Cost-benefit analysis of the scenarios supporting the Gothenburg Protocol revision

Presentation of draft results,

TFIAM Work Plan Item 1.1.46,

Stefan Åström, co-chair TFIAM,

Jesper Bak, chair WGE

CBA supporting the Gothenburg Protocol revision

- Funded by the Nordic Council of Ministers – Air & Climate unit
- Project participants
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  - Aarhus University: Jesper Bak,
  - EMRC: Mike Holland,
  - Menon Economics Research: Henrik Lindhjem, Ståle Navrud

Outline

- Why CBA?
- Method,
- Data,
- Current results,
- Biodiversity approach
- Continued developments,
    - including integrating results of other task forces,

Why CBA?

- A cost-effectiveness analysis identifies the cheapest ”out-of-pocket” expenses of reducing emissions,
- A cost-benefit analysis complements such cost estimates with estimations of the benefits of emission reductions,
- CBA allows for comparison of costs with improvements in human health and environmental integrity with a common metric (€),
- Using the money metric facilitates communication between environmental decision makers and decision makers at finance ministries etc.
- Many countries mandate the production of a ’socio-economic impact assessment’ prior to decisions related to environmental law,

Why CBA – earlier European experiences

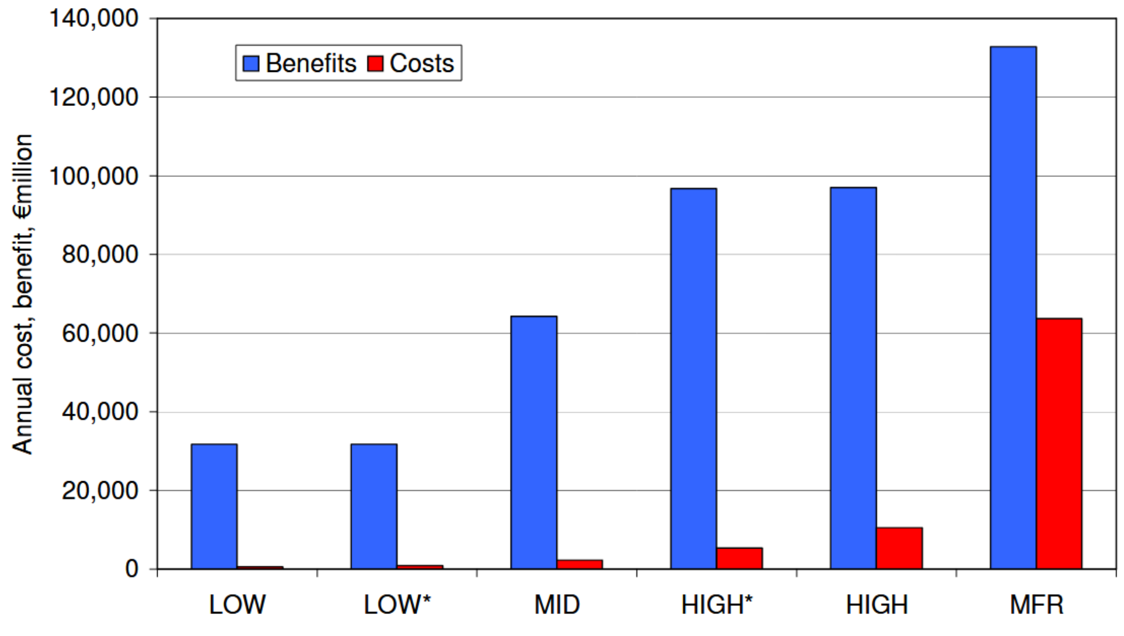


Figure (i) Comparison of health benefits and costs relative to the baseline scenario. Conservative valuation assumptions.

Holland, M., et al., (2011). *Cost Benefit Analysis for the Revision of the National Emissions Ceilings Directive: Policy Options for revisions to the Gothenburg Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution*.

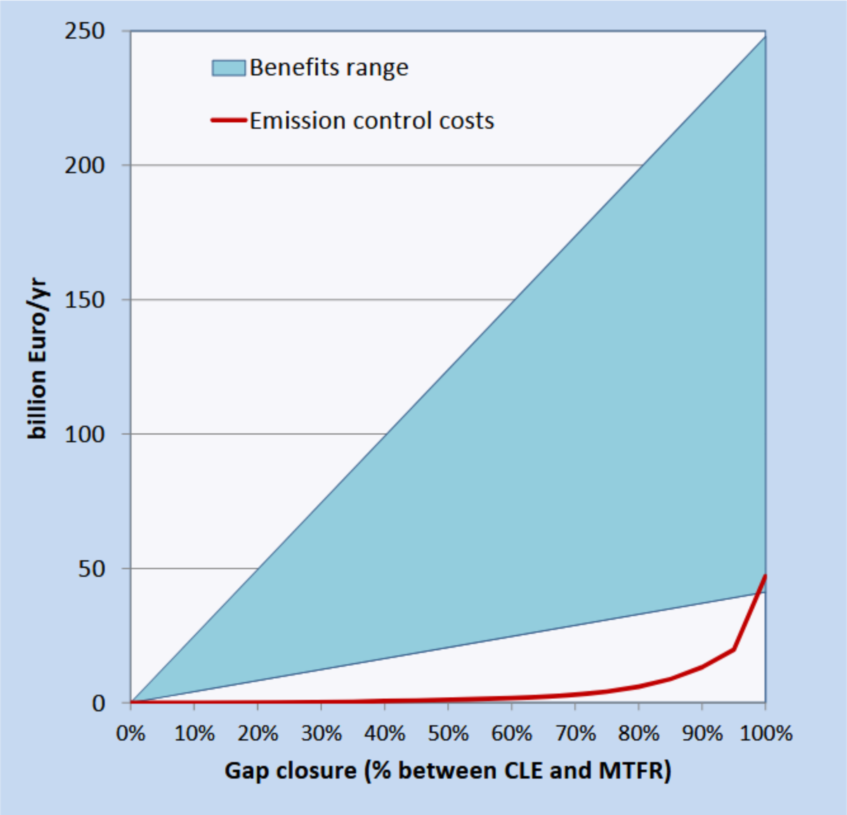


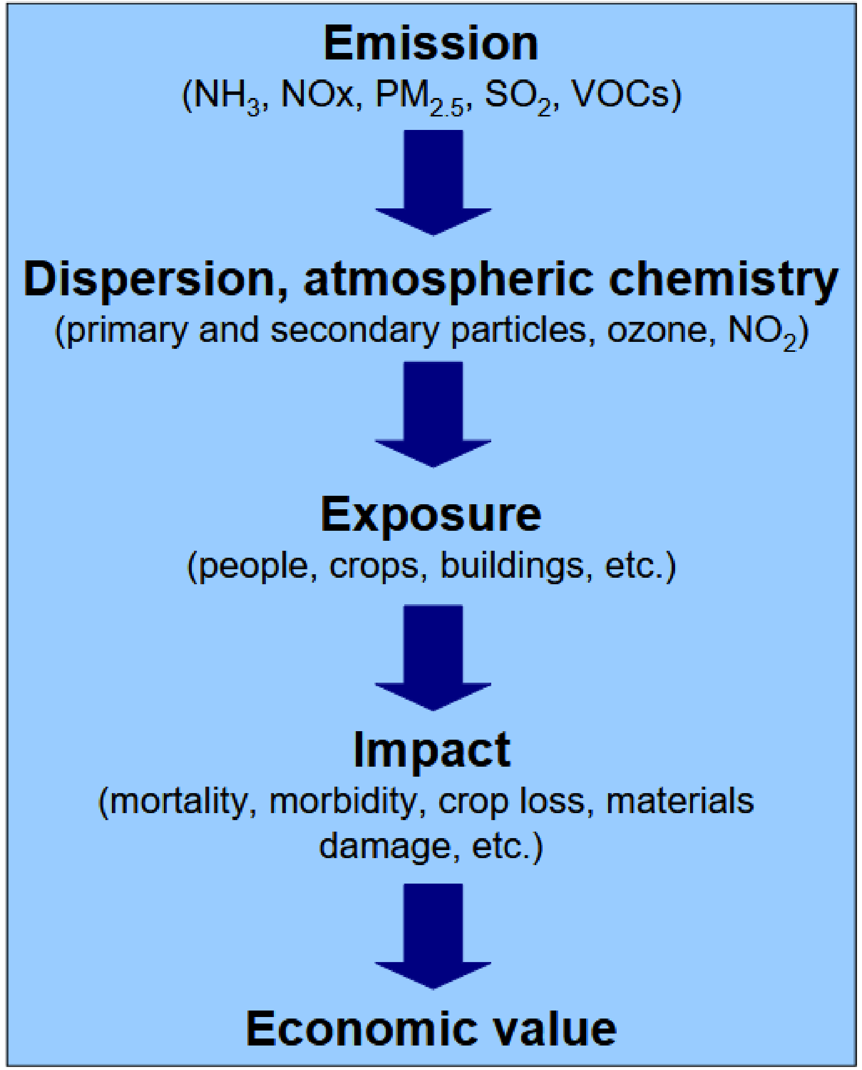
Figure 4.1: Total emission control costs and their health benefits in 2025

Amann, M., et al.. (2014). *The Final Policy Scenarios of the EU Clean Air Policy Package, TSAP report #11*.

Method

- Legacy deviation: Annual costs and benefits at target year,
  - Standard is ’Net Present Value’ of all current and future costs and benefits
- Impact pathway approach,
- Soft coupling of GAINS model with CBA model,
- CBA model in python code, will be made available online,
- CBA model set up to facilitate later recalculations,
- Considers reported uncertainty ranges when available,
- Calculates Benefit / Cost ratio, value over 1 is considered ’socio-economic efficient’,
- Presents benefits per ’benefit type’,

Impact pathway approach – General approach



Impact pathway approach – specific per benefit

Step	PM health	*O3 health**	Climate	Biodiv.*	Fertilisation	Crops
Emissions		*GAINS*	GAINS	GAINS		
Dispersion		*MSC-WEST*		GAINS (MSC-WEST)		
Exposure	GAINS	*MSC-WEST*		GAINS / CCE		GAINS
Impact	CBA	*GAINS?*	CBA	GAINS / CCE	GAINS	ICP Veg/ GAINS
Value	CBA	*CBA*	CBA	CBA	CBA	CBA

**IPA not fully implemented as of today*

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Data – overview of current sources

- TFIAM web page (emissions & emission control costs)
  - https://iiasa.ac.at/policy/applications/task-force-on-integrated-assessment-modelling-tfiam-under-lrtap-convention
- GAINS Explorer (health and ecosystem exposure)
  - https://gains.iiasa.ac.at/gains/GPV/index.login?logout=1
- VALESOR online valuation tool (impact & health economic values)
  - https://tool.valesor.eu/
- Nordic SLCF studies (climate impact & climate economic values)
  - https://www.norden.org/en/publication/damage-costs-nordic-emissions-short-lived-climate-pollutants-and-co2
- UN population Division Data portal (health impact).
  - https://population.un.org/dataportal/home?df=c3d066e3-6029-4ada-af60-5de93ccf8603
  - Sometimes using VALESOR adaptations of UN data,
- UKCEH ICP Vegetation (crops)
- Brink, C. et al., 2011 'Costs and benefits of nitrogen in the environment', i M.A. Sutton et al. (red.), *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives* (Biodiv economic values – forests)
- Hasler, B. m.fl., 2012 *Omkostninger ved hensigtsmæssig drift og pleje af arealer med naturplejebehov indenfor Natura 2000 og Naturbeskyttelseslovens §3*, Teknisk rapport nr. 12 (Biodiv economic values - Semi natural)

Data - morbidities

Pollutant	Core/non-core	Health endpoint	Exposure window	Age range	CRF	Applicable exposure range (µg/m3)	CRF_type	Source
PM2.5	Core	Asthma, children	Long-term	0-18	1.34 (95%CI: 1.1; 1.63)	5-38	RR	Khreis et al, 2017
	Core	COPD	Long-term	30+	1.18 (95%CI: 1.3; 1.23)	5-26	RR	Park et al, 2021
	Core	IHD events	Long-term	30+	1.13 (95%CI: 1.05; 1.22)	5-65	RR	Forastiere et al 2024
	Core	Stroke	Long-term	30+	1.16 (95%CI: 1.12; 1.2)	5-36	RR	Forastiere et al 2024
	Non-core	Dementia	Long-term	60+	1.17 (95%CI: 1.04; 1.25)	5-35	RR	Best Rogowski et al 2025
	Non-core	Diabetes	Long-term	30+	1.1 (95%CI: 1.03; 1.18)	5-79	RR	Forastiere et al 2024
	Core	Lung cancer	Long-term	30+	1.16 (95%CI: 1.1; 1.23)	5-44	RR	Yu et al, 2021
	Core	Cardiovascular hospital admissions	Short-term	All	1.0091 (95%CI: 1.0017; 1.0166)	5-25	RR	Héroux et al., 2015

Current CBA version = all PM2.5 exposure changes has health benefits

Current CBA version = core helth endpoints included

Current CBA version = only PM2.5 health effects included

Table taken from guidance document at: https://tool.valesor.eu/

Data - mortality

Pollutant	Core/non-core	Health endpoint	Exposure window	Age range	CRF	Applicable exposure range (μg/m3)	CRF type	Source
PM2.5	Core	Death	Long-term	30+	1.095 (95%CI: 1.064; 1.127)	5-70	RR	Orellano et al, 2024
	Core	Death	Short-term	All	1.0068 (95%CI: 1.0059; 1.0077)	5-100	RR	Liu et al, 2019

Current CBA version = all PM2.5 exposure changes has health benefits

Current CBA version = core helth endpoints included

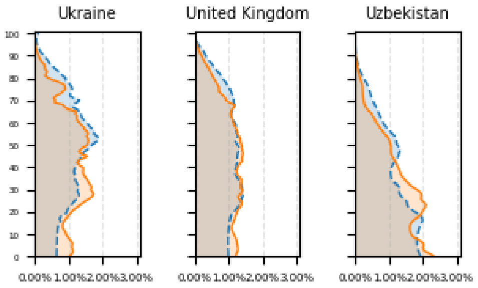
Current CBA version = only PM2.5 health effects included

OECD YOLL Pan-European = 97,500 €/YOLL

Table taken from guidance document at: https://tool.valesor.eu/

Population Demographics

- Age distribution [%]
  - Y-axis = Age,
  - X-axis = % of total population
- 2015 (orange) vs 2040 (blue)



Data - climate change (impact and values)

CH_4 equivalents			
	GTP20		
	5^{th} perc.	Mid	95^{th} perc.
PM-other	-0.829[a]	-0.866[a]	-1.00[a]
BC	7.67[b]	7.91[b]	7.97[b]
OC	-0.829[b]	-0.866[b]	-1.00[b]
NMVOC	-0.0737[c]	0.142[c]	0.146[c]
CH_4	1[a,c]	1[c]	1[a,c]
NO_x	-0.253[b]	-0.264[b]	-0.305[b]
SO_2	-0.641[b]	-0.642[b]	-0.646[b]
NH_3	0.553[a,e]	-0.283[d]	-0.507[a,e]

Current CBA version = Values from IPCC 5th AR
Newer consistent data should be possible to find?

Discount rate	Comparator	Scenario year	Damage cost (Euro per metric tonne emission)
2.5%	SCM	2020	1139
2.5%	SCM	2030	1664
2.5%	SCM	2040	2365
2.5%	SCM	2050	3066
2.0%	SCM	2020	1402
2.0%	SCM	2030	2102
2.0%	SCM	2040	2891
2.0%	SCM	2050	3679
1.5%	SCM	2020	2015
1.5%	SCM	2030	2803
1.5%	SCM	2040	3679
1.5%	SCM	2050	4643

Current CBA version = 2% discount rate,
Values from US EPA 2023

Data – first draft on biodiversity

- GAINS Exceedance scenariodata used to calculate
  - Exceeding N deposition as kg over forest areas, and
  - Area exceed in 1000 km2

Eutrophication: Exceedance of Critical Loads (all ecosystems)													
Scenario: Base_v6b													
Region:													
Year: 2040													
Unit: 1000 km2													
UserID: StefanA													
		Total ecosystems area	% Total ecosystems area exc	Total AAE	Total forest area	% Forest area exc	Forest AAE	Total catchment area	% Catchment area exc	Catchment AAE	Total semi-natural area	% Semi-natural area exc	Semi-natural AAE
EU27	Austria	50.48854	33.929363	84.323459	39.29283	35.764693	97.390231	0.00052	0	0	11.19519	27.48609	38.444801
EU27	Belgium	15.55151	48.692249	429.09544	12.81858	52.580395	493.34494	0.13515	18.039216	33.362644	2.59778	31.101171	132.64848

- Economic values
  - Forests: Brink et al. 2011: forest & grassland damages = 2.3 – 11.3 €/kg N deposited,
  - Semi-natural: Hasler et al. 2012: nutrient management on grasslands and similar = 4.5 – 13.5 million €/1000 km2 exceeded
    - Only applied to EU countries

First draft on Fertilisation & Crops

Fertilisation

- GAINS CL Exceedance data to calculate:
  - Delta N-deposition over forest for non exceeded areas (assume delta = delta AAE)
  - N deposition as kg

Eutrophication: Exceedance of Critical Loads (all ecosystems)													
Scenario: Base_v6b													
Region:													
Year: 2040													
Unit: 1000 km2													
UserID: StefanA													
		Total ecosystems area	% Total ecosystems area exc	Total AAE	Total forest area	% Forest area exc	Forest AAE	Total catchment area	% Catchment area exc	Catchment AAE	Total semi-natural area	% Semi-natural area exc	Semi-natural AAE
EU27	Austria	50.48854	33.929363	84.323459	39.29283	35.764693	97.390231	0.00052	0	0	11.19519	27.48609	38.444801
EU27	Belgium	15.55151	48.692249	429.09544	12.81858	52.580395	493.34494	0.13515	18.039216	33.362644	2.59778	31.101171	132.64848

- Economic values
  - Assumed price for nitrogen fertilisers of 1550 €/tonne, current prices are ~300

Crops

- ICP Vegetation data together with GAINS Exceedance data to calculate
  - Avioded production losses of *wheat* and *potato*
  - *Semi-natural area assumed to include agricultural land*

Annual avoided wheat production losses compared to 2015 baseline

	Tonnes	Euro
CLE 2040	3.16 million	694 million
OPT 2040	3.52 million	772 million
OPT_HV 2040	3.72 million	816 million
MTFR	4.64 million	1017 million

- Economic values
  - Costs from ICP vegetation
- GAINS Exceedance data will be replaced with ozone data once available

V5a group - the resulting YOLL and AAE

	Optimisation setting		**% reduction by 2040 from 2015 values**		
Model abbreviation	**Population**	**Scope**	**YOLL reduction**	**O3H**	**AAE reduction***
Base_v5a			35%	?	42%
A1r/s/D/v5a	Pop-const.	Domain	42%	?	46%
A1r/s/G/v5a	Pop-const.	Country	42%	?	47%
A2/s/D/v5a	Pop-const.	Domain	47%	?	50%
A3/s/D/v5a	Pop-const.	Domain	47%	?	50%
A1r/d/G/v5a	Pop-aging	Country	51%	?	57%
A1r/d/D/v5a	Pop-aging	Domain	51%	?	55%
B2/d/D/v5a	Pop-aging	Domain	51%	?	58%
B1/d/D/v5a	Pop-aging	Domain	51%	?	59%
A4/s/D/v5a	Pop-const.	Domain	53%	?	58%
A2/d/D/v5a	Pop-aging	Domain	56%	?	63%
A3/d/D/v5a	Pop-aging	Domain	56%	?	63%

*AAE for all areas in the GAINS Explorer result table:
"Eutrophication: Exceedance of Critical Loads (all ecosystems)"

V6b group - the resulting YOLL and AAE

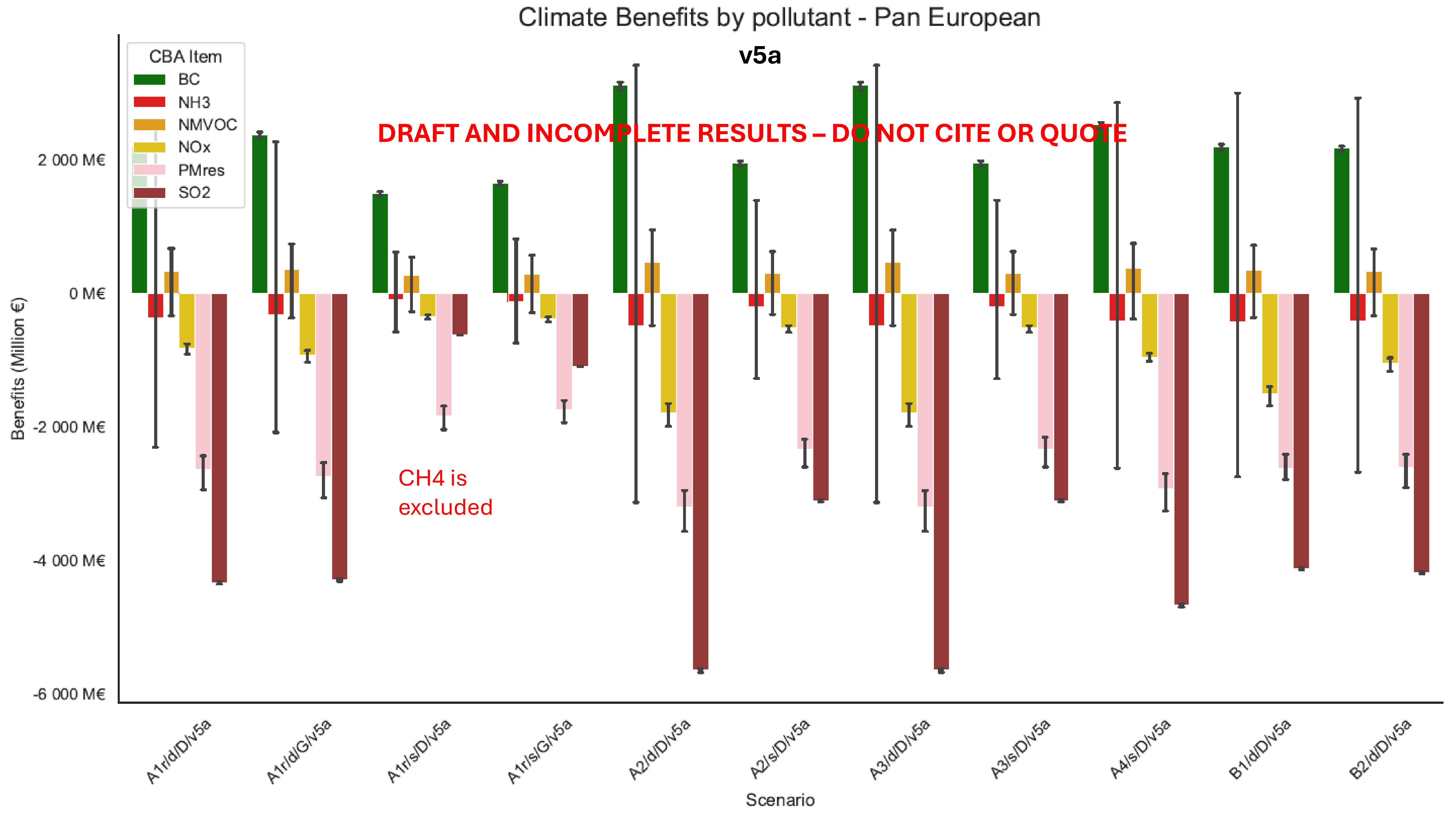
	Optimisation setting		**% reduction by 2040 from 2015 values**		
Model abbreviation	**Population**	**Scope**	**YOLL reduction**	**O3H**	**AAE reduction***
Base_v6b			34%	?	41%
D3/d/D/v6b	Pop-aging	Domain	51%	?	65%
C1/d/D/v6b	Pop-aging	Domain	51%	?	56%
C2/d/D/v6b	Pop-aging	Domain	51%	?	63%
D2/d/D/v6b	Pop-aging	Domain	51%	?	59%
D1/d/D/v6b	Pop-aging	Domain	51%	?	56%
A1r/d/D/v6b	Pop-aging	Domain	51%	?	55%

*AAE for all areas in the GAINS Explorer result table:
"Eutrophication: Exceedance of Critical Loads (all ecosystems)"

Current results – output illustrated

- Target year 2040
- V6b and V5a scenario groups (with high EU climate policy ambition compared to v7)
- All-cause long-term mortality
- Years of life lost calculated, and VOLY used to estimated mortality costs,
- Climate effect indicated with GTP20 without CH_4,
- Disutility not adjusted for future purchase power,
- Morbidities with solid (as of Dec 2025) causalities included (core),
- Benefit/Cost calculations are varied with respect to:
  - Baseline morbidity and mortality incidence rate (low-mid-high),
  - Health exposure response function value (low-mid-high)
  - GTP20 metric value of pollutants (low-mid-high),
  - Social cost of methane value (low-mid-high),
  - Biodiversity damage/restauration cost per ecosystem type (low-high),
  - ICP vegetations cost estimation of avioded losses (low-mid-high)

DRAFT AND INCOMPLETE RESULTS – DO NOT CITE OR QUOTE


Climate Benefits by pollutant - Pan European
v5a
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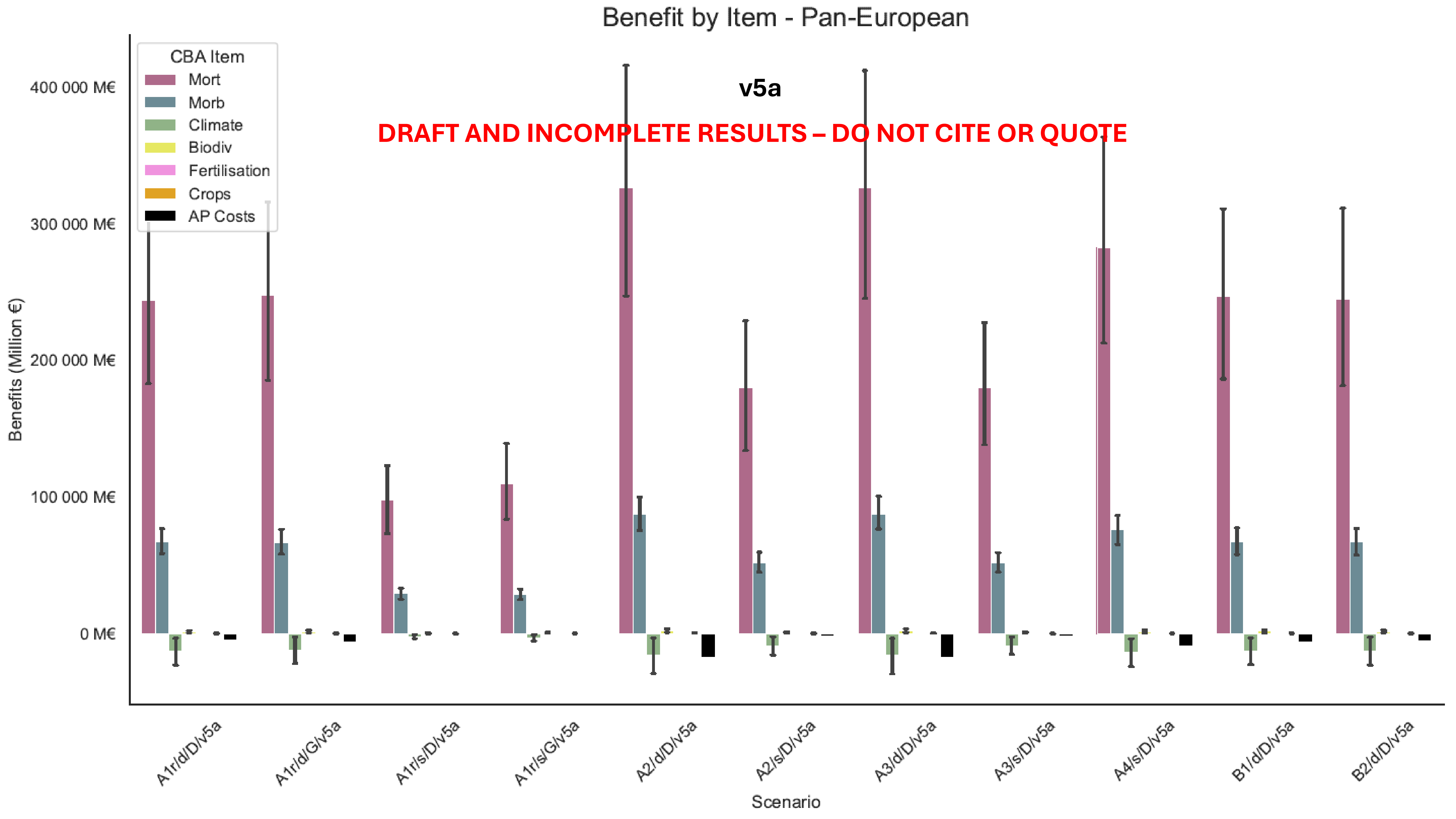
CBA Item
BC
NH3
NMVOC
NOx
PMres
SO2
CH4 is excluded
Benefits (Million €)
2 000 M€
0 M€
-2 000 M€
-4 000 M€
-6 000 M€
A1r/d/D/v5a
A1r/d/G/v5a
A1r/s/D/v5a
A1r/s/G/v5a
A2/d/D/v5a
A2/s/D/v5a
A3/d/D/v5a
A3/s/D/v5a
A4/s/D/v5a
B1/d/D/v5a
B2/d/D/v5a
Scenario



Benefit by Item - Pan-European
v5a
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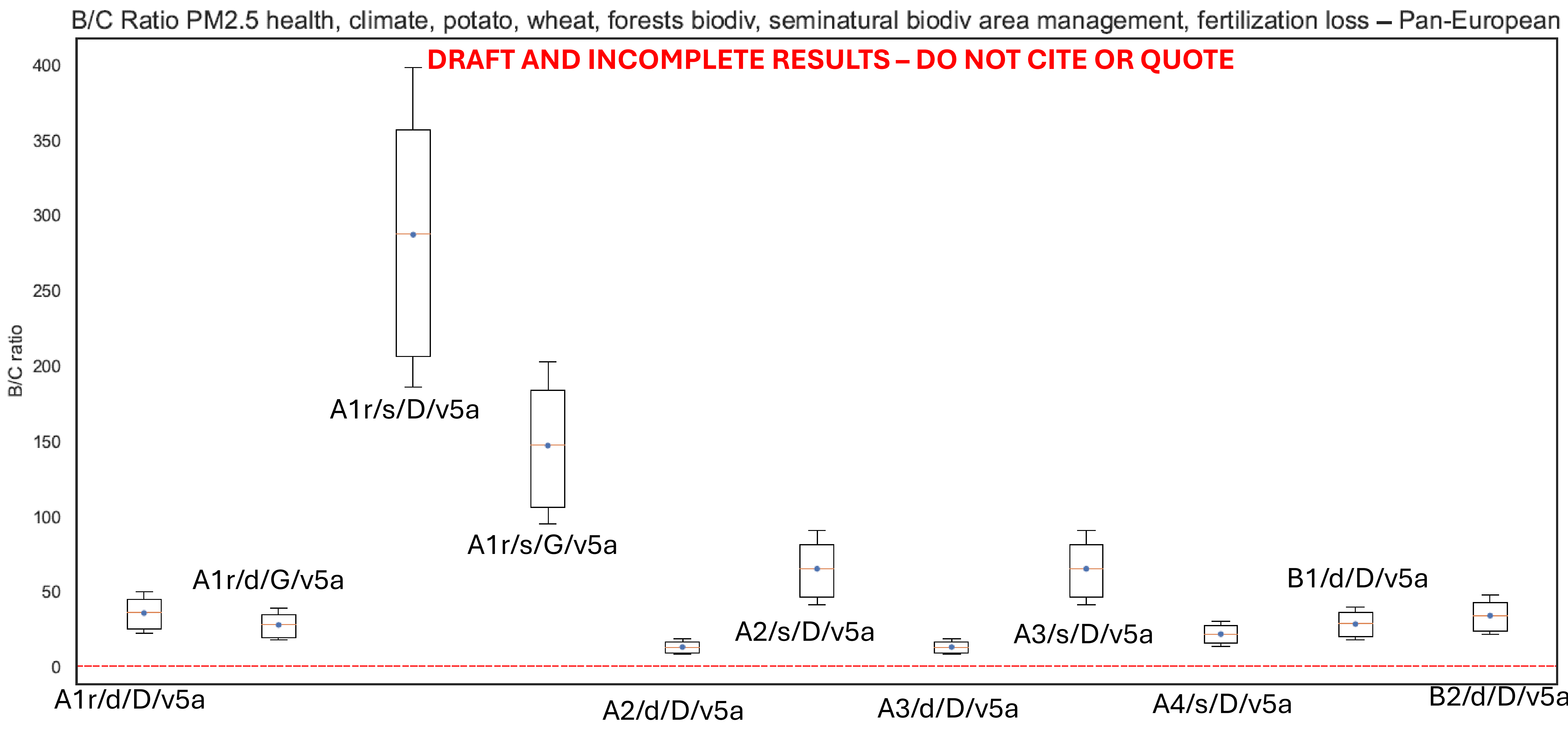
CBA Item
Mort
Morb
Climate
Biodiv
Fertilisation
Crops
AP Costs
400 000 M€
300 000 M€
200 000 M€
100 000 M€
0 M€
Benefits (Million €)
A1r/d/D/v5a
A1r/d/G/v5a
A1r/s/D/v5a
A1r/s/G/v5a
A2/d/D/v5a
A2/s/D/v5a
A3/d/D/v5a
A3/s/D/v5a
A4/s/D/v5a
B1/d/D/v5a
B2/d/D/v5a
Scenario

v5a


B/C Ratio PM2.5 health, climate, potato, wheat, forests biodiv, seminatural biodiv area management, fertilization loss – Pan-European
DRAFT AND INCOMPLETE RESULTS – DO NOT CITE OR QUOTE
B/C ratio
400
350
300
250
200
150
100
50
0
A1r/s/D/v5a
A1r/s/G/v5a
A1r/d/G/v5a
A2/s/D/v5a
A3/s/D/v5a
B1/d/D/v5a
A1r/d/D/v5a
A2/d/D/v5a
A3/d/D/v5a
A4/s/D/v5a
B2/d/D/v5a

v5a

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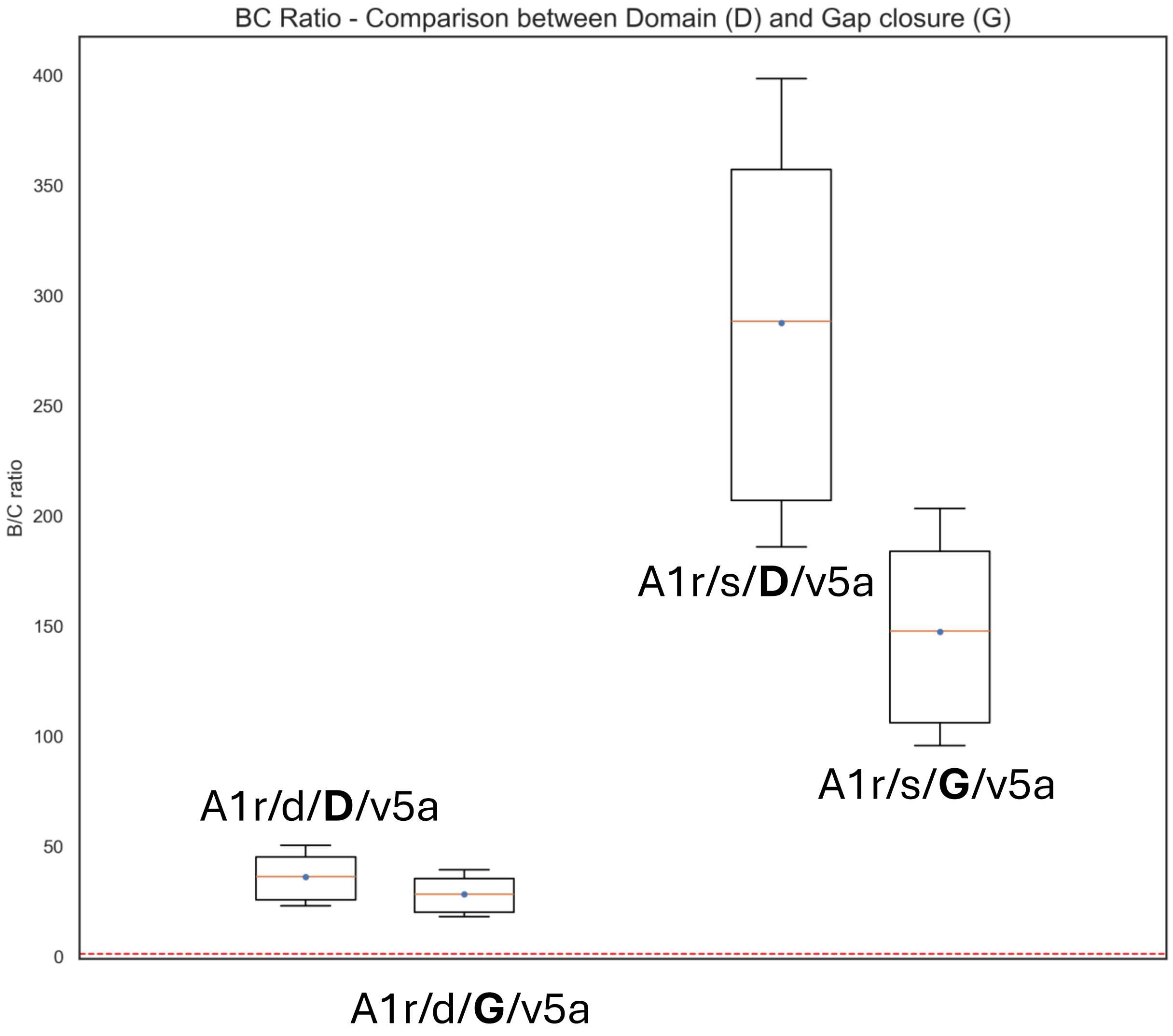

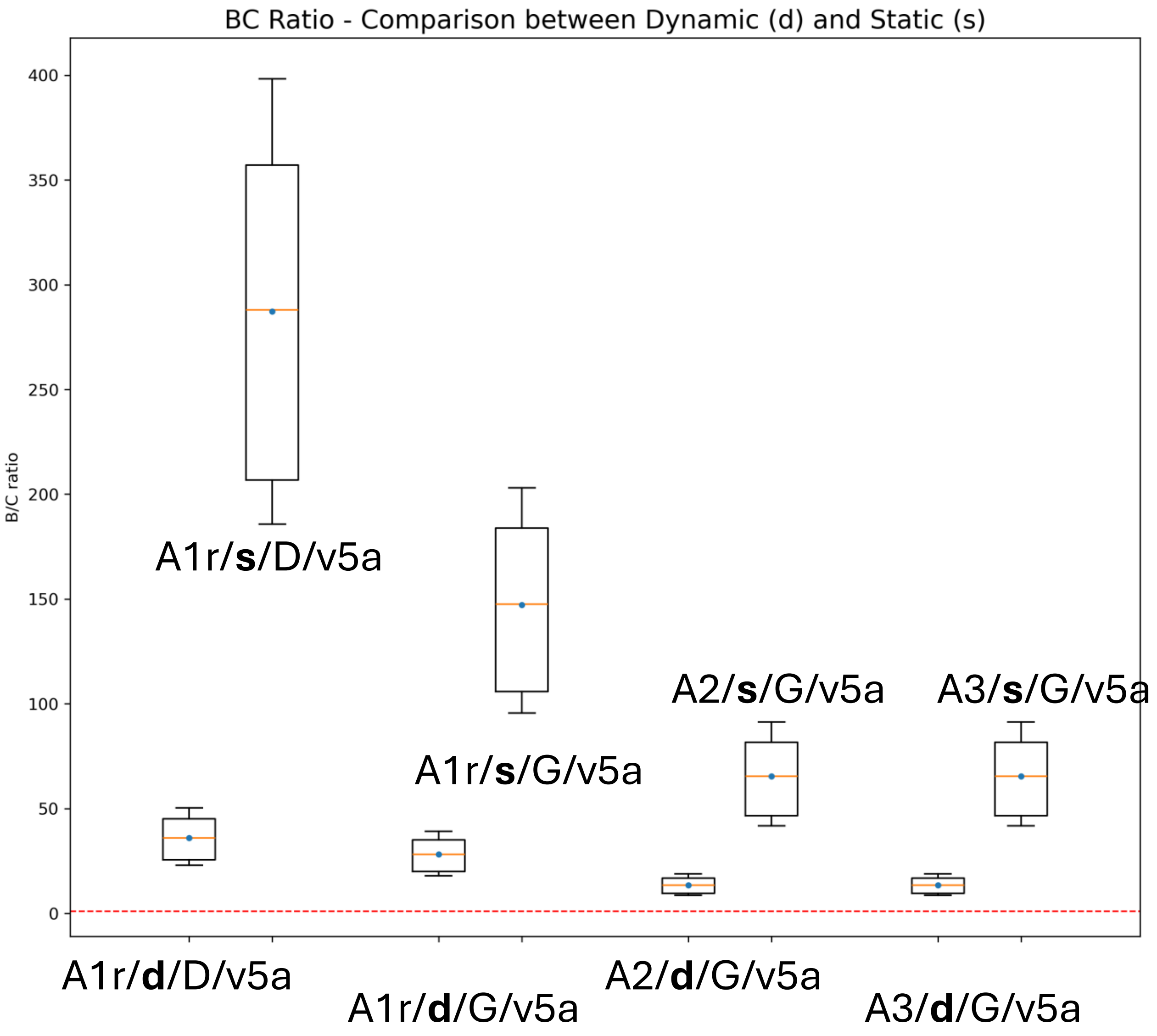

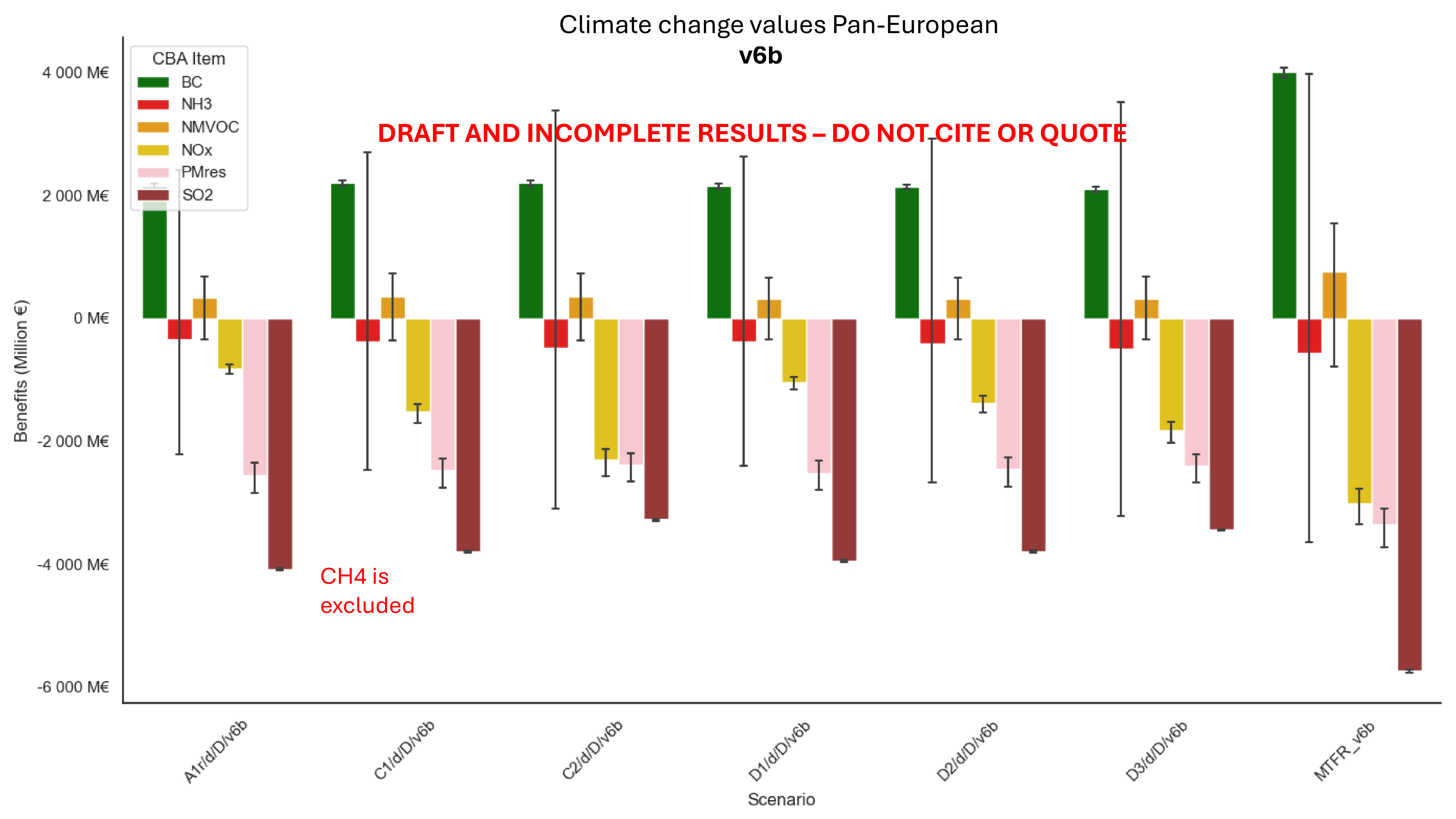

Climate change values Pan-European
v6b
CBA Item
BC
NH3
NMVOC
NOx
PMres
SO2
DRAFT AND INCOMPLETE RESULTS – DO NOT CITE OR QUOTE
CH4 is excluded
4 000 M€
2 000 M€
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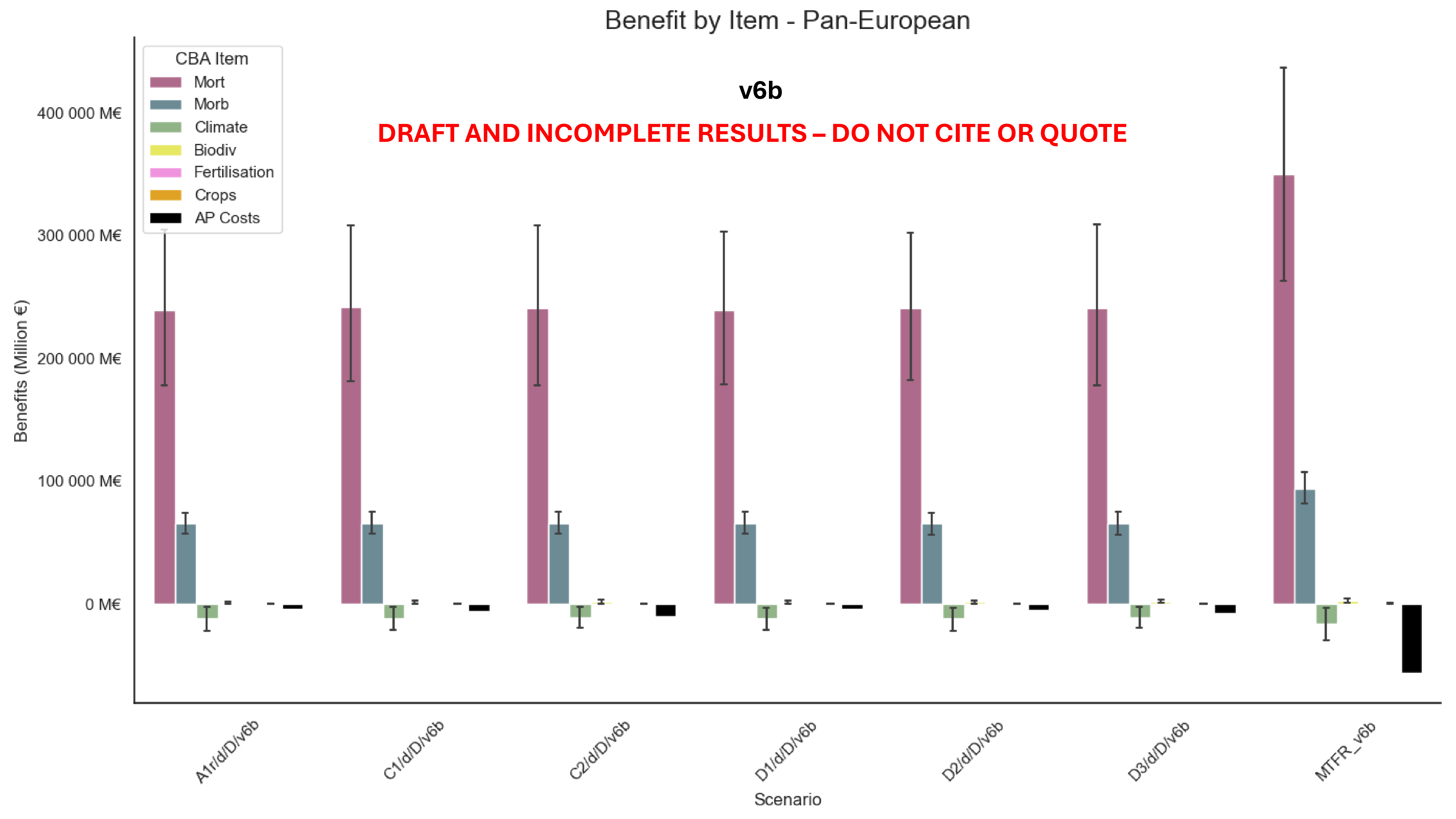
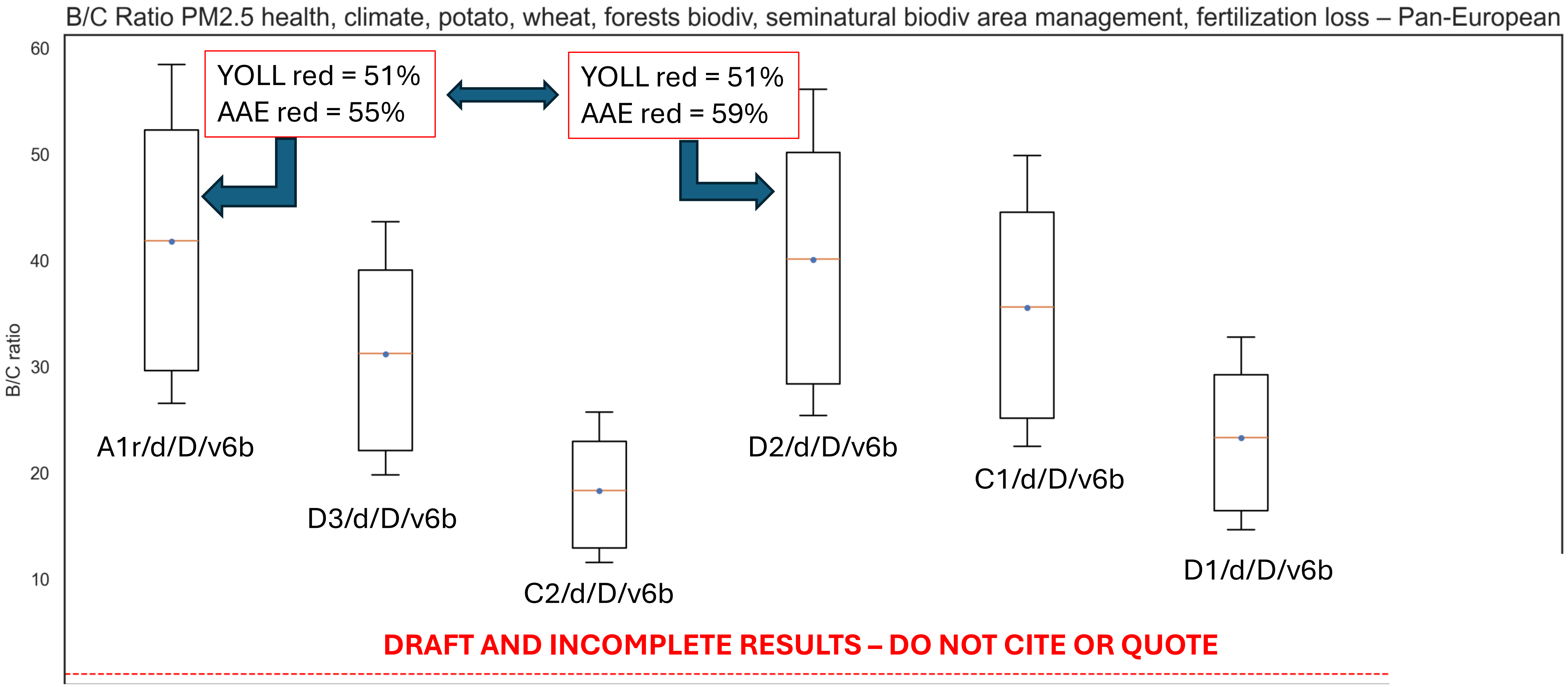
Benefits (Million €)
A1r/d/D/v6b
C1/d/D/v6b
C2/d/D/v6b
D1/d/D/v6b
D2/d/D/v6b
D3/d/D/v6b
MTFR_v6b
Scenario


Benefit by Item - Pan-European
v6b
DRAFT AND INCOMPLETE RESULTS – DO NOT CITE OR QUOTE
CBA Item
Mort
Morb
Climate
Biodiv
Fertilisation
Crops
AP Costs
400 000 M€
300 000 M€
200 000 M€
100 000 M€
0 M€
Benefits (Million €)
A1r/d/D/v6b
C1/d/D/v6b
C2/d/D/v6b
D1/d/D/v6b
D2/d/D/v6b
D3/d/D/v6b
MTFR_v6b
Scenario

v6b


B/C Ratio PM2.5 health, climate, potato, wheat, forests biodiv, seminatural biodiv area management, fertilization loss – Pan-European
B/C ratio
60
50
40
30
20
10
YOLL red = 51%
AAE red = 55%
YOLL red = 51%
AAE red = 59%
A1r/d/D/v6b
D3/d/D/v6b
C2/d/D/v6b
D2/d/D/v6b
C1/d/D/v6b
D1/d/D/v6b
DRAFT AND INCOMPLETE RESULTS – DO NOT CITE OR QUOTE

Continued developments

- Current version is incomplete, plan to add:
  - Ozone health effects (input from TFHealth, MSC-West, CIAM?),
  - More crops?
  - ”correlated” morbidity effects & economic values (input from TFHealth?),
  - Expanding restoration management costs to cover also areas still exceeded,
    - If more funding becomes available: Also utility-based valuation of biodiversity
  - Materials (input from ICP Materials),
  - Carbon sequestration value (input from ICP Veg?),
  - Improvements on Baltic Sea Nutrient Environmental status (Input from MSC-West, CCE?)

CBA methodology deep-dive

- Some methodological prerequisites of CBA
  - Benefits are often ’hidden’ or implicit, requires additional and rather cumbersome methods, ex:’willingness-to-pay’, cost-of-illness, replacement cost, adaptation cost etc.
    - In integrated CBA, ’benefit transfer’ from other studies has to be applied.
  - Benefits in the context of this Air Convention CBA are derived assuming:
    - Utilitarianism,
    - Economically rational decision-making,
    - All health and environmental services are fully substitutable (i.e. anything can be sold if the price is right).
  - In brief, the CBA takes the approach of Welfare Economics, and assumes that a ’benevolent dictator’ making decisions that is best for all.

CBA data deep dive – VALESOR population data treatment

- POPULATION, LIFE EXPECTANCY, ALL-CAUSE MORTALITY
  - Data on population, life expectancy at birth, and all-cause mortality in VALESOR is from UN World Population Prospects (UNWPP) 2024 database (median projection, extracted during May-October 2025). Data is provided by 1-year age group, for 2001 to 2100, for 49 VALESOR countries.
  - Assumptions and simplifications:
    - Population of the following countries is merged with population of small countries and dependencies, also available from UNWPP: Austria (includes Liechtenstein), UK (includes Isle of Man), France (includes Andorra, Monaco, Guernsey, Jersey), Italy (includes San Marino), Spain (includes Gibraltar).
    - European Territory of Russia (ETR) is often defined as area covered by 6 federal districts: Volga, Central, Northwestern, Southern, North Caucasian, and Ural. VALESOR adopts this ETR definition. ETR population is assumed to account to 80% of the country's total population, based on estimates provided by Rosstat.
    - For all-cause mortality, VALESOR tool applies an assumption of a share of all-cause deaths due to natural mortality in the total mortality (as opposed to injury-caused deaths) - 95% (as estimated based on WHO data, Table A1.1 in HRAPIE-2, 2025). This share is applied to mortality in relevant age groups (30+ and 'All ages' excluding infants (for infants, more accurate estimate is done based on other data sources, see below)).
- CAUSE-SPECIFIC MORTALITY AND MORBIDITY
  - Cause-specific mortality and morbidity incidence data in VALESOR are from the 2021 update of the IHME Global burden of disease (GBD) database, extracted during May-October 2025). GBD provides incidence rates per 100 000 persons in the age groups specified below, for 2001 to 2021, for 49 VALESOR countries. Age groups include 0 years (infants), 1 year, 2-4 years, 5-9 years, and subsequent 5-year intervals up to 95+.
  - For hypertension, EBD does not provide incidence rates, this data is missing.
  - Assumptions and simplifications:
    - Respiratory disease mortality (not explicitly provided in the GBD database) is estimated as a sum of ALRI and chronic respiratory mortality within each age group.
    - For years 2022-2100, VALESOR assumed constant incidence rates of morbidity and cause-specific mortality.
- POST-NEONATAL INFANT MORTALITY
  - To estimate post-neonatal infant mortality due to natural causes, VALESOR used data from (GBD) database, extracted during September-October 2025). GBD provides number of deaths from injuries and all-cause death in age groups 1-28 days (neonatal mortality) and 29 days – 1 year (post-neonatal mortality); these are processed into post-neonatal all-cause natural mortality.
- HOSPITAL ADMISSIONS
  - Respiratory and cardiovascular hospital admission rates are from WHO database, extracted in September 2025. The data considers the entire population (all ages) and is in the tool applied to all years 2001-2100. For countries in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan), this data is missing.
- DATA HANDLING ASPECTS
  - Specificity of the online tool architecture requires certain ways of data processing. For smooth and uniform data handling in the tool database, all baseline health data are presented in the database as rates per 100 000 population, by 1-year age group. This applies both to data presented per 1-year age group in the original sources, and to data presented per other age intervals (e.g., 5-year intervals for morbidity, all ages for hospital admissions). Further multiplied by population in each relevant 1-year age group and summed up (approach used in ARP AIR), these numbers result in the same number of cases as if calculated by multiplication of population-weighted baseline health and population in a specific age interval (approach used in ARP CHEM).

Thank you for your attention