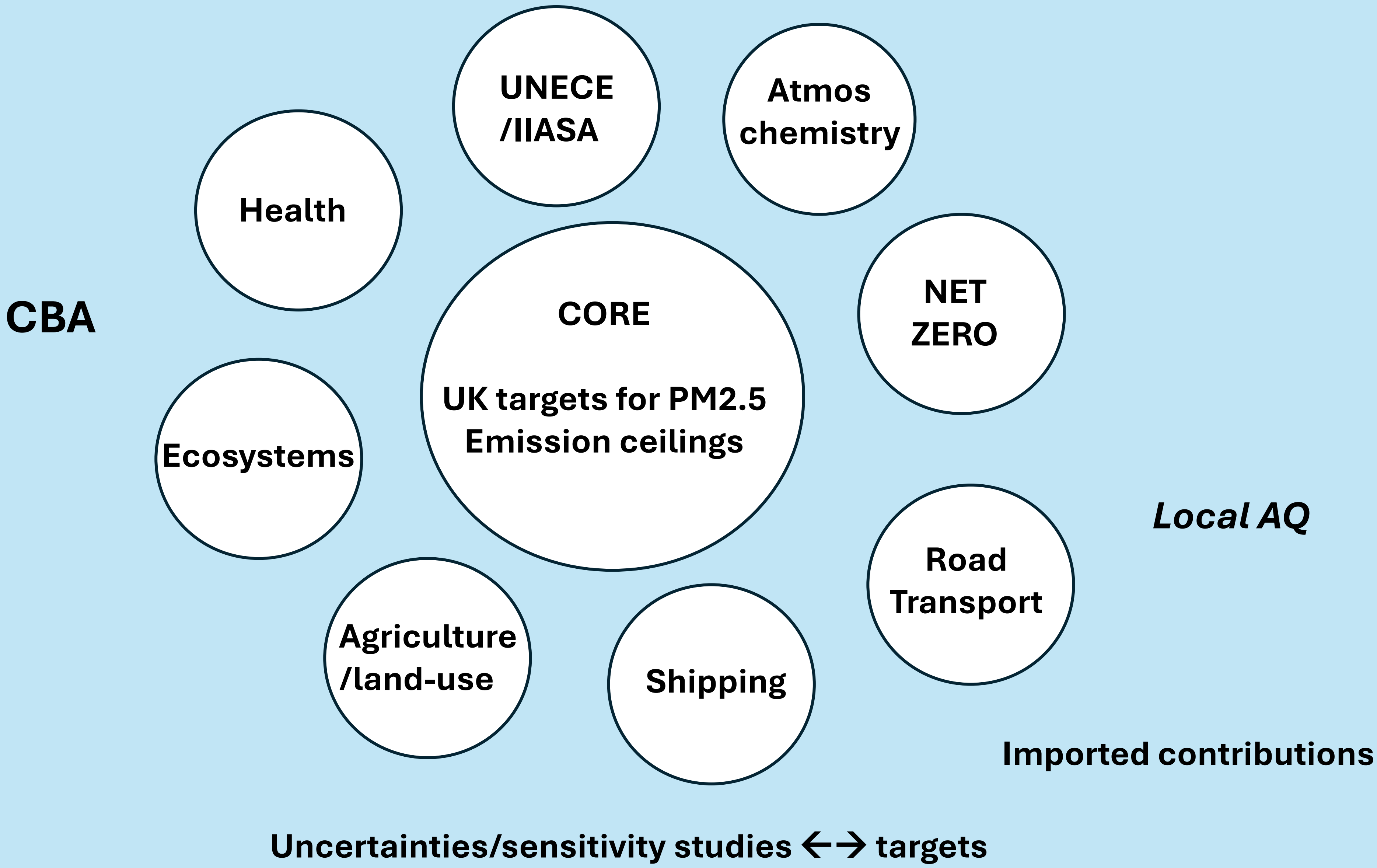
Core work UK: Applying the UK Integrated Assessment Model, UKIAM to modelling future air pollution across the UK to 2050
Applications: setting of and compliance with targets for $PM_{2.5}$. Attainment of emission ceilings

For $PM_{2.5}$ in England a population exposure reduction target, PERT, of 35% by 2040 relative to 2018
& an annual maximum concentration target, AMCT, of 10 $ug.m^{-3}$.

NB Compliance judged against measurements, and applies to total $PM_{2.5}$. (as well as primary PM and SIA, includes natural, SOA, and water which changes with SIA)

Many uncertainties-> how to explore and what are the priorities?


CBA
UNECE /IIASA
Atmos chemistry
Health
CORE
UK targets for PM2.5
Emission ceilings
NET ZERO
Ecosystems
Local AQ
Road Transport
Agriculture /land-use
Shipping
Imported contributions
Uncertainties/sensitivity studies ←→ targets

Uncertainties in modelling road transport emissions of NOx

GAINS: fuel (PRIMES as PJ) x emission/PJ

Guidebook (UKIAM & NAEI): COPERT speed-dependent g/km.
Evolving model versions: data from driving cycles
Greater resolution vehicle categories (e.g. Euro 6a to 6d diesel cars)
Cold starts, vehicle deterioration.

HBEFA: reflects local traffic conditions and congestion

Remote sensing-> speed dependent g/km

->differences in national NOx emissions between models and model versions ~ 10 to 20%. More for individual vehicle categories or urban areas

Uncertainties in scenarios: Example Net Zero energy projections

UKIAM linked to the TIMES model for energy projections to explore effects of different net zero scenarios on air pollution -> illustration for future scenarios to reach Net Zero with "zero", "likely" and " likely plus possible" use of hydrogen.

New technologies for hydrogen production and use for combustion-> challenge to map emissions and define emission factors. Defined 2 sets of EFs

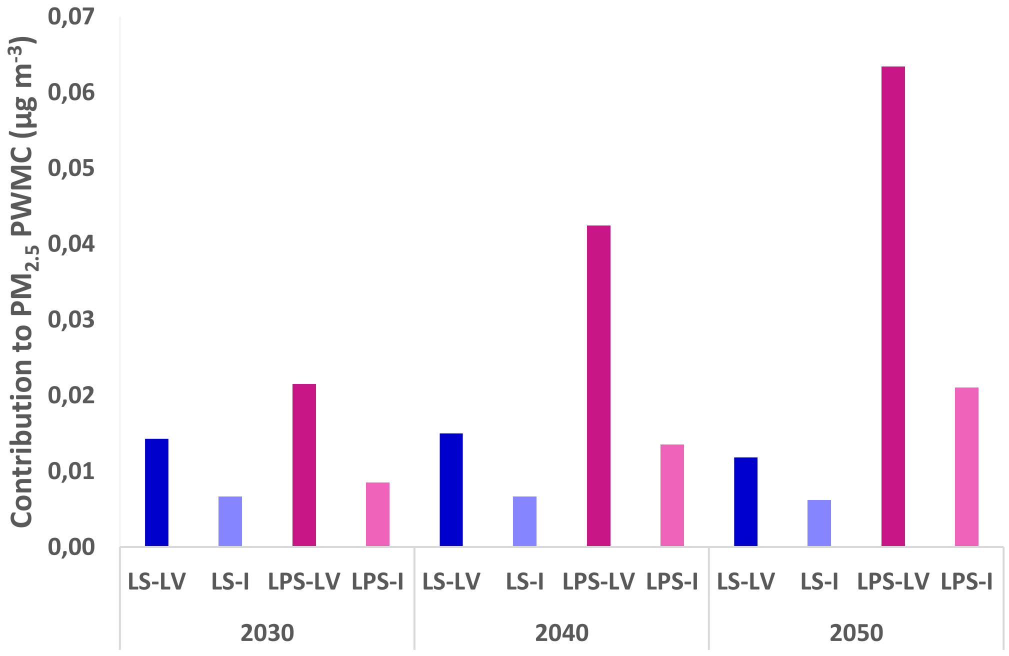
a) "Limit values" (potential regulatory) .
b) "Improved" reflecting potential improvements in technology.

Results show all Net Zero strategies give big improvements in air quality – $PM_{2.5}$ & NO_x.

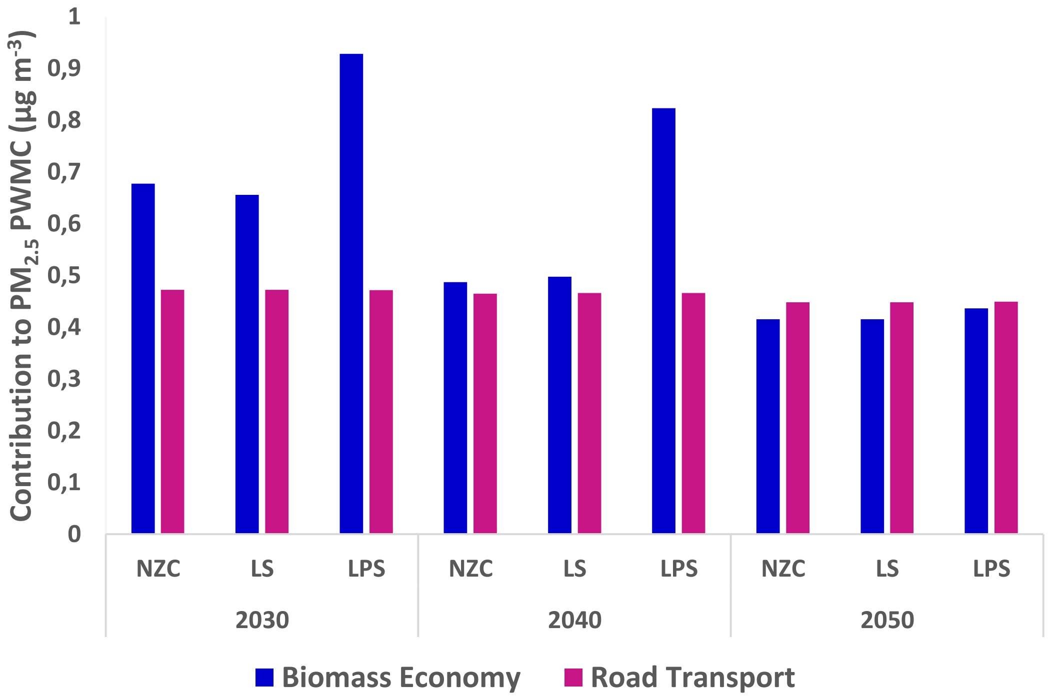
Contributions to $PM_{2.5}$ PWMC from different sources

Contributions from the hydrogen and biomass economies and road transport

- Hydrogen economy appears to contribute minimally to $PM_{2.5}$ PWMC by 2050 (0.06 µg m^{-3})
  - Difference in pathways using limit values to improved values up to around 0.04 µg m^{-3}

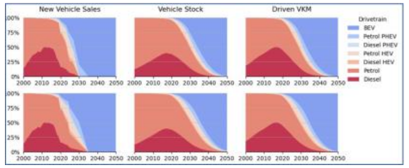


- Contributions from biomass economy and road transport contribute significantly more to $PM_{2.5}$ PWMC.

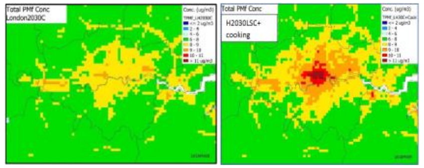


Assessing uncertainty in air pollution scenarios

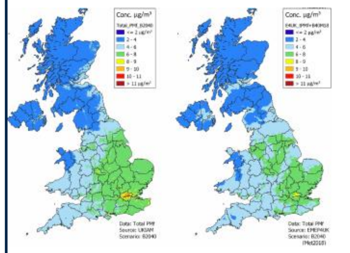
Alternative RT fleet projections



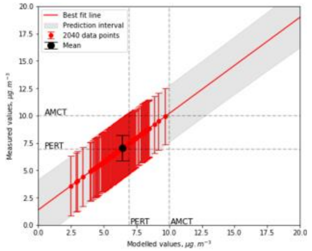
Sensitivity studies



Model intercomparison



Measurement vs modelled values

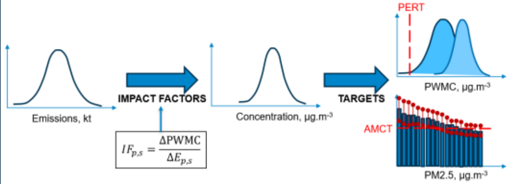


Communicating uncertainty using traffic light diagram

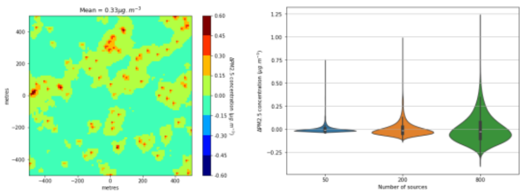
England					
ug/m3	B2018	Med2030	*less wood*	M2030LH	*less wood*
8	1902	213	*336*	166	*305*
9	1136	55	*113*	29	*93*
10	591	3	*19*	1	*12*
11	278	0	*2*	0	*1*
12	112	0	*0*	0	*0*

Our many different methods to assess individual/specific uncertainties in air pollution scenarios

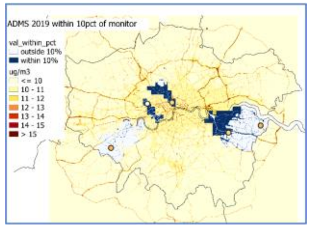
Projecting emission uncertainties



Assessing concentration variation within grid square



Representativeness of measurement values



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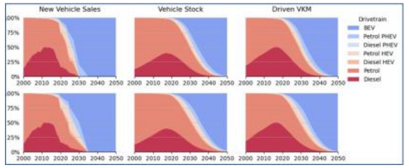
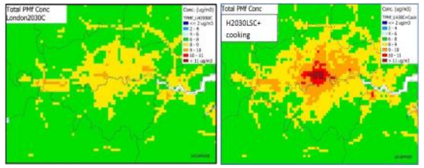


Sensitivity studies



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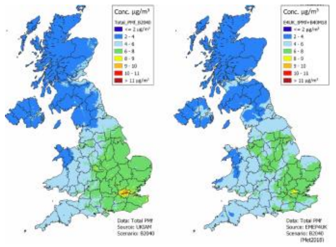

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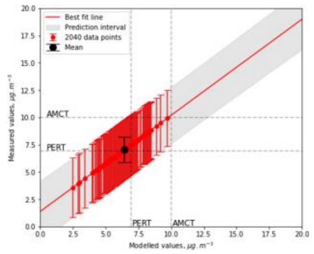

Can we perform a comprehensive uncertainty analysis?

- Which uncertainties are missing from our analysis?
- Which should be prioritised for further research/understanding?
- Can we improve transparency of model assumptions?

Communicating uncertainty using traffic light diagram

England ug/m3	B2018	Med2030	*less wood*	M2030LH	*less wood*
8	1902	213	*336*	166	*305*
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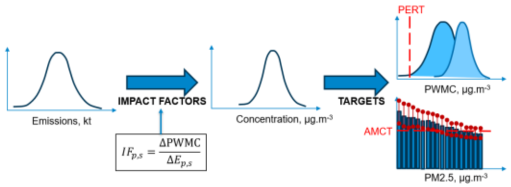
Projecting emission uncertainties



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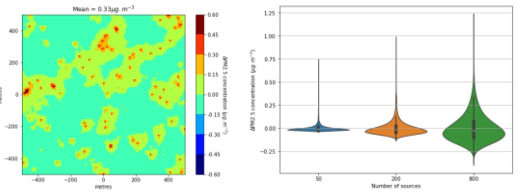

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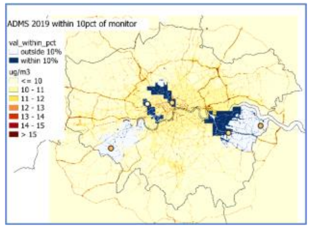
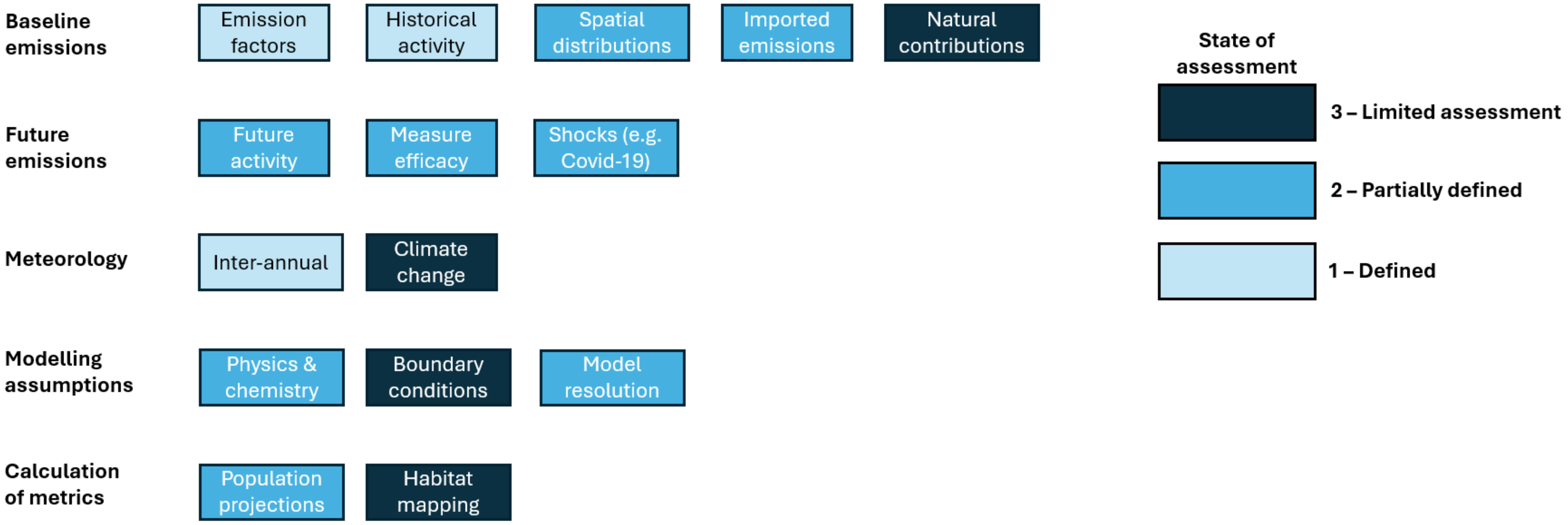


Identifying gaps and prioritising uncertainties

- Uncertainties exist throughout the modelling chain. Some have been considered to a greater extent than others.
- The diagram below illustrates the different sources of uncertainties which exist in our scenario modelling.
- We have assigned a “state of assessment” score from 1 (defined) to 3 (limited assessment).
- These are intended to be challenged by stakeholders, to encourage discussion regarding the degree to which we understand uncertainties in the system.

State of assessment of uncertainties in UKIAM projections of future air pollution impacts



Identifying gaps and prioritising uncertainties

- **Which uncertainties matter depend on the target being considered**, e.g. emission ceiling (NECD) vs Population Exposure Reduction Target (PERT).
- We assign a "vulnerability" score to our uncertainties. We consider vulnerability to be a combination of both the potential magnitude of the uncertainty and the likelihood that it will significantly affect the model outcomes.
- The vulnerability depends on the target being considered – some uncertainties are less or more important for certain targets, while some are not relevant at all.
- By considering the state of assessment alongside the "*vulnerability*" of a target to each uncertainty we can identify gaps in our analysis and uncertainties to prioritise for analysis. We calculate an overall "priority" score as:

Priority = State of assessment x Vulnerability

	State of assessment - A	Vulnerability – B		Overall score = A x B		
		NECD	PERT 2040	NECD	PERT 2040	Existing approaches
Baseline emissions						
Emission factors	1	3	3	3	3	NAEI uncertainties, sensitivity analysis
Historical activity	1	3	3	3	3	NAEI uncertainties, road transport, sensitivity analysis
Spatial distributions	2		3		6	Future agricultural ammonia, road transport
Imported emissions	2		3		6	GAINS scenarios, Int shipping, sensitivity analysis
Natural + SOA	3		3		9	Wildfires, model comparisons
Future emissions						
Future activity	2	3	3	6	6	Road transport, energy projections, new sources, sensitivity analysis
Measure efficacy	2	3	3	6	6	Agriculture, literature
Shocks (e.g. Covid-19)	2		2		4	Covid-19
Meteorology						
Inter-annual variation	1		3		3	Historical variability
Climate change	3		3		9	
Modelling assumptions						
Physics & chemistry	2		2		4	Model intercomparisons
Boundary conditions	3		1		3	Model intercomparisons
Model resolution	2		1		2	Wood burning, road transport, literature
Calculation of metrics						
Population projections	2		2		4	Sensitivity analyses

Colour code

3 Limited assessment
2 Partially defined
1 Defined

3 High vulnerability
2 Medium vulnerability
1 Low vulnerability

9 High priority
1 Low priority

Top sources for achieving the national emission ceiling target

- For our High 2040 scenario we can look at **which sources contribute the most to the national emission ceilings** for each air pollutant. The table below lists the top 5 sources for each pollutant.

Top 5 emission sources in 2040

	NH3 (kT)		SO2 (kT)		NOx (kT)		PM2.5 (kT)	
	Dairy	48.1	Refineries Combustion	21.0	Other Ind Comb	55.5	Domestic Comb Wood	8.8
	Beef	38.9	Bricks	7.7	Off-shore Oil & Gas	43.1	Other Ind Comb	5.9
	Fertiliser	36.0	Ships National NonECA	4.3	Fertiliser	24.7	Ships Int ECA	4.6
	Anaerobic Digestion	29.9	Cement	2.9	Ships National NonECA	22.4	Other SNAP04	3.6
	Other Poultry	24.8	Sinter	2.8	Small Power Other	20.7	Natural SNAP11	3.1
Proportion of UK total:	73%		80%		72%		56%	

- We can also look at **which sources contribute the most to the uncertainty** in emission estimates for the High 2040 scenario. Note that these uncertainty values are based on UK inventory estimates of uncertainty in ***historic*** emissions and don't include uncertainty in the projection to 2040.

- *These values are intended to guide efforts to reduce uncertainty rather than as accurate estimates.*

Top 5 emission uncertainties in 2040

	NH3 (kT)		SO2 (kT)		NOx (kT)		PM2.5 (kT)	
	Beef	16.3	Refineries Combustion	3.9	Fertiliser	9.3	Domestic Comb Wood	6.8
	Fertiliser	13.5	Domestic Comb Wood	1.6	Domestic Comb Wood	6.4	Other Ind Comb	4.5
	Dairy	9.7	Bricks	0.8	**Airports Takeoff Land**	4.5	Other SNAP04	2.7
	Other Poultry	9.5	Domestic Comb Coal	0.7	Industrial off-road transport	4.5	Natural SNAP11	2.3
	Anaerobic Digestion	6.0	**Airports Takeoff Land**	0.6	Other Ind Comb	4.2	Road Transport HGV	1.5
Proportion of total uncertainty variance*:	69-95%		74-98%		63-98%		80-99%	

*Depends on how uncertainty is estimated

- In the UK we are likely to reach our SO_2, NO_x and $PM_{2.5}$ emission ceilings. The NH_3 target is a bigger challenge, therefore **the agricultural sources listed in the NH_3 column should be prioritised for any additional analysis** when assessing the likelihood of achieving the national ceiling targets.

- The top **5 emission sources contribute the majority of the emissions** remaining in 2040, while the **top 5 emission uncertainties contribute the (vast) majority of the remaining uncertainty**. Note that the sources in these two lists vary.

Top sources for achieving the Population Exposure Reduction Target (PERT)

- Using our UKIAM model we can look at **which emission reductions contribute the most to reductions in the Population Weighted Mean Exposure (PWMC)** to $PM_{2.5}$ concentrations relative to 2018. We now list the top 5 sources on the right-hand side in terms of reduction in PWMC.

Top 5 emission sources in 2040

NH3 (kT)		SO2 (kT)		NOx (kT)		PM2.5 (kT)		Reduction in PWMC ($\mu g.m^{-3}$)	
Dairy	48.1	Refineries Combustion	21.0	Other Ind Comb	55.5	Domestic Comb Wood	8.8	**Road Transport Diesel Cars**	0.44
Beef	38.9	Bricks	7.7	Off-shore Oil & Gas	43.1	Other Ind Comb	5.9	Other Ind Comb	0.23
Fertiliser	36.0	Ships National NonECA	4.3	Fertiliser	24.7	Ships Int ECA	4.6	**Domestic Comb Wood**	0.21
Anaerobic Digestion	29.9	Cement	2.9	Ships National NonECA	22.4	Other SNAP04	3.6	Industrial off-road transport	0.19
Other Poultry	24.8	Sinter	2.8	Small Power Other	20.7	Natural SNAP11	3.1	Domestic Combustion Coal	0.16
Proportion of UK total reduction from measures:	73%		80%		72%		56%		60%

- We can also project the inventory uncertainty estimates to get the top 5 sources that **contribute to the uncertainty in the expected PWMC reduction**. While diesel cars delivers the greatest reduction in PWMC, it is 5th in the list in terms of uncertainty, with domestic wood burning top.

Top 5 emission uncertainties in 2040

NH3 (kT)		SO2 (kT)		NOx (kT)		PM2.5 (kT)		Reduction in PWMC ($\mu g.m^{-3}$)	
Beef	16.3	Refineries Combustion	3.9	Fertiliser	9.3	Domestic Comb Wood	6.8	**Domestic Comb Wood**	0.17
Fertiliser	13.5	Domestic Comb Wood	1.6	Domestic Comb Wood	6.4	Other Ind Comb	4.5	Other Ind Comb	0.09
Dairy	9.7	Bricks	0.8	Airports Takeoff Land	4.5	Other SNAP04	2.7	Industrial off-road transport	0.05
Other Poultry	9.5	Domestic Comb Coal	0.7	Industrial off-road transport	4.5	Natural SNAP11	2.3	Domestic Comb Coal	0.04
Anaerobic Digestion	6.0	Airports Takeoff Land	0.6	Other Ind Comb	4.2	Road Transport HGV	1.5	**Road Transport Diesel Cars**	0.04
Proportion of total uncertainty variance*:	69-95%		74-98%		63-98%		80-99%		65-93%

*Depends on how uncertainty is estimated

- When assessing the likelihood of achieving the UK's PERT target the sources listed in the right-hand column should be prioritised for further analysis – **domestic wood burning, other industrial combustion, industrial off-road transport, domestic coal burning and diesel cars.**
- The top **5 PWMC reduction sources contribute the majority of the total scenario reduction**, while the **top 5 PWMC reduction uncertainties contribute the (vast) majority of the uncertainty in this reduction**.

Summary

- Uncertainties come in many forms and exist throughout the modelling system. We have many different methods to assess these individual uncertainties, providing essential context for scenario interpretation.
- We give two examples of specific uncertainty analysis undertaken in the UK, we showed that:
    - There is significant variation between different model estimates of road transport emissions.
    - The implications of different Net Zero pathways is a key uncertainty. Our analysis suggests that the hydrogen economy is unlikely to contribute significantly to population exposure, however the biomass economy and road transport are expected to be significant sources.
- While these analyses are essential, they don't provide a comprehensive analysis of uncertainty across the system.
- We are working towards a **framework which allows gaps to be identified and uncertainties to be prioritised** for further analysis, **pursuing a holistic uncertainty analysis** and **improving transparency in modelling assumptions**. Our conclusions so far include:
    - Which uncertainty is of most concern **depends on the target being considered.**
    - More broadly it **depends on the stakeholder and their priorities.** We are working with UK stakeholders towards a mapping exercise to identify the uncertainties of concern to them.
    - We aim to **collaborate more closely with other teams along the modelling chain – including international partners –** in addition to policymakers working towards:
        - More **consistency in uncertainty assessment**
        - More **open sharing of data**
        - **Identifying gaps in analysis and the uncertainties of most concern** at different stages of the modelling

Thanks for listening.
Any questions?