Recent developments in the economic assessment of the long-term health effects of air pollution

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What are we talking about?

Short term ≠ Long term

Short-term / acute health effects: occur in the hours / days following exposure.

Long-term / chronic health effects: result from long-term exposure and occur in the years following exposure.

Morbidity

- prevalence (number of cases a given year) => cost per year,
- incidence (number of new cases) => Lifetime Economic Value (LEV).

Mortality

Several indicators of a change in mortality risk can be used:

- the “number of premature deaths” approach => Value of a Statistical Life (VSL),
- the “number of life years saved” approach (using dynamic life-tables) => Value of a Life Year (VOLY).

Sketch of the presentation

1. Estimation of LT morbidity impacts
    - 1.1 Methodological aspects of economic assessment
    - 1.2 Application to France

2. Estimation of LT mortality impacts
    - 2.1 Methodological aspects of economic assessment
    - 2.2 Estimating VSL and VOLY for 202 countries and territories
    - 2.3 Application to France

3. Temporal issues regarding application of LT impacts in CBA
    - 3.1 Methodological aspects of economic assessment
    - 3.2 Application to 4 health indicators

1. Estimation of LT morbidity impacts

1.1 Methodological aspects of economic assessment

We need to compute a LEV for each disease.

1.1.1 Which cost components?

Tangible/marketable costs

- **Health costs (HC)**: medical resources consumed and non-medical resources linked to the disease => Based on prices and tariffs

- **Production losses (PL)**: lost resources (loss of production by the patient / family, and presenteeism) => Based on salary

Intangible component (IC)

Costs of disutility for patients and/or their families (grief, fear, pain, unhappiness, loss of well-being and loss of quality of life,…)

=> Based on approximated real markets

1.1.2. From the full complex theoretical LEV to a simple tractable LEV

The LEV of an individual of age *a* whose disease onset occurs at date *t* is:

$$LEV_a^t = \sum_{n=0}^{120-a} \left[\frac{{}^tP_{n,a}({}^tHC_{n,a} + {}^tPL_{n,a} + {}^tIC_{n,a})}{(1+{}^t\delta_n)^n} \right] \qquad (1)$$

where :

- *n* a time indicator of time elapsed since disease onset,
- 120 the upper age limit ,
- ${}^tP_{n,a}$ the probability, estimated at time *t*, that a patient of age *a* is alive at the beginning of year *n* after disease onset (with ${}^tP_{0,a} \equiv 1$ and ${}^tP_{120-a,a} \equiv 0$),
- ${}^tHC_{n,a}$ the healthcare costs of a patient of age *a* in year *n* after disease onset, assessed in year *t*, ,
- ${}^tPL_{n,a}$ the productivity losses of a patient of age *a* in year *n* after disease onset, assessed in year *t*,
- ${}^tIC_{n,a}$ the intangible component of a patient of age *a* in year *n* after disease onset, assessed in year *t*,
- ${}^t\delta_n$ the annual discount rate in year *n* after disease onset, assessed in year *t*.

Simplification #1: In practice, evaluations often rely on observed survival probabilities after the onset of a given disease computed on a sample of patients without accounting for age:

$$LEV^t = \sum_{n=0}^{120} \left[\frac{{}^tP_n({}^tHC_n + {}^tPL_n + {}^tIC_n)}{(1+{}^t\delta_n)^n} \right] \quad \textbf{(2)}$$

where:

- ${}^tP_n$ the average probability, anticipated at time *t*, of being alive at the beginning of year *n* after disease onset,
- ${}^tHC_n$, ${}^tPL_n$ *et* ${}^tIC_n$ the 3 average components for a given age group (or all age groups) in year *n* after the disease onset, anticipated in year *t*.

Simplification #2 : The future evolution of the various components is difficult to anticipate from year *t*, and assumptions are required on the probabilities of being alive, the annual growth rates of the healthcare expenditure (α) the average wages (β), the intangible component (γ) or the discount rate (δ). If we consider that the probabilities of being alive are fixed as those observed in *t*, and that the three annual growth rates and the discount rate are constant over time, equation (**2**) is:

$$LEV^t = \sum_{n=0}^{120} \left[\frac{P_n^t}{(1+\delta_n^t)^n} \right] [HC_n^t(1+\alpha)^n + PL_n^t(1+\beta)^n + IC_n^t(1+\gamma)^n] \quad \textbf{(3a)}$$

An acceptable approximation to equation (**3a**) can be derived for diseases for which the three components do not strongly depend on the duration *n* since the disease onset, and which does not strongly impact life expectancy. Hence, for a given age class (or for all age classes):

$$LEV^t = \sum_{n=0}^{D-1} \left[\frac{\overline{HC^t}\,(1+\alpha)^n + \overline{PL^t}\,(1+\beta)^n + \overline{IC^t}\,(1+\gamma)^n}{(1+\delta^t)^n} \right] \qquad \textbf{(3b)}$$

where:

- *D* the average duration with the disease,
- $\overline{HC^t}$, $\overline{PL^t}$, $\overline{IC^t}$ the average annual values of the three components in the sample of patients, estimated in year t, i.e. the average prevalent cost.

Simplification #3 : Under the assumptions that the average annual growth rates of each of the 3 components do not significantly differ from the annual discount rate δ, there is no further discounting to be carried out (Medina et al., 2025).

a) Diseases significantly affecting survival whose cost components vary with the time elapsed from onset (cancer, AMI, stroke …):

$$LEV = \sum_{n=0}^{120} P_n \,(HC_n + PL_n + IC_n)$$

b) Diseases not significantly affecting survival and whose cost components do not vary a lot with the time elapsed from onset:

$$LEV = D(\overline{HC} + \overline{PL} + \overline{IC})$$

1.2 Application to France: EMAPEC project

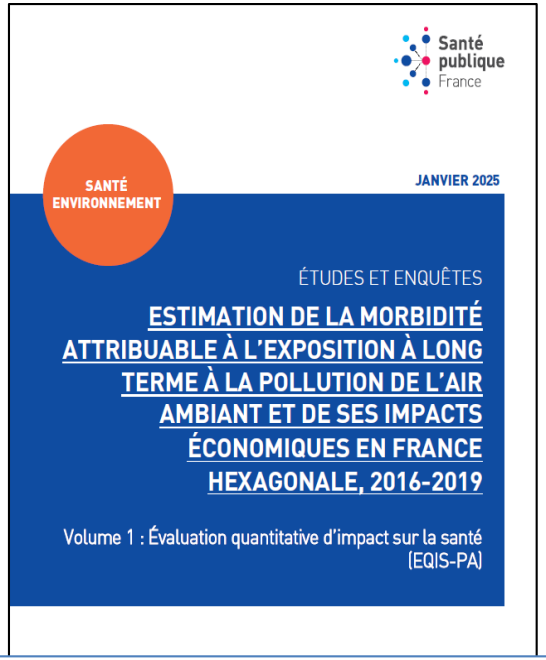
(work with colleagues from Ineris, Santé publique France and ORS Ile-de-France)

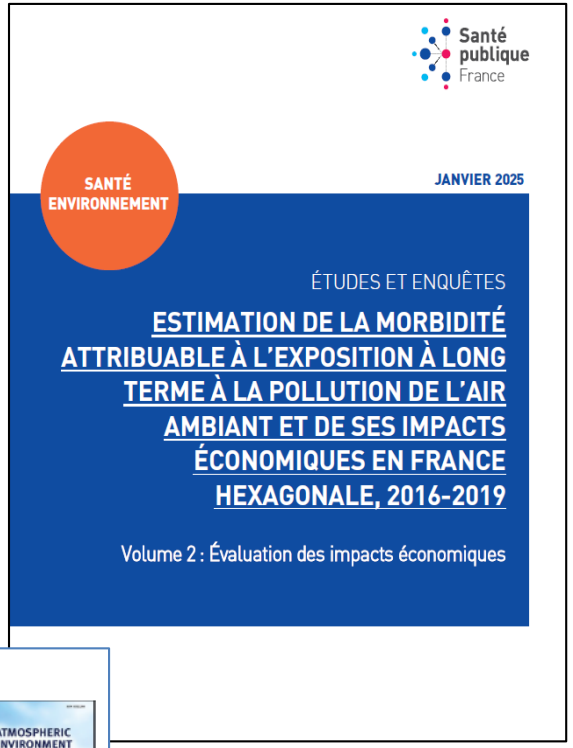
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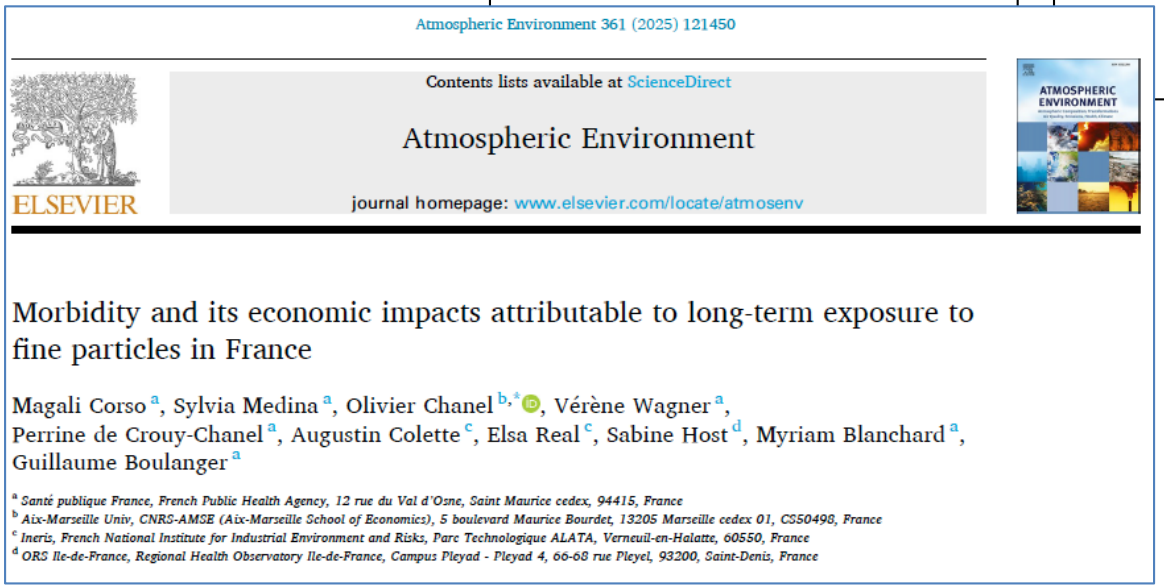
World Health Organization

Estimation of Morbidity from Air Pollution and its Economic Costs – EMAPEC project: review and application of concentration-response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide

Final report







1.2.1 Context

- **Study period**: 2016-2019.

- **Study area**: mainland France and Corsica (64.5 million inhabitants, 2016) at the municipality level (35,228).

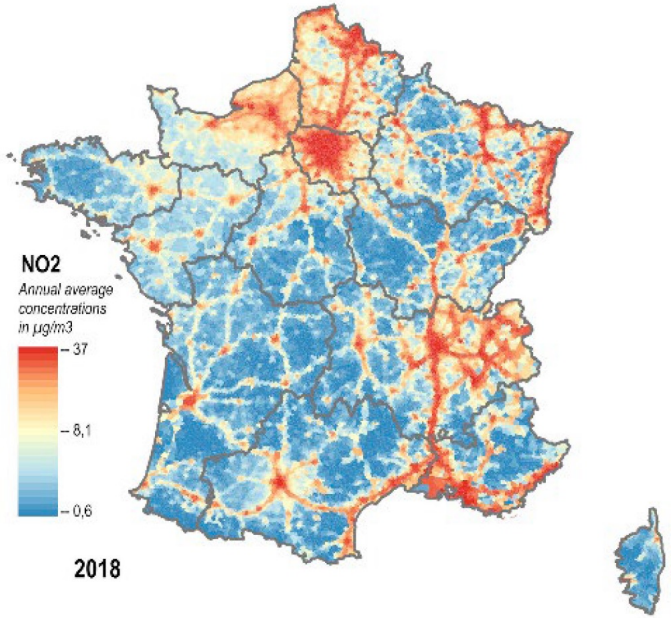
- **8 long term (LT) diseases (incidence)**: Lung cancer (35+), COPD (40+), Asthma (0-17 & 18-39), ALRI (0-12) per episode, Stroke (35+), IHD events (30+), Hypertension (18+), Type 2 Diabetes (45+).

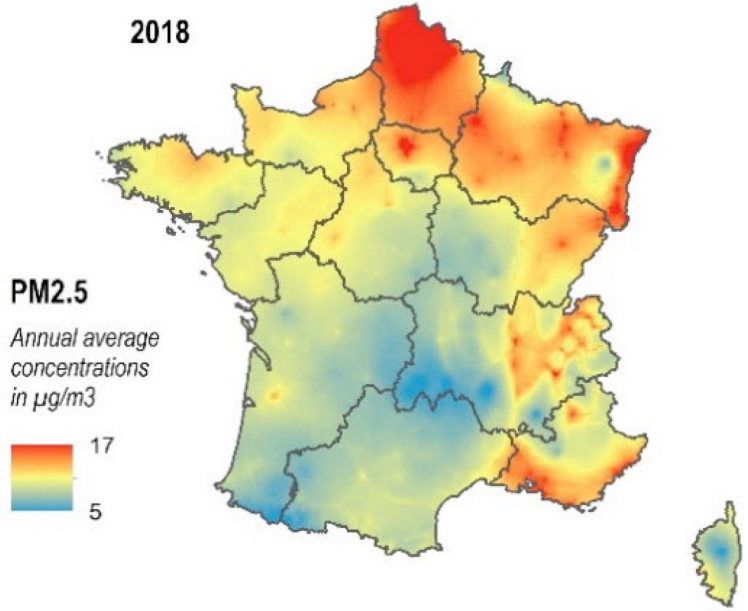
- **2 pollutants**: $PM_{2.5}$ (for 8 diseases) and NO_2 (for ALRI, asthma in children and adults).

- **3 scenarios**:
  - Without anthropogenic pollution: Total burden (NO_2=1 µg/m^3, $PM_{2.5}$=3 µg/m^3),
  - Compliance with WHO AQG 2021 (NO_2=10 µg/m^3, $PM_{2.5}$=5 µg/m^3),
  - Respect of the 2030 European directive (NO_2=10 µg/m^3, $PM_{2.5}$=20 µg/m^3).

1.2.2 Health Impact Assessment (QHIA)

- Pollutant concentration estimates (French National Institute for the Industrial Environment and Risks, **INERIS**)





- Population exposure assessment (**INERIS**)
- Health data on incidence (French national public health agency, Santé publique France**, SpF**)
- Concentration-response functions (**WHO-EMAPEC project**)

=> computation of the annual # of cases by pollutant, disease and scenario (**SpF**).

1.2.3 Lifetime economic value estimates

- HC and PL based on literature review (+/- 250 publications) and on French specific data.
- IC based on average Disability Adjusted Life Year (DALY) per case (GBD-IHME, 2020) and the monetary value of €$_{2018}$ 45,000 per DALY (own estimate).

Table 1 Lifetime economic value for an incident case (€$_{2018}$ rounded)

	Average duration per case	DALY per case	Health costs (HC)	Production losses (PL)	Total tangible component	Intangible component (IC)
Lung cancer (35+)	2.2 years	0.924	54 000	8 800	63 000	42 000
COPD (40+)	12 years	2.771	62 000	12 000	74 000	125 000
Asthma (0-17)	36.2 years	0.908	35 000	32 000	67 000	41 000
Asthma (18-39)	23.6 years	0.592	21 000	30 000	51 000	27 000
ALRI (0-12) per episode	0.019 year (1 week)	0.001	260	120	380	60
Stroke (35+)	7 years	0.728	77 000	15 000	92 000	33 000
IHD events (30+)	10 years	0.674	23 000	2 000	25 000	30 000
Hypertension (18+)	15 years	0	7 300	1 400	8 700	0
Type 2 Diabetes (45+)	12 years	0.812	52 000	6 000	58 000	37 000

1.2.4 Main economic results

Figure 1 Potential annual economic benefits of reducing annual mean for 3 reduction scenarios, France, 2016-2019 ($€_{2018}$ Million)

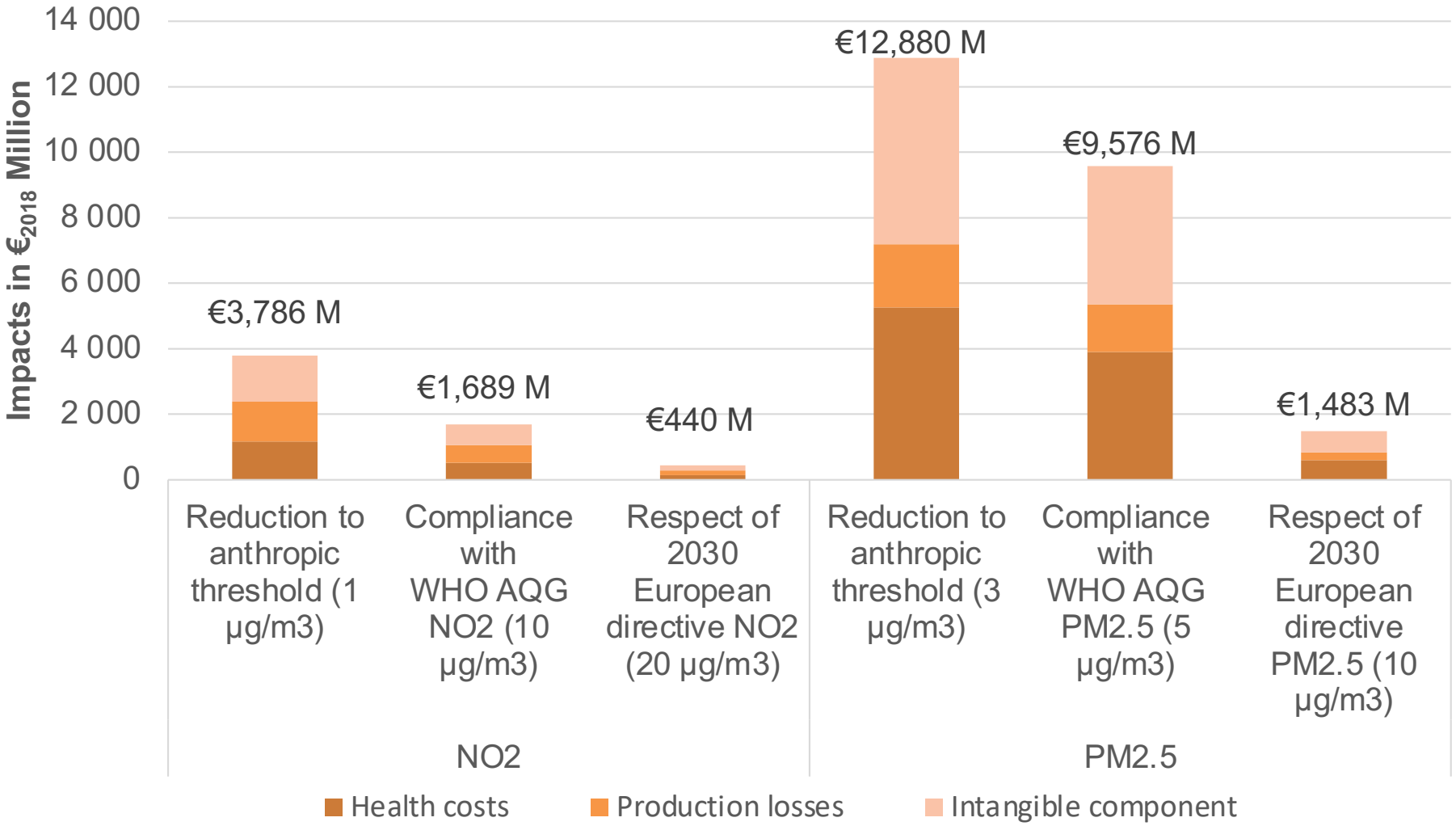


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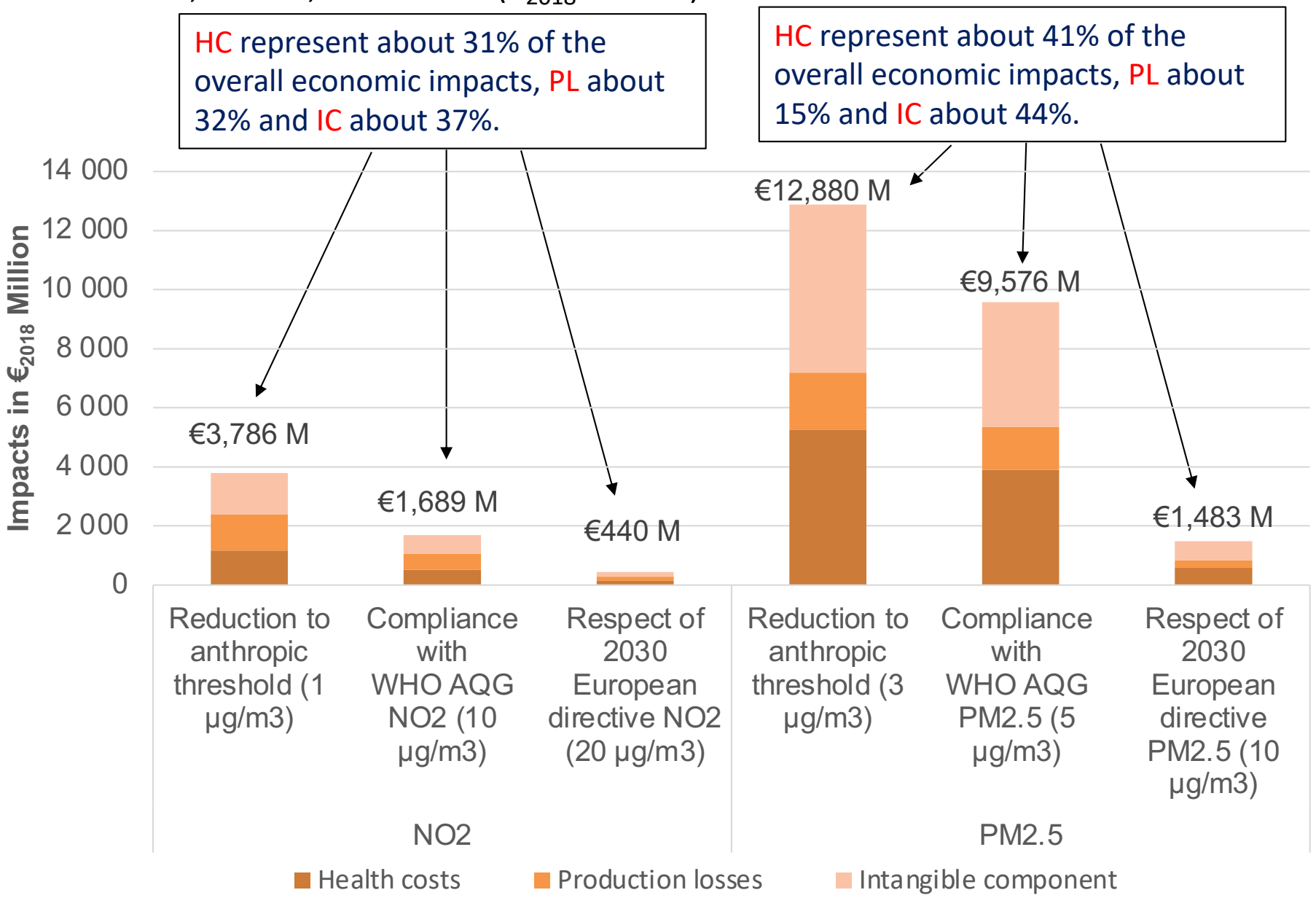


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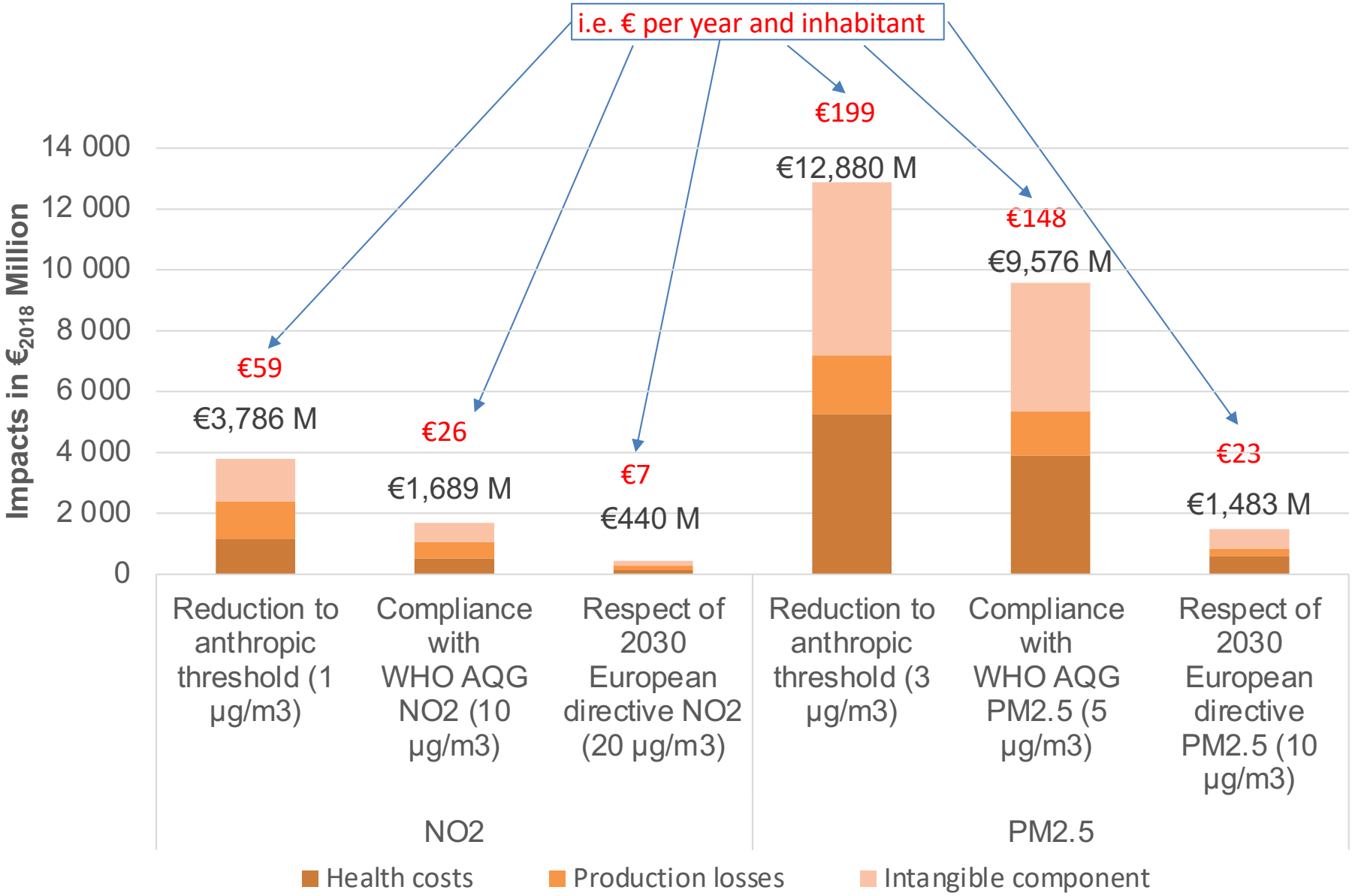
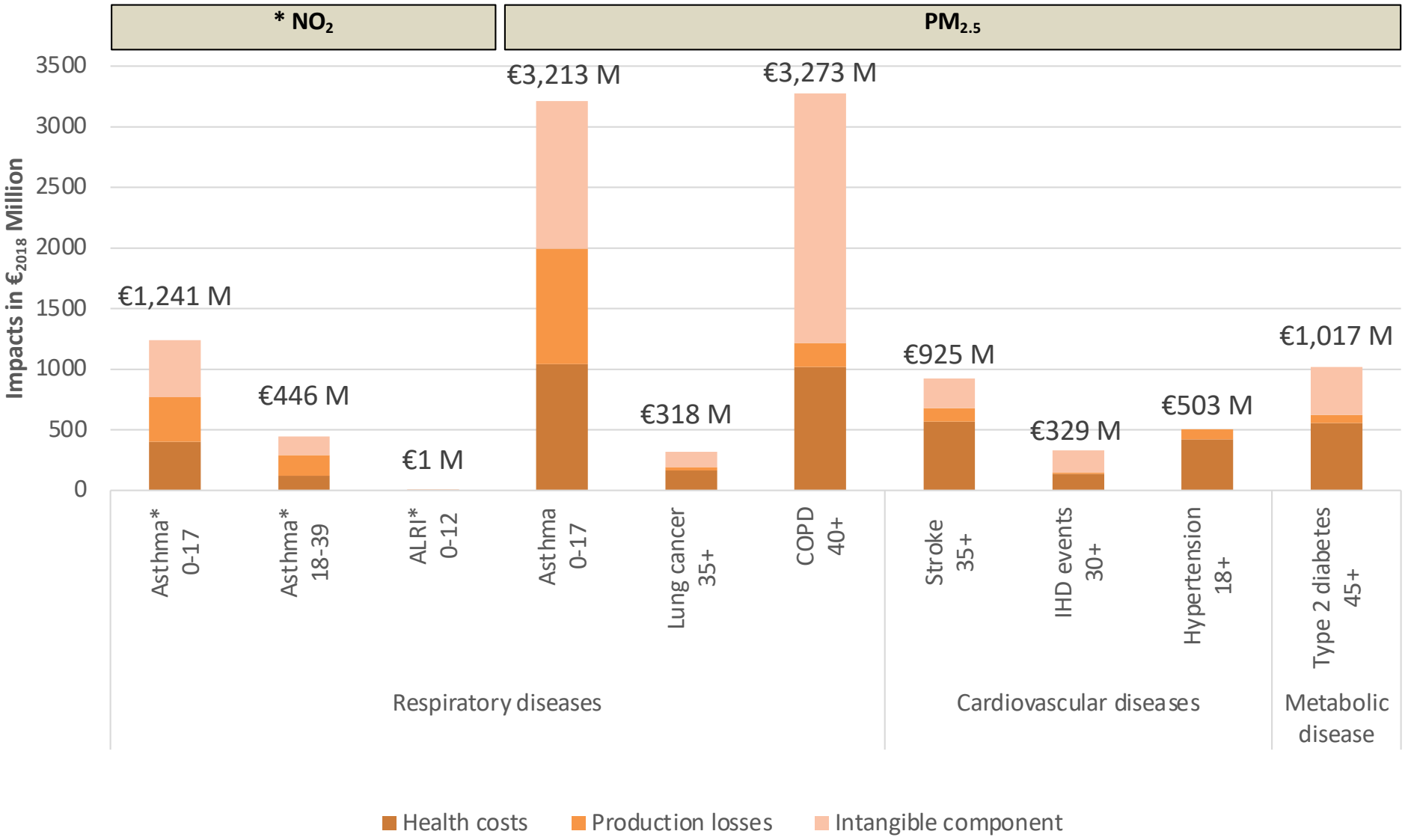


Figure 2 Potential annual economic benefits of reducing annual mean levels to **WHO AQG levels,** France, 2016-2019, by disease ($€_{2018}$ Million)



1.3 Concluding remarks

Main results

- If the WHO AQG value for $PM_{2.5}$ was respected in France, annual health and welfare benefits for the 8 LT diseases studied would be $€_{2018}$ 9.6 billion.
- 34% for asthma in children and for COPD (40+), 10% for stroke (35+) and for Type 2 diabetes (45+).
- LT morbidity represents about 8% of LT mortality in economic terms.

Future issues

- Adding new diseases (premature births, low birth weight, dementia, autism spectrum disorders …).
- Explore the feasibility of multi-pollutant estimations.
- Conduct sensitivity analyses on temporal issues (cf. section 3).

2. Estimation of LT mortality impacts

("Standardizing Global Economic Valuation of Mortality Impacts", with Aurelio Tobias (Spanish Council for Scientific Research) and Lina Madaniyazi (Nagasaki University))

2.1 Methodological aspects of economic assessment

The mortality component of environmental-related health impacts generally dominates the economic assessment.

=> The choice of VSL / VOLY is crucial in international studies to ensure comparability between countries or cities.

BUT one faces

a wide disparity in approaches (revealed or stated preferences, methodology)

+

a lack of relevant VSL values in many countries:

- in Viscusi and Masterman (2017), only 2 out of 68 of the wage-based studies deal with middle-income countries;
- in Robinson et al. (2018), 15 low- or middle-income countries VSL estimates out of 172 satisfy sufficient quality.

=> **We fill this gap by estimating country-specific VSL / VOLY for every country or territory by transferring values from the most recent and comprehensive meta-analysis of VSL studies (OECD, 2025: 3,963 VSL estimates from 276 RP and SP studies).**

Transferring country-specific VSL

The VSL in a given country *C* is transferred from a reference VSL_{REF} as (cf. also Hammitt and Robinson, 2011; OECD 2014, 2025; Viscusi and Masterman, 2017):

$$VSL_C = VSL_{REF} \times (GDP_C/GDP_{REF})^{\eta} \quad (1)$$

where η is the income elasticity of VSL and GDP the GDP/capita.

Empirical choices for VSL computation (2022 data)

- VSL_{REF} : smallest group of countries a country belongs to among 5 REF (cf. OECD, 2025),
- GDP_C & GDP_{REF}: country-specific GDP/capita in international USD at PPP (IMF, 2026a),
- η =1 for all countries (in accordance with Viscusi and Masterman, 2017; Carleton et al., 2022; Bressler and Heal, 2022; or OECD, 2025).

Deriving country-specific VOLY

VSL is considered as a flow of discounted age-independent VOLYs over the average loss of life expectancy (LLE) (see Leksell and Rabl, 2001; or Kniesner and Viscusi, 2024):

$$VOLY_C = \delta VSL_C/[1-(1+\delta)^{-LLE_C}] \quad (4)$$

where δ is the annual discount rate and LLE_C is the average LLE in country C.

Empirical choices for VOLY computation (2022 data)

LLE_C: difference between life expectancy at birth (UN Population Division, 2026a) and median population age (UN Population Division, 2026b).

δ: set to 3%/year, in accordance with most official recommendations (US-EPA, 2021; OECD, 2018; France Stratégie, 2021).

2.2 Estimating VSL and VOLY for 202 countries and territories

Figure 3 VSL estimates by country or territory (in USD_{2022} million)

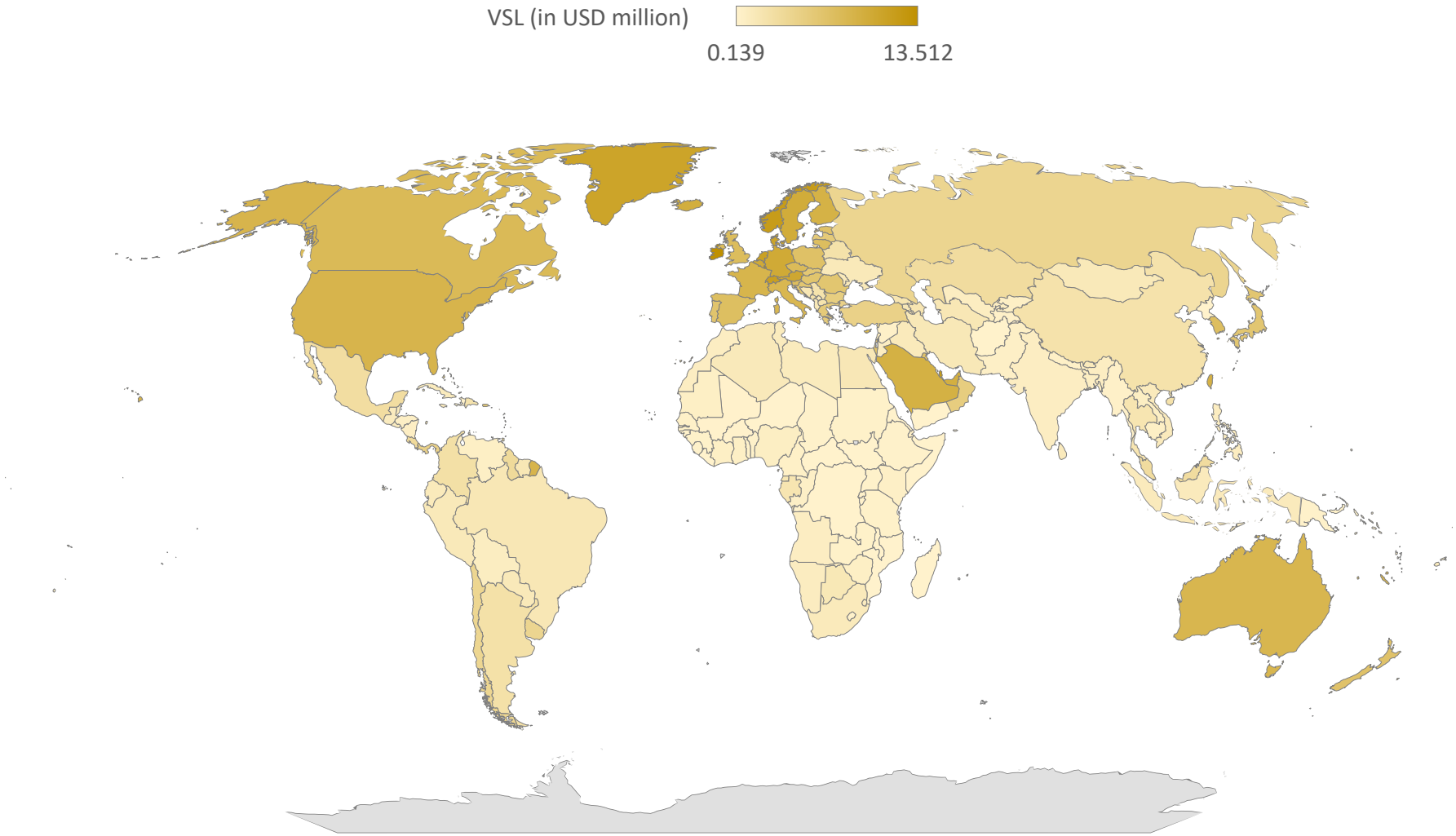
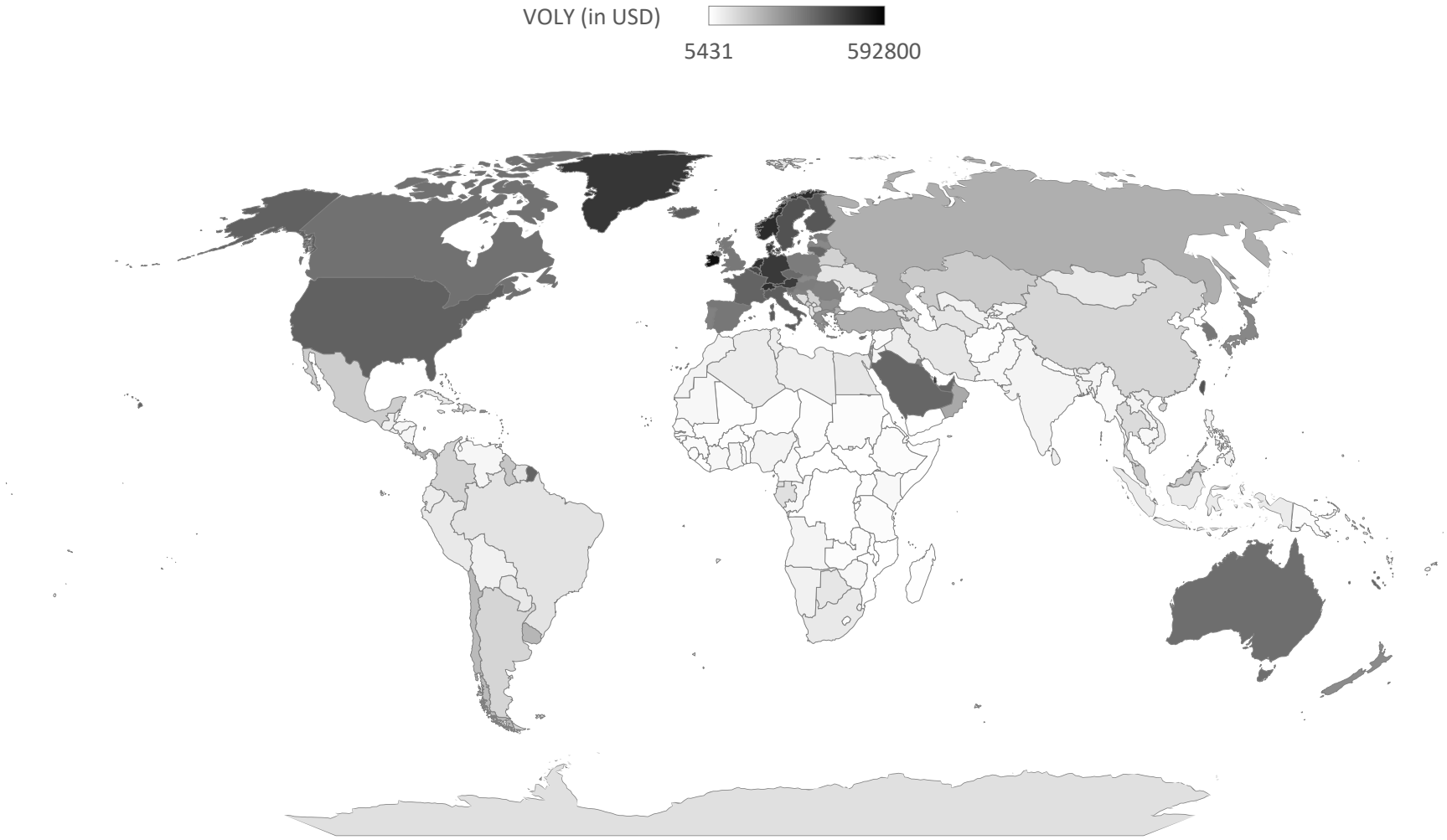


Figure 4 VOLY estimates by country or territory (in thousanUSD$_{2022}$)



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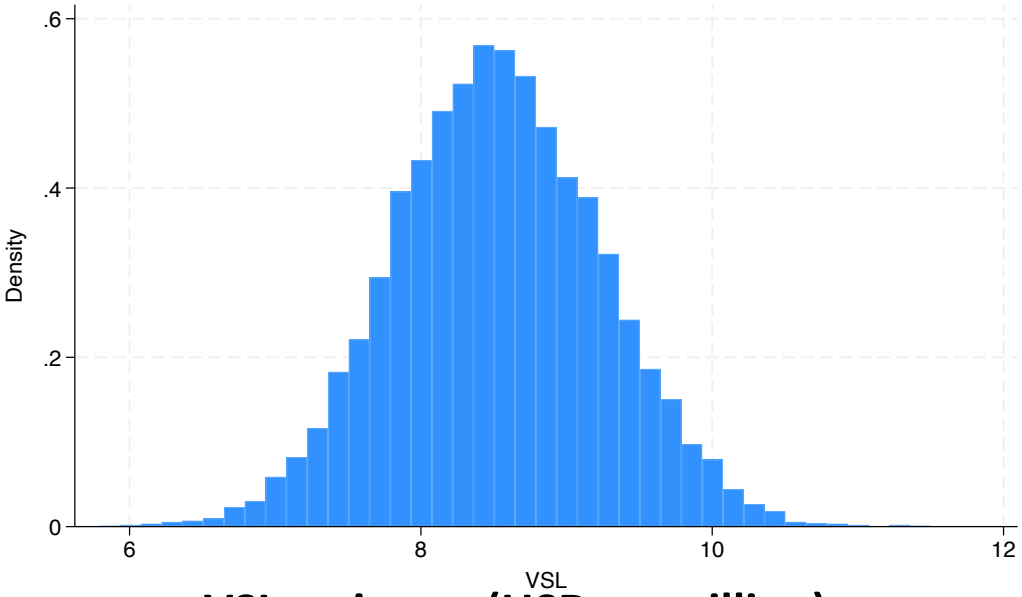
2.3 Application to France

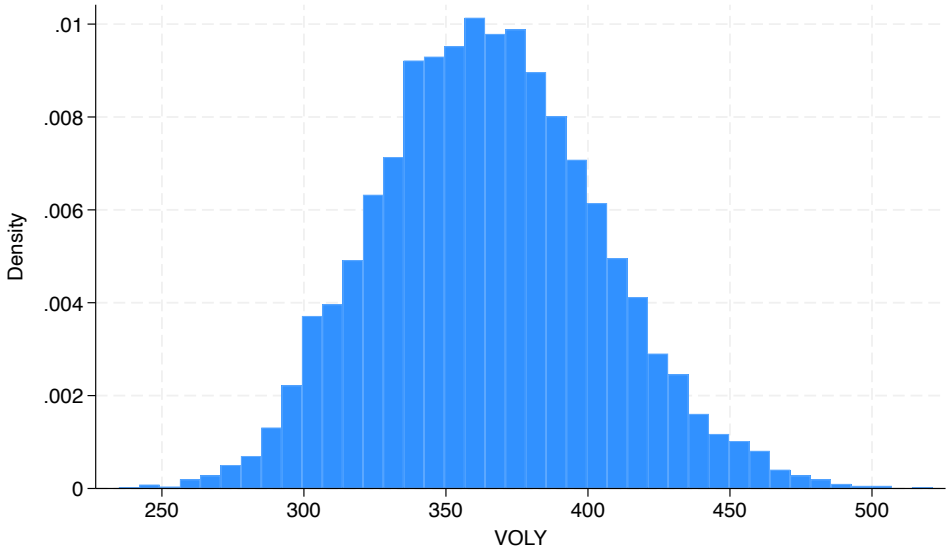
2.3.1 VSL and VOLY estimates for France

10,000 Monte Carlo simulations with:

- **normal distribution** for VSL_{UE27} : $\mathcal{N}(\mu,\sigma)=(8.37;0.702)$ in USD_{2022} Million.
- **triangular distributions:** - for income elasticity η (1 as central value, min= .5 max= 1.5),
  - for discount rate δ (3% as central value, ± 33% range around the central value (i.e., 2% and 4%).

Figure 5 VSL and VOLY estimates for France





VSL estimate (USD_{2022} million):
Mean: 8.53 M.
SD: 0.716 M.
eIC95%: 7.15 M. - 9.95 M.

VOLY estimate (USD_{2022}):
Mean: 365,055
SD: 39,155
eIC95%: 293,073 - 446,855

2.3.1 Exploratory results with a historical perspective

Table 2 Estimates of the number of attributable deaths (compliance with WHO AQG 2021 for $PM_{2.5}$=5 µg/m^3)

Source	Year	Attributable deaths	VSL (in million €)	Total (in billion €)
Santé publique France (2016)	2007-8	48,283 (17,527-74,426)	3 M (in $€_{2008}$)	145 (43-223)
Santé publique France (2021)	2016-9	39,541 (14,160-61,690)	3.3 M (in $€_{2018}$)	130 (47-204)
Personal provisional calculations (2026)*	2025	24,900* (15,340 – 31,708)	3.80 M (in $€_{2025}$)	94 (58 – 120)
Personal provisional calculations (2026)*	2025	24,900* (15,340 – 31,708)	8.35 M** (in $€_{2025}$)	208 (128 – 265)

*: Definitive results to be released by Santé publique France. Provisional calculations based on the RR recommended by HRAPIE-2 for long term natural mortality ≥25 years (1.10 for a 10 µg/m^3 $PM_{2.5}$ change, IC95% 1.06-1.13, WHO, 2025), average French population-weighted annual exposure (9.6 µg/m^3), and average annual French natural mortality ≥25 years (580,000).

**: VSL in USD_{2022} expressed in $€_{2025}$.

2.4 Concluding remarks

Does a single VSL apply to all causes of death?

No, a contextual VSL would be preferable but …

… very few studies provide contextual values,

… OECD (2012) found no marked differences between environment, health and transport,

… OECD (2025) found that among the 12 risk types considered, VSL was statistically significantly affected only by cancer (positively) and military risk (negatively),

… Masterman and Viscusi (2025) found that VSL was positively affected by cancer, but no difference between heat-related and accidental deaths, nor between deaths in the general population or among seniors (+65).

=> non-contextual VSL can be a reasonable proxy for contextual VSL when the characteristics of the deaths do not differ too much.

Future issues

- Compare transferred values with countries' official values (when they exist),
- Discuss the age-independent VSL / VOLY assumption (child vs. adult or elderly, quality of life at death …).

3 Temporal issues associated with LT economic assessment

3.1 Methodological aspects of economic assessment

- **Implementation timeframe:** the change in population exposure will (generally) not be immediate (**as assumed in standard QHIA)** but gradual, due to political/technical implementation timescales.
- **Accounting for the cessation lag:** since LT health effects result from the impact of a cumulative process on health status, their degeneration and improvement are not immediate once exposure has ceased (**as assumed in standard QHIA**).

=> A **comprehensive impact assessment (CIA)** should correct QHIA-based economic impacts when used in CBA.

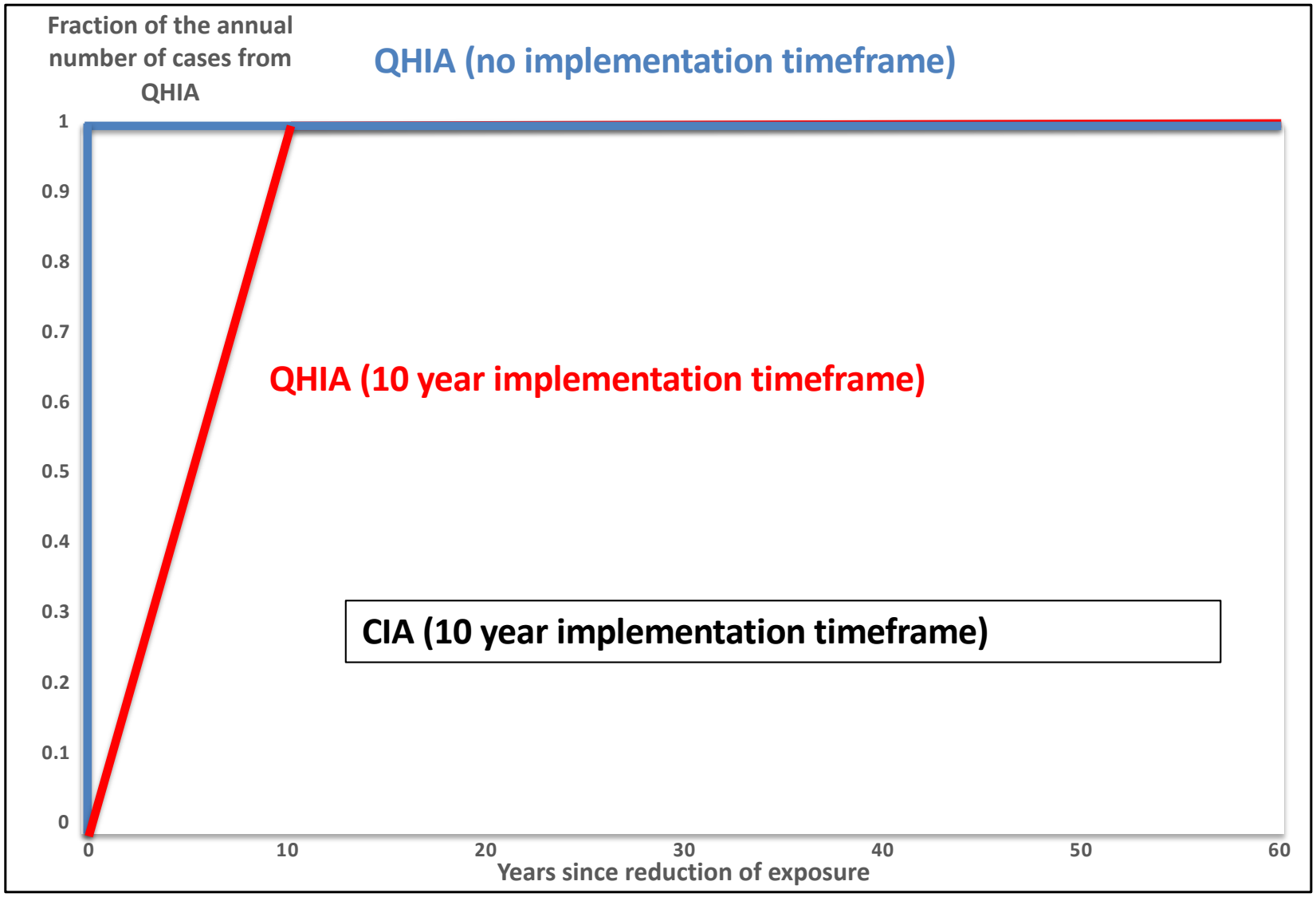
The correction factor depends on the disease, on the implementation of reduction policies, on the horizon and on the discount rate (Chanel & Cucchi, 2024; Medina et al., 2025; Who-Emapec, 2026).

Computations for LT morbidity and mortality are based on the following functional form:

$$\#cases_t = \#cases\ without\ exposure + (\#cases\ with\ exposure - \#cases\ without\ exposure).exp(-t/\tau)$$

3.2 Application to 4 health indicators

Figure 6 Comparing QHIA's and CIA's numbers of cases over time for 4 health outcomes



3.2 Application to 4 health indicators

Figure 6 Comparing QHIA's and CIA's numbers of cases over time for 4 health outcomes

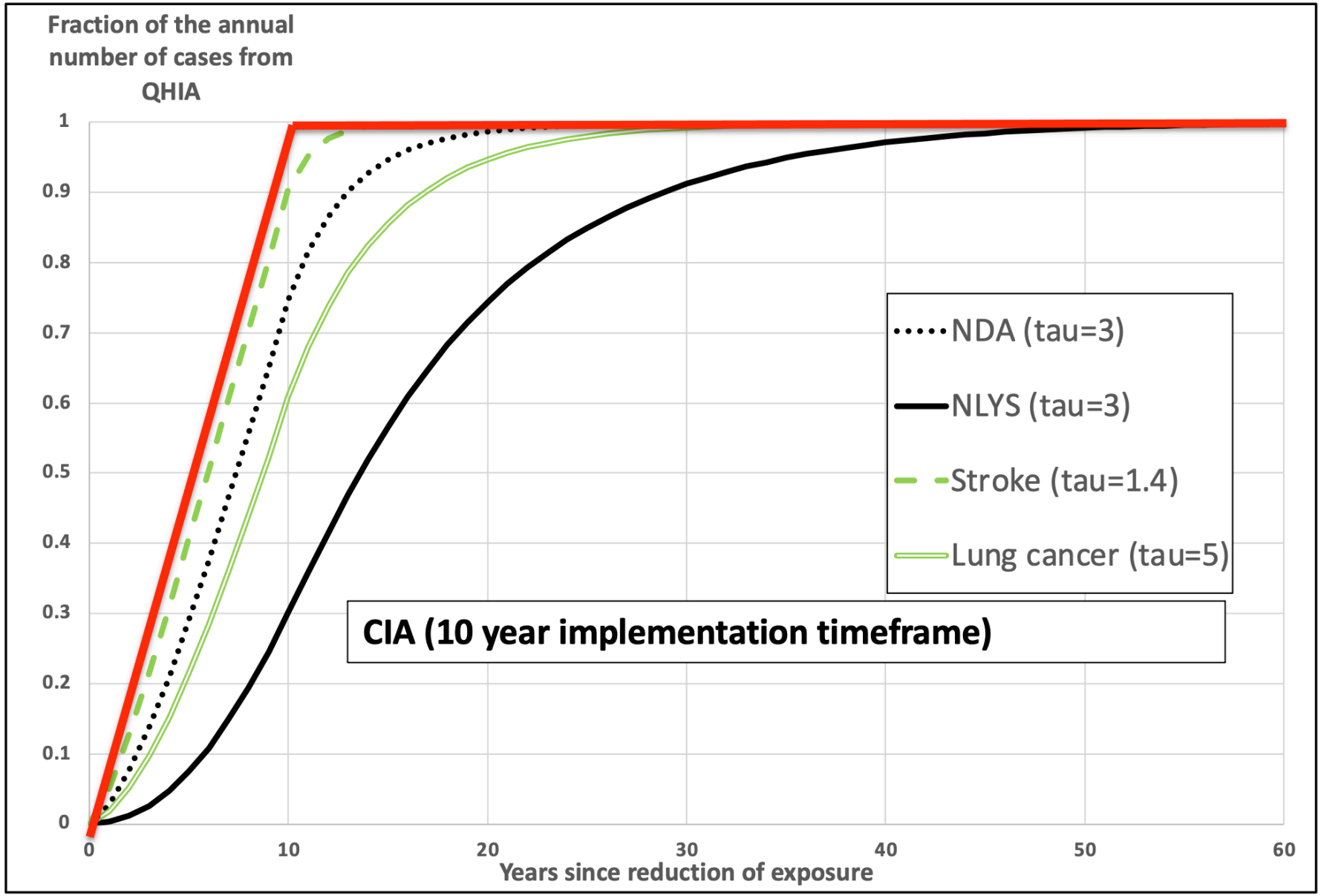


Table 3 Correction factors to be applied to QHIA economic valuations to obtain CIA valuations (10 year implementation timeframe)

T (in years)	**1**	**5**	**10**	**20**	**50**	**100**
$\boldsymbol{\delta = 0\%}$						
A_D $(\tau = 3)$	0.028	0.149	0.359	0.658	0.878	0.951
A_{LY} $(\tau = 3)$	0.003	0.032	0.114	0.337	0.687	0.853
A_{Stroke} $(\tau = 1.4)$	0.051	0.223	0.493	0.788	0.957	0.994
$A_{Lung\ cancer}$ $(\tau = 5)$	0.018	0.110	0.295	0.628	0.920	0.989
$\boldsymbol{\delta = 3\%}$						
A_D $(\tau = 3)$	0.028	0.145	0.339	0.603	0.788	0.842
A_{LY} $(\tau = 3)$	0.003	0.032	0.110	0.313	0.596	0.699
A_{Stroke} $(\tau = 1.4)$	0.051	0.223	0.469	0.740	0.908	0.963
$A_{Lung\ cancer}$ $(\tau = 5)$	0.018	0.107	0.279	0.575	0.845	0.937
$\boldsymbol{\delta = 7\%}$						
A_D $(\tau = 3)$	0.028	0.141	0.314	0.531	0.655	0.671
A_{LY} $(\tau = 3)$	0.003	0.031	0.106	0.292	0.538	0.625
A_{Stroke} $(\tau = 1.4)$	0.051	0.217	0.439	0.673	0.809	0.844
$A_{Lung\ cancer}$ $(\tau = 5)$	0.018	0.103	0.258	0.505	0.707	0.760

Source: Chanel & Cucchi (2024)

3.3 Concluding remarks

- The standard QHIA estimates lead to greater health and economic benefits than the CIA.
- The overestimation is about 50% under reasonable assumptions.
- It increases *ceteris paribus* with the magnitude of the cessation lag and the discount rate.
- It decreases *ceteris paribus* both with the time horizon and with the implementation timeframe.

4. Conclusion

- The economic assessment of the long-term health impacts of environmental exposure is more complex than that of short-term impacts.
- They place a heavier burden on society.
- Including them in a CBA requires precautions.

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