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## Research article

## Air, land, and water pollutants and public health expenditures: Empirical data from selected EU countries in the transport sector

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## ABSTRACT

The increase in economic activity, particularly in transport, leads to a significant increase in emissions of pollutants, such as ammonia, arsenic and cadmium, at the European Union (EU) level. This can seriously impact human health and, consequently, public health spending. Based on data from 15 European Union countries from 1992 to 2020, a panel co-integration approach is used to study these pollutants' short- and long-term co-movements and per capita health expenditure. The results show a long-term relationship between ammonia, arsenic and cadmium emissions and per capita health spending, as they are panel-cointegrated. Ammonia and cadmium emissions exert a statistically significant positive effect on health expenditure in the short run, and arsenic emissions have a statistically significant positive impact in the long run. The forecast assessment of reductions in health spending resulting from policies to reduce emissions of air, land and water pollutants, such as ammonia, arsenic and cadmium, from the transport sector supports investments in its policies that reduce pressure on health spending. The reduction in annual healthcare expenditure is greater when these reductions are made sooner and more severely. Indeed, varying the reduction in emissions for each pollutant by 10% and 100%, respectively, from the first year for all countries over a 3-year period results in an average annual reduction in health spending of 2.05% and 51.02%, respectively. However, if we wait until the third year, the annual reduction is only 0.77% and 17.63% respectively.

## 1. Introduction

According to the European Environment Agency (EEA), emissions of ammonia, arsenic, and cadmium from the transport sector have steadily increased in European Union countries.<sup>1</sup> However, the transport sector needs to improve in regulating these emissions compared to other sectors, such as agriculture. This is alarming because these emissions harm the environment and health (Tumolo et al., 2020; Wyer et al., 2022).

Ammonia emissions contribute to biodiversity loss and climate change. Indeed, ammonia can be deposited onto land and water surfaces, leading to acidification and eutrophication. Soil acidification affects nutrient availability and alters ecosystem dynamics, while aquatic acidification harms marine organisms, disrupts ecosystems, and impairs water quality. In addition, excess ammonia in water bodies also contributes to eutrophication, which is the over-enrichment of nutrients in the water, promoting excessive growth of algae and aquatic plants and harming fish populations, impairing the usability of water resources for drinking and recreational purposes. Moreover, when released into the

atmosphere, ammonia reacts with other pollutants, such as nitrogen oxides and sulphur dioxide, to form fine particulate matter and secondary pollutants, like ammonium nitrate and ammonium sulphate. These create smog and haze, impairing air quality and potentially affecting human health with asthma, bronchitis or chemical pneumonitis (Farren et al., 2020; Gu et al., 2021; Giannakis et al., 2019; Ma et al., 2021).

Arsenic emissions also significantly impact the environment due to their toxicity and persistence in water, land and air. They pose a severe threat to aquatic ecosystems and soil-dwelling organisms and a significant risk to human health when consumed in water and food. Chronic exposure to arsenic leads to various health problems, such as skin lesions, cancers, cardiovascular diseases, neurological disorders, and developmental abnormalities (Bundschuh et al., 2021; Muzaffar et al., 2023; Vishwakarma et al., 2021; Zhang et al., 2020).

Cadmium emissions accumulate in the soil, water bodies, and atmosphere. This accumulation in aquatic and terrestrial ecosystems can disrupt the ecosystem's balance and lead to biodiversity declines.

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<sup>1</sup> See: <https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer-4>.

Additionally, humans can be exposed to cadmium by consuming contaminated fish, other seafood, vegetables, meat and fruits. Cadmium, a toxic heavy metal, mainly affects the kidneys and can cause renal failure. In addition, cadmium is classified as a human carcinogen, a suspected mutagen and a reproductive toxin and contributes to the risk of osteoporosis (Li et al., 2021; Ougier et al., 2021; World Health Organization, 2019).

Therefore, the impacts of ammonia, arsenic and cadmium emissions on social welfare can be wide-ranging. In this paper, we propose highlighting the magnitude of the financial health costs of ammonia, arsenic, and cadmium emissions that are polluting and harmful to the population's health. In this regard, we analyse the short- and long-term co-movements between ammonia, arsenic and cadmium emissions from the transport sector and per capita health expenditure and estimate the future financial consequences of policies to reduce its emissions. This will allow us to give more arguments for stricter regulation of these air, land, and water pollutants in the transport sector.<sup>2</sup>

Most analyses of health expenditure per capita (Atilgan et al., 2017; Rahman et al., 2018; Usman et al., 2019; Zaidi and Saidi, 2018) focused on the impacts of economic (Gross domestic product-GDP and income) and non-economic (ageing population, annual growth of population, gender, life expectancy, and proportion of health care financed by the State and households) aspects. A few studies (Jerrett et al., 2003; Li et al., 2019; Ma et al., 2018; Yazdi and Khanalizadeh, 2017) examined the role of air pollutant emissions on health expenditure, and they generally observed a positive relationship. The Lancet Commission on Pollution and Health (2017) stated that pollution was expensive and generated health costs, representing 1.7% of annual expenditure on health in high-income countries. This echoes the finding of Jerrett et al. (2003), who used cross-sectional data on 49 counties in Ontario (Canada) to examine the relationship between air pollution and health expenditure. They found that more polluted counties had higher health expenditure per capita. In addition, a study by Yazdi and Khanalizadeh (2017) on the Middle East and North African countries from 1995 to 2014 found that carbon and particulate emissions between 2.5 µm and 10 µm were significantly and positively linked to higher health expenditure. Recently, Li et al. (2019) and Ma et al. (2018) also discovered a positive relationship between air pollution emissions and healthcare expenditure in China. To complement this literature, the impact of pollutants affecting air, water and land on health expenditure should be studied. The current study deals with this topic. It focuses on emissions of ammonia, arsenic, and cadmium, which are air, land, and water pollutants from the transport sector in countries of the European Union that are constantly increasing and poorly regulated.<sup>3</sup>

Although governments constantly question the sustainability of financing health systems, which strains already overstretched public budgets, only a few articles address the temporal dynamics between health expenditure and pollutants. Narayan and Narayan (2008) examined the short-term and long-term impacts of air pollutant emissions on health expenditure in eight Organisation for Economic Co-operation and Development (OECD) countries (Austria, Denmark, Iceland, Ireland, Norway, Spain, Switzerland, and the UK) over 20 years from 1980 to 1999, while Mutjaba and Shahzad (2021) studied it in 28 OECD countries from 2002 to 2018. They found that sulphur and carbon

oxide emissions had a statistically significant positive effect on health expenditure over the long term. Yahaya et al. (2016) analysed 125 developing economies from 1995 to 2012. They found that carbon dioxide emissions had a positive impact on health expenditure per capita, and this impact increased over time. To enrich this literature, our paper examines, from a panel of 15 European Union countries during 1992–2020, the short- and long-term co-movements of ammonia, arsenic and cadmium emissions and per capita health expenditure. We use Pedroni's (1999, 2000) panel cointegration approach and estimate short- and long-run elasticities. This is crucial since knowing whether the short-run or long-run elasticity is essential for policymakers and other econometric modelling exercises like forecasting. To avoid a bias in the estimation of the parameters of interest, here pollutant emissions, we specify by controlling with other variables whose effects have already been well discussed in the literature, such as *Average annual wage*, *Consultation of a medical doctor*, *Fraction of children vaccinated against tetanus*, *Fraction of the population aged 65 or over*, *Gross domestic product*, *Insurance coverage*, *Life expectancy*, *The proportion of women in the population*, and *Total population*. Then, based on the results of the econometric models, we make forecasts of health spending by applying policies to reduce the emissions of the pollutants studied.

The main findings show a long-term relationship between ammonia, arsenic and cadmium emissions and per capita health spending, as they are panel-cointegrated. In the short run, the increase in ammonia and cadmium emissions increases the health expenditure per capita. In the long run, only the increase of arsenic emissions significantly increases it. Our study also indicates that reducing ammonia, arsenic or cadmium emissions in the countries studied would reduce health expenditure per capita. For example, a short-term policy to reduce the emissions of each of these three pollutants by 10% over three years could lead to an average reduction in per capita health spending across all countries studied from \$36.85 (0.77%) to \$97.57 (2.05%).<sup>4</sup> Therefore, policymakers should invest in stricter policies to reduce air, land, and water pollutant emissions to preserve the environment, prevent diseases, and reduce health expenditures. This could incentivise sustainable innovations, improve overall population health and potentially reduce the need for costly medical interventions.

The article is organised as follows. Section 2 describes the data and the model and outlines the a priori expectations. Section 3 presents the empirical results and the forecasts. Section 4 discusses the key findings and the policy recommendations. Finally, Section 5 concludes.

## 2. Data and model

### 2.1. Data

The empirical analysis is based on 15 European Union countries: Belgium, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, and Sweden. The country sample was dictated by data availability. We use annual data for 1992 to 2020. Table 1 presents all the variables and the descriptive statistics of our study.<sup>5</sup> All variable definitions are in the appendix.

<sup>2</sup> Other pollutants from the transport sector, such as lead, mercury, and nickel (heavy metals), which contaminate land, air, and water, could have been studied. However, according to EEA data, lead and nickel levels have significantly decreased over time to low levels, and mercury represents a small quantity. We have therefore chosen to focus on the pollutants that pose the greatest risk to health and the environment.

<sup>3</sup> From EEA, ammonia, arsenic and cadmium emissions in the other sectors (agriculture, energy supply, manufacturing and extractive industry, residential, institutional and commercial, and waste) are fairly stable or decreasing over time. Moreover, in these sectors, there is strong regulation.

<sup>4</sup> Other policies have been studied and are presented in section 3.4.

<sup>5</sup> Data are missing in the databases used: 3.4% for *Average annual wage per capita*; 8.5% for *Insurance coverage*; 1.8% for *Fraction of children vaccinated against tetanus*, and 26.6% for *Consultation of a medical doctor per capita and per year*. Values are missing completely randomly and can be processed. We used the multiple imputation techniques, which are the most robust technique because they provide values significantly close to those we could have observed (Aurélien and Steve, 2016).

**Table 1**  
Variables and descriptive analysis.

Variable	Min	Max	Mean	Median	Standard deviation
<i>Dependent variable</i>					
Health expenditure per capita (USD. current PPPs)	324.83	6938.98	2666.71	2420.85	2666.71
<i>Economic indicators</i>					
Average annual wage per capita (USD. current PPPs)	16,319.00	67,163.00	42,672.99	44,201.00	638.06
Consultation of a medical doctor per capita and per year	2.19	13.75	6.17	6.20	0.10
Fraction of children vaccinated against tetanus (%)	62.00	100.00	95.47	97.00	0.23
Fraction of the population aged 65 or over (%)	10.30	23.30	16.54	16.60	0.13
Gross domestic product per capita (GDP. USD. current PPPs)	6196.50	93,355.60	30,914.34	29,051.50	631.86
Insurance coverage (%)	61.40	100.00	98.95	100.00	0.17
Life expectancy (Years)	69.20	84.00	78.75	79.10	0.13
The proportion of women in the population (%)	49.60	52.80	51.10	51.00	0.03
Total population	3,558,400.00	83,160,900.00	25,222,692.87	10,573,100.00	1,172,066.16
<i>Air, Land, and Water Pollutants</i>					
Ammonia emissions (kg)	39,347.22	32,892,972.55	4,000,642.36	1,991,214.55	260,440.41
Arsenic emissions (kg)	2.59	1631.91	211.70	60.42	17.68
Cadmium emissions (kg)	4.00	556.72	95.81	27.85	6.35

Sources: Dependent variable and Economic indicators from OECD and Air, Land, and Water Pollutants from European Environment Agency, May 2023

2.2. Health expenditure model

2.2.1. Panel cointegration approach

We use Pedroni's (1999, 2000) panel cointegration approach to estimate ammonia, arsenic and cadmium emissions' short and long-run impacts on health expenditure per capita. This method is divided into two steps. First, the model is written as follows:

$$lny_{it} = \gamma_0i + (lnx_{it})'\gamma_i + \epsilon_{it} \tag{1}$$

where the subscripts *i* and *t* are respectively country and time, *y<sub>it</sub>* is the dependent variable,  $\gamma_{0i}$  is the intercept, *x<sub>it</sub>* is a K-dimensional vector of the independent variables,  $\gamma_i$  is a (K \* 1) coefficients vector, and  $\epsilon_{it}$  is the error term. All variables are in natural logarithm form to allow their interpretation as elasticities.

Second, after estimating, we store the residual  $\hat{\epsilon}_{it}$ . We difference the original data series for each country and compute the residuals for the differenced model:

$$\Delta lny_{it} = (\Delta lnx_{it})'\sigma_i + \nu_{it} \tag{2}$$

where  $\sigma_i$  is a (K\*1) coefficients vector, and  $\nu_{it}$  is the error term. Next is the computation of the long-run variance of  $\hat{\nu}_{it}$ . Using the residual  $\epsilon_{it}$  of the original cointegrating equation (1), we calculate the autoregressive model.

In our study, the dependent variable, *y<sub>it</sub>*, is the health expenditure per capita. The independent variables, *x<sub>it</sub>*, are the economic indicators (control variables) and air, land and water pollutants (ammonia, arsenic and cadmium emissions) described in Table 1.

2.2.2. A priori expectations

Fig. 1 represents scatter plots for ammonia, arsenic and cadmium emissions and per capita health expenditure in the European Union countries studied. Both plots maintain the positive link between health expenditure and emissions, and all the Pearson correlation coefficients are significantly positive. Therefore, this indicates that per capita health expenditure increases as the ammonia, arsenic and cadmium emissions increase.

In addition, the trend in health spending from 1992 to 2020 in all the studied countries is on the rise. The ammonia, arsenic and cadmium emissions presented in Table 2 also show an upward trend from 1992 to 2020 for most European Union countries studied and the aggregation of all European Union countries. Sweden, however, is an exception. Over the period, it decreased the emission levels of the three pollutants. Sweden is a forerunner in the energy transition. Since the late 1980s, it has been subsidising and using alternative fuels to fossil fuels for its transport network. The carbon tax that hits all fossil fuels like oil has

existed since 1991. These interventions explain the decrease. According to the health economics literature (Sisko et al., 2019), there is a positive correlation between population growth and health expenditure. Sweden stands out among European countries due to its high population growth rate of 0.63% during the study period. In contrast, most other European countries have experienced population growth rates between 0 and 0.5% during the study period.<sup>6</sup> Therefore, the rise in healthcare spending in Sweden, despite the decrease in emissions of the three pollutants, could be attributed to the significant growth of the Swedish population during the period. This growth could counterbalance the effect of reducing pollutants on health spending.

Based on Fig. 1, Table 2 and the direct and negative link between human health and emissions of ammonia, arsenic and cadmium that has been scientifically established, we hypothesise that: *short- and long-run elasticities will reveal that ammonia, arsenic and cadmium emissions exert a statistically significant positive effect on health expenditure per capita.* We then expect positive and significant coefficients in equations (1) and (2) for ammonia, arsenic and cadmium emissions variables.

3. Empirical results

We realise a cointegration analysis to consider ammonia, arsenic and cadmium emissions' short- and long-term impacts on health expenditure per capita. To have more precision on the effects of emissions, we introduce control variables, i.e., the economic indicators in Table 1.

3.1. Panel unit root tests

Before testing panel cointegration, we need to verify that all the model variables are integrated in the order of one. We then run two-panel unit root tests - the Fisher-Augmented Dickey-Fuller (Fisher-ADF) and the Im, Pesaran, and Shin (IPS) tests.

The IPS (Im et al., 2003) test for a sample of N groups observed over T periods, and the IPS panel unit root regression of the conventional ADF test takes the following form:

$$\Delta z_{i,t} = \alpha_i + \beta_i z_{i,t-1} + \sum_{j=1}^k \psi_{i,j} \Delta z_{i,t-j} + u_{i,t}$$

The null hypothesis of a unit root in the panel compared to the alternative of all series being stationary processes is defined as:

<sup>6</sup> For more details see: <https://www.worlddata.info/europe/sweden/populationgrowth.php>.

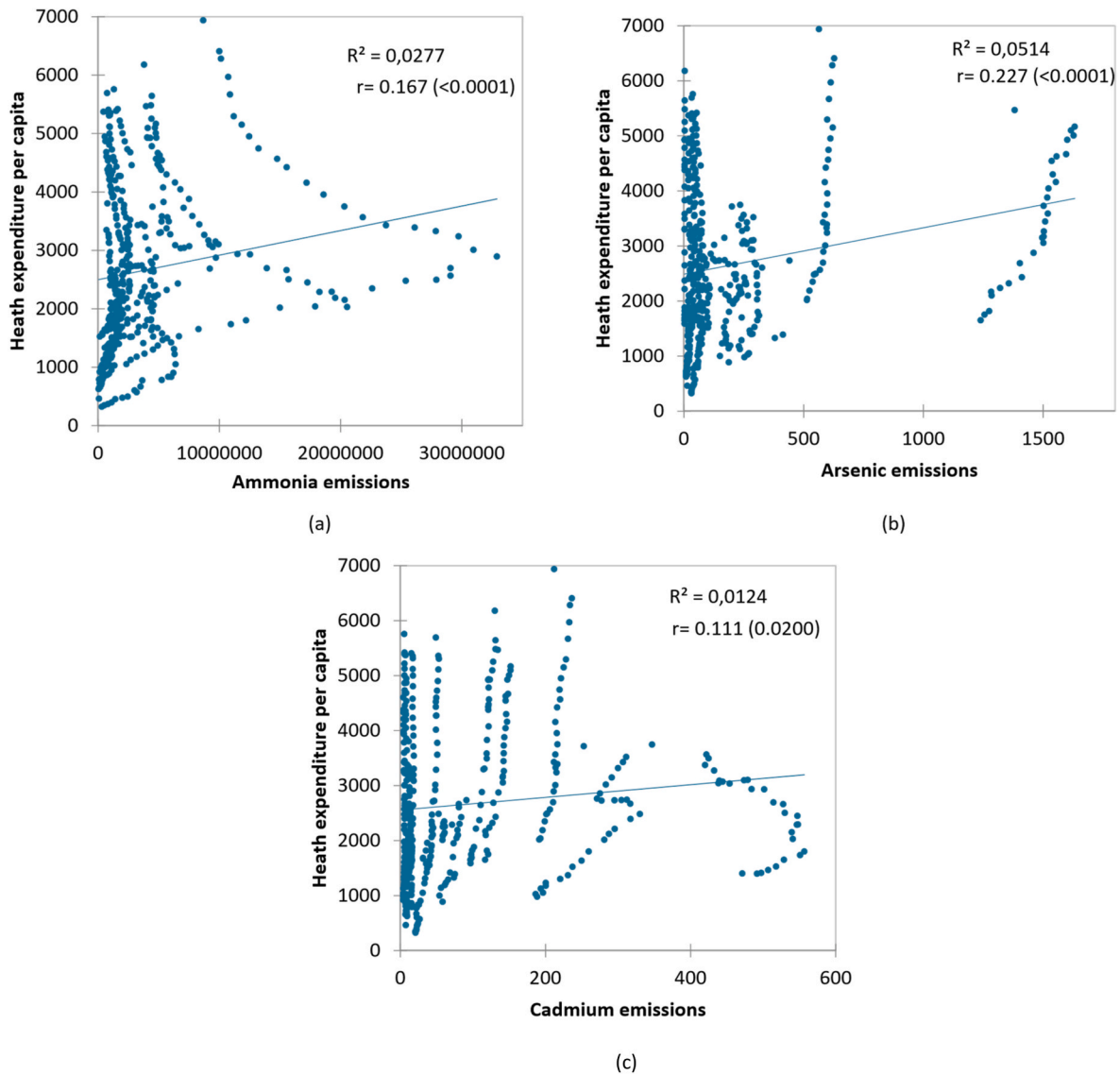


Fig. 1. Scatter plots for per capita health expenditure and Ammonia emissions (a); Arsenic emissions (b); and Cadmium emissions (c) in Union European countries. The straight line and r represent the linear trend and the Pearson correlation coefficient, respectively. P-values (Pearson) are in parenthesis.

$$H_0. \beta_i = 0 \text{ for all } i$$

$$H_1. \beta_i < 0 \text{ for } i = 1, 2, \dots, N1 \text{ and } \beta_i = 0 \text{ for } i = N1 + 1, N1 + 2, \dots, N.$$

The Fisher-ADF test used the results of Fisher (1932) and was proposed by Maddala and Wu (1999). The Fisher-ADF combines the p-values from individual unit root tests.

Table 3 reports the results of the Fisher-ADF and IPS tests. The null unit root hypothesis tests are based on log levels and the first differences of the log-level variables.

In the case of the log levels of the series' Consultation of a medical doctor per capita and per year, Fraction of children vaccinated against tetanus, Insurance coverage and Life expectancy, the Fisher-ADF and/or IPS tests reject the hypothesis of a null unit root. Moreover, for the first differences of the log-level variables, both tests reject the null unit root hypothesis at the 1% levels, except for Fraction of the population aged 65 or over. We then exclude this variable for the subsequent analysis. These results imply that all the other variables are integrated at order one. This confirms the integrational properties of all these variables, which are prerequisites for panel cointegration tests.

### 3.2. Panel cointegration test

This section aims to test for panel cointegration. Therefore, we include only the variables integrated at order one, excluding the variable Fraction of the population aged 65 or over from the remaining analysis. We perform a panel cointegration test using the Kao cointegration test, which tests the validity of the null hypothesis of no cointegration and the alternative cointegration with the panel ADF statistics. The Kao cointegration test suggests that health expenditure per capita and all the independent variables are cointegrated (t-Statistic:  $-5.7581$ ; p-value  $< 0.0001$ ). Since the test is significant at the 1% level, this confirms that our variables are panel-cointegrated and that our model is valid.

### 3.3. Panel elasticities

After verifying that none of our explanatory variables were correlated using Pearson's correlation test, we conducted a cross-sectional dependence test. This is a crucial diagnostic step before conducting panel data analysis. Since all the studied factors are common in industrialised countries, cross-sectional dependence may appear. Ignoring the cross-sectional dependences may provide inefficient statistical

**Table 2**  
Trend and average growth in health expenditure per capita and air, land, and water pollutants over 1992–2020.

Country	Year	Health expenditure per capita	Ammonia emissions	Arsenic emissions	Cadmium emissions
Belgium	1992	1525.71	145,613.60	34.48	14.98
	2020	5406.97	844,609.78	33.33	15.28
	1992–2020	4.66%	10.28%	−0.06%	0.11%
Czech Republic	1992	462.64	71,885.42	13.84	7.52
	2020	3805.14	763,446.22	25.39	11.49
	1992–2020	8.08%	12.00%	2.31%	1.64%
Denmark	1992	1554.37	347,488.33	66.25	40.35
	2020	5693.65	734,755.45	32.42	49.00
	1992–2020	4.79%	4.06%	−2.23%	0.71%
Finland	1992	1334.32	544,222.26	60.18	5.07
	2020	4604.62	685,324.33	44.61	4.01
	1992–2020	4.61%	1.37%	−0.82%	−0.75%
France	1992	1651.13	979,940.57	1239.34	116.85
	2020	5468.41	3,950,368.40	1381.23	134.42
	1992–2020	4.42%	6.63%	0.44%	0.55%
Germany	1992	2019.3	14,994,624.95	513.53	191.45
	2020	6938.98	8,661,387.63	563.73	211.98
	1992–2020	4.52%	−1.58%	0.36%	0.39%
Greece	1992	887.70	339,195.53	187.32	58.26
	2020	2486.09	1,145,402.86	217.13	52.82
	1992–2020	3.94%	5.59%	5.02%	−0.09%
Hungary	1992	627.19	39,347.22	9.11	9.41
	2020	2401.99	982,272.29	18.61	11.62
	1992–2020	5.07%	14.4%	2.79%	1.00%
Ireland	1992	919.42	136,043.93	22.18	4.01
	2020	5372.81	431,955.90	18.70	7.31
	1992–2020	6.61%	6.52%	−0.21%	2.36%
Italy	1992	1403.63	895,975.56	286.78	471.20
	2020	3747.17	4,483,689.75	235.04	346.94
	1992–2020	3.62%	9.64%	−0.63%	−0.99%
Netherlands	1992	1587.96	1,544,865.31	2.59	96.71
	2020	6180.01	3,788,336.33	3.26	130.30
	1992–2020	5.09%	3.11%	0.83%	1.08%
Poland	1992	324.83	301,295.32	31.48	20.94
	2020	2286.11	3,660,908.94	104.19	43.65
	1992–2020	7.31%	11.14%	4.61%	2.87%
Portugal	1992	790.8	75,482.16	58.41	15.95
	2020	3348.203	685,995.10	51.82	11.33
	1992–2020	5.41%	14.39%	−0.26%	−1.13%
Spain	1992	980.36	395,849.85	252.67	188.59
	2020	3718.05	2,108,226.16	200.57	252.80
	1992–2020	4.91%	11.3%	0.75%	1.20%
Sweden	1992	1537.27	2,123,132.88	94.64	5.83
	2020	5757.29	1,300,000.48	36.95	5.50
	1992–2020	4.97%	−1.25%	−3.08%	−0.18%
All the countries	1992	1173.78	1,528,997.53	191.52	83.14
	2020	4481.04	2,281,778.64	197.79	85.90
	1992–2020	5.19%	7.25%	0.69%	0.58%

Note: The third line for each country shows growth from 1992 to 2020. For 'All the countries', the years 1992 and 2020 represent the average of all countries.

inference. We check the presence of cross-sectional dependence in the panel data using the Pesaran CD statistic (Pesaran, 2021). We obtain a Pesaran CD coefficient at 10.1544 with a p-value lower than 0.0001. Therefore, this result shows that the null hypothesis of cross-sectional dependence is rejected at the 1% statistical significance level, implying strong evidence of the presence of cross-sectional dependence. The panel-corrected standard error (PCSE) technique effectively deals with cross-sectional dependence (Ikpesu et al., 2019; Le and Nguyen, 2019). Therefore, the long- and short-run panel elasticities are generated using panel-corrected standard error (PCSE) estimators and panel vector error correction model (VECM) estimators, respectively. Tables 4 and 5 present the long- and short-run elasticities, respectively.

From Table 4, we first observe that the coefficients of *Average annual wage per capita*, *Fraction of children vaccinated against tetanus*, *Gross domestic product per capita*, *Insurance coverage*, *The proportion of women in the population*, *Total population* and *Arsenic emissions* are statistically significantly positive. This suggests that an increase in the quantity (as a percentage) of each of these independent variables leads to a corresponding increase in health expenditure per capita.

Our results confirm that income positively and significantly influences health spending in the long run (as in Bhatia and Cleland, 2001). Thus, when the income of the inhabitants of a country increases, this generates a demand for better quality services (Colombo, 2011) and, therefore, an increase in public health expenditure. Although our study shows that health expenditure increases proportionally less quickly than income, we have an income effect. The elasticity value is lower than one. Thus, healthcare expenditure may not be catalogued as a luxury good.

Moreover, our results verify that medical practice progress is one of the determinants in the level and growth of health expenditure (Ke et al., 2011). Indeed, increasing the price of vaccines and their use increases health expenditure.

Besides, our results justify that the GDP per capita is positively associated with healthcare expenditure in the short- and long-run. A wide strand of literature (Usman et al., 2019; Yao et al., 2019) examined the connection between healthcare and GDP and verified this result. One explanation is the price levels of care, which vary considerably depending on the country. Generally, the higher the country's GDP per capita, the higher the prices of the care services provided (linked to

**Table 3**  
Panel unit root tests.

Variable	ln (Variable)		Δln(Variable)	
	IPS test	Fisher-ADF test	IPS test	Fisher-ADF test
Health expenditure per capita	0.4510 (0.6740)	23.5074 (0.7938)	-5.9523*** (<0.0001)	91.2078*** (<0.0001)
Average annual wage per capita	-0.0688 (0.4725)	37.5283 (0.1622)	-8.0346*** (<0.0001)	123.2317*** (<0.0001)
Consultation of a medical doctor per capita and per year	-0.7564 (0.2246)	63.4885*** (0.0003)	-8.5965*** (<0.0001)	142.0138*** (<0.0001)
Fraction of children vaccinated against tetanus	-5.0866*** (<0.0001)	83.4369*** (<0.0001)	-10.4283*** (<0.0001)	156.3860*** (<0.0001)
Fraction of the population aged 65 or over	6.9760 (0.9999)	5.0511 (0.9999)	-0.2691 (0.3939)	25.4460 (0.7030)
Gross domestic product per capita	-0.6890 (0.2454)	29.0280 (0.5161)	-6.2642*** (<0.0001)	96.6526*** (<0.0001)
Insurance coverage	-3.0254*** (0.0012)	42.3543*** (0.0001)	-8.2880*** (<0.0001)	80.9411*** (<0.0001)
Life expectancy	-2.2999** (0.0107)	48.5881** (0.0173)	-7.7372*** (<0.0001)	121.2593*** (<0.0001)
The proportion of women in the population	4.6449 (0.9999)	21.3717 (0.8759)	-8.0798*** (<0.0001)	124.8277*** (<0.0001)
Total population	1.4729 (0.9296)	27.8190 (0.5800)	-4.3622*** (<0.0001)	69.9678*** (<0.0001)
Ammonia emissions	0.2851 (0.6122)	37.7775 (0.1555)	-5.2651*** (<0.0001)	89.6616*** (<0.0001)
Arsenic emissions	-0.1853 (0.4264)	39.4650 (0.1156)	-6.2118*** (<0.0001)	102.7094*** (<0.0001)
Cadmium emissions	0.7970 (0.7872)	26.7973 (0.6338)	-4.0411*** (<0.0001)	69.5859*** (<0.0001)

Note: \*\*\*, \*\* and \* denote statistical significance at the 1%, 5% and 10% levels, respectively. p-values are in parenthesis.

salaries and the level of technical progress). Our results also underline that its expenditure is growing faster than GDP in the long run. This effect is frequently linked to the inflationary effect of technical progress.

Moreover, our results underline that a higher level of social health insurance increases health expenditure. This highlights that moral hazard in health insurance exists (Einav and Finkelstein, 2018). In other words, individuals, on average, consume less healthcare when they are required to pay more for it out of pocket. Wagstaff and Bank (2009) and Wagstaff and Moreno-Serra (2009) also found this result in examining OECD countries and Eastern European and Central Asian countries.

Likewise, our results show that a higher proportion of women in the population strongly increases health expenditure. A 2019 study by the Kaiser Family Foundation found that women pay more than men for healthcare services during every phase of their life. This result is also verified in Owens (2008) and a study of DREES (2023). This difference is because women are more diligent about annual health check-ups than men and have to pay for gynaecological care, while men are not.

Afterwards, contrary to Hitiris and Posnett (1992) and Di Matteo and Di Matteo (1998), our results demonstrate that the size of the population is significant in determining health expenditure. An explanation may be linked to the phenomenon of density dependence.

Indeed, when the density of a population is high, the members of a population meet more frequently, and the probability of transmission of a disease or parasites increases. All of this could then generate an increase in health expenditure.

Concerning arsenic emissions, our results indicate a positive effect on health expenditure. Its chronic exposure is a source of illnesses. Over time, it increases the weakened individuals, making them more vulnerable to disease. Individuals increasingly and frequently use care,

**Table 4**  
Long-run elasticities  
Model: Panel-corrected standard error (PCSE) Dependent variable: ln Health expenditure per capita.

Coefficient	Std. Error	t-Statistic	Prob.
Const	-24.3749***	1.0013	-24.3431 <0.0001
ln Average annual wage per capita	0.2699***	0.0107	25.0344 <0.0001
ln Consultation of a medical doctor per capita and per year	-0.0654***	0.0082	-7.9217 <0.0001
ln Fraction of children vaccinated against tetanus	0.2016***	0.0270	7.4643 <0.0001
ln Gross domestic product per capita	1.1777***	0.0130	89.9553 <0.0001
ln Insurance coverage	0.3604***	0.0376	9.5843 <0.0001
ln Life expectancy	-0.5197***	0.1325	-3.9195 <0.0001
ln The proportion of women in the population	4.1630***	0.2522	16.5024 <0.0001
ln Total population	0.0348***	0.0046	7.4668 <0.0001
ln Ammonia emissions	-0.0026	0.0033	-0.7982 0.4251
ln Arsenic emissions	0.0191***	0.0019	9.9015 <0.0001
ln Cadmium emissions	-0.0010	0.0018	-0.5430 0.5873
Observations	435		
R2	0.9925		
Adjusted R <sup>2</sup>	0.9923		
P-value(F)	<0.0001		

Note: \*\*\* denotes statistical significance at the 1% levels. Pesaran CD coefficient: 0.4458 (p-value: 0.6557).

increasing more significant long-term health expenditure.

Then, from Table 4, we observe that the coefficients of Consultation of a medical doctor per capita and per year and Life expectancy are statistically significantly negative. This implies that decreasing these determinants leads to increased health expenditure per capita.

Hence, our results show that the number of consultations reduces health expenditure over time. Intuitively, as shown by Bhatia and Cleland (2001), having recourse to consultations generates health expenditure. Nevertheless, health monitoring can also reduce the risk of serious illnesses. This preventive measure may reduce health expenditure costs in the long term.

Moreover, our results indicate that life expectancy decreases health expenditures. These results are also verified in part of Linden and Ray's (2017) work for OECD countries from 1970 to 2012 and in Bilgel and Tran (2013), which studied the Canadian provinces from 1975 to 2002. The latter find that a one-year increase in life expectancy determines a decrease in health spending. Thus, our result rejects the assumption that population ageing increases public spending (Bayar et al., 2021). Every older adult would not necessarily have more expenses each year to treat themselves, especially if they are in good health.

Finally, the emissions of ammonia and cadmium do not significantly impact health expenditure per capita in the long run.

Table 5 shows that the coefficients of Gross domestic product per capita remain statistically significantly positive. We observe that the

**Table 5**  
Short-run elasticities  
Model: Panel vector error correction model (VECM) Dependent variable:  $\Delta \ln$  Health expenditure per capita.

Coefficient		Std. Error	t-Statistic	Prob.
Const	<b>0.0304***</b>	0.0040	7.4876	<0.0001
$\Delta \ln$ Average annual wage per capita	0.0428	0.0420	1.0204	0.3081
$\Delta \ln$ Consultation of a medical doctor per capita and per year	0.0170	0.0288	0.5890	0.5561
$\Delta \ln$ Fraction of children vaccinated against tetanus	0.0136	0.0697	0.1959	0.8447
$\Delta \ln$ Gross domestic product per capita	<b>0.2075***</b>	0.0736	2.8192	0.0050
$\Delta \ln$ Insurance coverage	0.0013	0.0826	0.0161	0.9871
$\Delta \ln$ Life expectancy	-0.2349	0.6386	-0.3678	0.7132
$\Delta \ln$ The proportion of women in the population	-0.7681	1.8572	-0.4135	0.6794
$\Delta \ln$ Total population	0.3366	0.4312	0.7806	0.4355
$\Delta \ln$ Ammonia emissions	<b>0.0204*</b>	0.0110	1.8468	0.0655
$\Delta \ln$ Arsenic emissions	<b>-0.0450**</b>	0.0228	-1.9731	0.0491
$\Delta \ln$ Cadmium emissions	<b>0.1789***</b>	0.0636	2.8130	0.0051
$ECT_{t-1}$	<b>-0.0101**</b>	0.0041	-2.4428	0.0150
Observations		405		
R2		0.1734		
Adjusted R <sup>2</sup>		0.1460		
P-value(F)		<0.0001		

Note: \*\*\*, \*\* and \* denote statistical significance at the 1%, 5% and 10% levels, respectively.

explanatory power of this determinant is considerably more significant in the long compared to the short run. This implies that this factor tends to have a higher impact on health expenditure per capita over time.

Moreover, we observe that the coefficient of *Arsenic emissions* is statistically significantly negative while the coefficients of *Ammonia emissions* and *Cadmium emissions* are statistically significantly positive.

Hence, our results indicate that ammonia and cadmium emissions have a significant positive relationship with health expenditure in the short run but no effect in the long run. In contrast, arsenic emissions have a bidirectional relationship in the short and long run. This highlights the importance of adequately dissociating short-term and long-term effects. Numerous studies have examined the link between healthcare and air pollutants (for example, [Chaabouni and Saidi, 2017](#); [Yazdi and Khanalizadeh, 2017](#)). These studies reveal that air pollutants are positively and significantly linked to health expenditure. Our results separate the short and long-term effects. In the short run, ammonia and cadmium emissions weigh heavily on the economic cost for people by increasing their health expenditures. These pollutants' direct and immediate harmful effects on human health can explain these results. Concerning arsenic emissions, its positive effect only appears in the long run. Its chronic exposure is a source of illnesses. Over time, it increases the weakened individuals, making them more vulnerable to disease. Individuals increasingly and frequently use care, increasing more significant long-term health expenditure.

Finally, our results show that the one period lagged error correction term,  $ECT_{t-1}$ , is statistically significant at the 5% level. The fact that the

one-period lagged error correction term is negative implies that after a shock to the system, health expenditure per capita equilibrium returns. We note that the coefficient on the one-period error correction term is  $-0.0101$ . This implies that after a shock, the speed of adjustment to equilibrium for the panel of fifteen Union European countries is considerably slow.

### 3.4. Forecasts

We now quantify the impact of policies aimed at reducing emissions of the pollutants studied on health spending. For this, we make projections. First, we estimate future explanatory variables from fixed-effect panel models.<sup>7</sup> For  $i \in N$  observations and  $t \in T$  periods:

$$\ln y_{it} = \omega_i + \Omega \ln y_{it-1} + w_{it}$$

where  $\ln y_{it}$  is the dependent variable observed for individual  $i$  at time  $t$ ,  $\ln y_{it-1}$  is the independent variable,  $\Omega$  is the parameter,  $\omega_i$  is the unobserved time-invariant individual effect, and  $w_{it}$  is the error term.

Once the future explanatory variables have been estimated, we evaluate future health spending from the Panel vector error correction model (VECM) for the short term and the Panel-corrected standard error (PCSE) model for the long term. Then, we vary pollutant emissions and recalculate future health spending from these models. The reduction in future health spending is estimated by making the difference between future health expenditures without and with variations.

Typically, the duration of the short-term policies will be three years, and the long term policies will be twenty years. The average annual reduction of country  $i$  over the period between the year  $t + 1$  and the year  $t + p$  will be assessed as follows:

$$R_i^{t+1/t+p} = \frac{1}{p} \sum_{n=t+1}^{t+p} R_{in}$$

Where is  $R_i^{t+1/t+p}$  the average reduction of country  $i$  over the period between the year

$t + 1$  and the year  $t + p$ ,  $p \in \{3; 20\}$ , and  $R_{in}$  is the reduction of country  $i$  of year  $n$ .

Based on the results of [Tables 4 and 5](#), we propose different policies. For short-term policies, since all pollutants significantly impact health spending, we first envisage a policy to reduce all pollutants. Secondly, since only ammonia and cadmium emissions positively affect health spending, we focus on two policies to reduce these pollutants respectively. Concerning long-term policies, since only arsenic emissions positively and significantly impact health spending, we propose only a policy to reduce arsenic emissions. [Table 6](#) summarises the results of reducing health spending based on these policies with different emission reduction levels (10%, 50% and 100%).<sup>8</sup> The reference year  $t$  is the last year of our study, i.e. the year 2020. This implies that  $t = 2020$ .

[Table 6](#) shows that for low pollutant emission reduction rates (10%), there may be increases in health spending for some countries (see lines min in [Table 6](#)). It points out that the higher the rate of reduction in pollutant emissions, the higher the reduction in health spending. This is in favour of strict policy.

In addition, [Table 6](#) indicates that the earlier the policy is applied, the greater the reduction effects on health spending. So, acting quickly is more effective.

<sup>7</sup> The object of the time series is the study of variables over time. In our sample, we have both individual (country) and temporal (year) data. The time series has only one (temporal) dimension. However, individual data should be taken into account. For this, the panel models are the most suitable because they represent a double dimension: individual and temporal. The results of the models are in [Table 7](#) in the appendix.

<sup>8</sup> Reductions under different policies were also calculated at the country level. The results are presented in [Tables 8–11](#) in the appendix.



**Table 6**  
Annual reduction in health expenditures according to different policies for all countries.

Average annual reduction in health expenditures per capita in USD (in %) over the period 2021–2023												
	10 % reduction in emissions compared to 2020 of each pollutant from the first year.		10 % reduction in Ammonia emissions compared to 2020 from the first year.		10 % reduction in Cadmium emissions compared to 2020 from the first year.		10 % reduction in emissions compared to 2020 of each pollutant from the third year.		10 % reduction in Ammonia emissions compared to 2020 from the third year.		10 % reduction in Cadmium emissions compared to 2020 from the third year.	
<b>Min</b>	51.93	(1.53)	-1.1	(-0.01)	47.95	(1.61)	20.15	(0.51)	-2.52	(-0.04)	17.21	(0.66)
<b>Max</b>	226.63	(2.45)	82.29	(0.89)	194.2	(2.91)	89.01	(0.96)	37.49	(0.4)	69.52	(0.77)
<b>Mean</b>	97.57	(2.05)	24.47	(0.50)	96.06	(2.08)	36.85	(0.77)	10.59	(0.21)	34.28	(0.72)
<b>Median</b>	89.94	(2.17)	18.05	(0.59)	102.31	(1.93)	30.91	(0.84)	8.14	(0.26)	37.3	(0.72)
Average annual reduction in health expenditures per capita in USD (in %) over the period 2021–2023												
	50 % reduction in emissions compared to 2020 of each pollutant from the first year.		50 % reduction in Ammonia emissions compared to 2020 from the first year.		50 % reduction in Cadmium emissions compared to 2020 from the first year.		50 % reduction in emissions compared to 2020 of each pollutant from the third year.		50 % reduction in Ammonia emissions compared to 2020 from the third year.		50 % reduction in Cadmium emissions compared to 2020 from the third year.	
<b>Min</b>	254.9	(10.07)	42.67	(1.17)	282.01	(9.16)	90.55	(3.45)	16.23	(0.36)	98.56	(4.03)
<b>Max</b>	1008.67	(10.91)	191.52	(2.07)	1097.74	(17.39)	353.49	(3.86)	74.46	(0.80)	375.94	(4.17)
<b>Mean</b>	500.25	(10.55)	80.7	(1.69)	559.78	(12.14)	175.04	(3.70)	29.9	(0.62)	193.61	(4.09)
<b>Median</b>	520.75	(10.66)	70.19	(1.78)	571.31	(11.37)	184.43	(3.74)	25.73	(0.67)	198.42	(4.09)
Average annual reduction in health expenditures per capita in USD (in %) over the period 2021–2023												
	100 % reduction in emissions compared to 2020 of each pollutant from the first year.		100 % reduction in Ammonia emissions compared to 2020 from the first year.		100 % reduction in Cadmium emissions compared to 2020 from the first year.		100 % reduction in emissions compared to 2020 of each pollutant from the third year.		100 % reduction in Ammonia emissions compared to 2020 from the third year.		100 % reduction in Cadmium emissions compared to 2020 from the third year.	
<b>Min</b>	1252.8	(30.21)	599.62	(23.78)	996.76	(23.79)	438.5	(10.47)	209.58	(8.15)	348.4	(7.67)
<b>Max</b>	3824.33	(67.62)	2198.46	(27.66)	3688.27	(83.94)	1309.25	(23.24)	753.8	(9.48)	1268.26	(22.45)
<b>Mean</b>	2404.83	(51.02)	1,204,000	(25.45)	2128.04	(47.33)	829.2	(17.63)	415.74	(8.8)	733.06	(15.67)
<b>Median</b>	2396.11	(53.19)	1170.8	(25.08)	2093.58	(43.33)	828.98	(18.54)	405.77	(8.73)	719.47	(17.18)
Average annual reduction in health expenditures per capita in USD (in %) over the period 2021–2040												
	10 % reduction in Arsenic emissions compared to 2020 from the fifth year.		10 % reduction in Arsenic emissions compared to 2020 from the tenth year.		10 % reduction in Arsenic emissions compared to 2020 from the twentieth year.		50 % reduction in Arsenic emissions compared to 2020 from the fifth year.		50 % reduction in Arsenic emissions compared to 2020 from the tenth year.		50 % reduction in Arsenic emissions compared to 2020 from the twentieth year.	
<b>Min</b>	-7.59	(-0.10)	-7.94	(-0.11)	-1.34	(-0.01)	35.58	(0.86)	26.25	(0.60)	2.72	(0.05)
<b>Max</b>	32.81	(0.47)	26.38	(0.38)	3.19	(0.04)	128.53	(1.42)	93.46	(1.06)	9.44	(0.11)
<b>Mean</b>	11.51	(0.18)	8.54	(0.14)	0.89	(0.01)	68.91	(1.15)	50.56	(0.85)	5.2	(0.08)
<b>Median</b>	12.72	(0.22)	10.17	(0.17)	1.14	(0.01)	60	(1.18)	43.43	(0.87)	4.57	(0.09)
Average annual reduction in health expenditures per capita in USD (in %) over the period 2021–2040												
	100 % reduction in Arsenic emissions compared to 2020 from the fifth year.				100 % reduction in Arsenic emissions compared to 2020 from the tenth year.				100 % reduction in Arsenic emissions compared to 2020 from the twentieth year.			
<b>Min</b>	151.67	(2.01)			112.6	(1.50)			11.85	(0.16)		
<b>Max</b>	762.9	(20.87)			558.91	(15.19)			57.32	(1.53)		
<b>Mean</b>	392.4	(7.22)			287.94	(5.30)			29.64	(0.54)		
<b>Median</b>	365.89	(6.68)			267.79	(4.85)			27.38	(0.50)		

In conclusion, policies to reduce pollutant emissions effectively reduce health spending. They are all the more so when strict (high reduction rate) and implemented as soon as possible (from the first years).

#### 4. Discussion

The European Union has implemented several policies and regulations to reduce ammonia emissions. On December 14, 2016, the new Directive (EU) 2016/2284 relating to reducing national emissions of certain atmospheric pollutants (Directive National Emission Ceilings-NEC) entered into force. It sets national commitments to reduce emissions such as ammonia in the agricultural sector. The European Community has set itself the target of a 19% reduction by 2030 compared to 2005. Indeed, ammonia is mainly emitted by the agricultural sector (livestock, use of nitrogen fertilisers). Although agricultural emissions are dominant, other less studied sources, particularly the transport sector, may become critical. New projects using ammonia are emerging. For example, using ammonia in maritime transport efficiently stores the

energy needed to propel large ships on long voyages.<sup>9</sup> Road traffic continues to emit ammonia through the use of catalytic converters and, in particular, the selective catalytic reduction system (SCR). The recent integration and future increase of SCR could thus contribute to the increase in ammonia emissions from diesel and petrol vehicle traffic. Our study points out that reducing ammonia emissions in the countries studied would reduce health expenditure per individual (see Table 6). Therefore, strict regulations to control ammonia emissions as soon as possible are needed in the transport sector to limit health spending.

Moreover, efforts to mitigate arsenic emissions should also involve strict regulations in the transport sector. Arsenic is currently registered under REACH (Regulation (EC) No 1907/2006) but is still authorised for fuel. The European Union 2019/983 directive on protecting workers from the risks related to exposure to carcinogens or mutagens at work introduces an occupational limit value for arsenic inhalation. However, truck drivers constantly experience arsenic emissions through road

<sup>9</sup> <https://www.globalmaritimeforum.org/news/ammonia-as-a-shipping-fuel>.

wear, tire abrasion and brakes, which are difficult to control daily. Nevertheless, our study shows that a policy to reduce countries' arsenic emissions over the long term would reduce individual health spending (see Table 6). Therefore, it seems crucial to consider introducing a stricter policy to control arsenic emissions in the transport sector.

In 2016, the EU's National Emission Reduction Commitments Directive (NECD) required the EU to provide annual information on heavy metal emissions, such as cadmium. The amended NECD also introduced more ambitious reduction commitments, aiming to reduce air pollution's health impacts by half by 2030 compared with 2005 levels. Nevertheless, the regulation of cadmium is slowed down by limited knowledge of losses of heavy metals from harbours, shipping and gasoline vehicles. Our study goes against this slowdown. It shows the importance of health spending and supporting strict policies aimed at a short-term reduction in ammonia emissions. These will have a significant effect on reducing health spending (see Table 6).

Therefore, reducing ammonia, arsenic and cadmium emissions in the transport sector is a health challenge. It requires implementing measures and enhancing the knowledge of these pollutants. For road transport, it would be relevant to promote, through National and European funding, the development of pedestrian and bicycle traffic, sustainable mobility with an extensive public transport network, car parks at the entrance to cities, carpooling, electric vehicles, and encouraging rail freight transport. Another alternative, less costly for public finances, would be to reduce the need for transport by promoting, for example, teleworking and videoconference meetings. Concerning maritime transport, it would be preferable not to encourage the use of ammonia as a fuel instead of heavy fuel oils. Allowing the boats to have an electrical connection to the quay and encouraging the installation and maintenance of filters and other pollution control technologies would be preferable to avoid an increase in use and, therefore, in the emission of ammonia, arsenic and cadmium into the land, the air and water.

## 5. Conclusion

This paper emphasises the relationships between air, water and land pollutants (ammonia, arsenic and cadmium) and public health expenditures (per capita) in selected European Union countries. It aims to contribute to the economic literature on modelling the determinants of health expenditure per capita to help decision-makers better understand the levers allowing them to control state budgets. Its main contribution

## Appendix

### 5.1 Definitions from OECD and EEA

**Health expenditure per capita:** The per capita health spending level covers individual and population health care needs.

**Average annual wage per capita:** The average annual wages per full-time and full-year equivalent employee in the total economy. Average annual wages per full-time equivalent dependent employee are obtained by dividing the national-accounts-based total wage bill by the average number of employees in the real economy, which is then multiplied by the ratio of average usual weekly hours per full-time employee to average usual weekly hours for all employees.

**Consultation of a medical doctor per capita and per year:** It is the number of consultations of a medical doctor (in private practice or as an outpatient) per inhabitant and year.

**Fraction of children vaccinated against tetanus:** The percentage of children receiving the tetanus vaccination in the recommended timeframe.

**Fraction of the population aged 65 or over:** It is the elderly dependency rate defined as the ratio between the elderly population and the working age (15–64 years) population.

**Gross domestic product per capita:** It is the standard measure of the value added by producing goods and services in a country per capita. As such, it also measures the income earned from that production or the total amount spent on final goods and services (less imports) per capita.

**Insurance coverage:** It is the total public and primary voluntary health insurance, i.e., the share of the population eligible for a defined set of primary health care goods and services. This may be under government schemes, social health insurance, compulsory private insurance, compulsory medical savings accounts and voluntary health insurance.

**Life expectancy:** It is the life expectancy at birth, defined as how long, on average, a newborn can expect to live if current death rates do not change.

**The proportion of women in the population:** It is the ratio between the women and the total population.

is to highlight the magnitude of the financial health costs to give more arguments in favour of stricter regulation of emissions of ammonia, arsenic and cadmium polluting and harmful to the population's health as soon as possible, particularly in the transport sector. Hence, the results of this work support the need for measures for a "zero pollution" transition and the ambition to preserve countries' public health systems.

This study has faced some limitations. We wanted to include a large dataset over a long period with all the countries of the European Union (27 countries). The study aimed to ensure reliable analysis and forecasts by maximising the number of valid observations, following the law of large numbers. Due to a lack of data, we could retain only 15 countries, and our field of study had to be reduced from 60 to 28 years. Moreover, we could not include other influencing determinants due to the lack of data on variables such as cancer incidence, physician and hospital density, etc., which could have been incorporated as variable explanations in the models.

Further research could be carried out. It could be interesting to quantify the benefits and costs of implementing the proposed policies in sectors other than health. This would not detract from the need to implement these policies that preserve public health systems but would shed light on the consequences for the economy as a whole. In addition, this work could be replicated for countries other than the European Union. Indeed, it could be exciting to extend it to Southeast Asian countries that are highly polluted by transport.

## CRediT authorship contribution statement

**Caroline Orset:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

**Total population:** It is defined as all nationals present or temporarily absent from a country and aliens permanently settled in a country. This indicator shows the number of people that usually live in an area.

**Ammonia emissions:** It is a measure of the amount of ammonia (NH<sub>3</sub>) emissions as a result of the transport sector (logistics and air freight or airlines, marine, road and rail, and their respective infrastructures).

**Arsenic emissions:** It is a measure of the amount of arsenic (As) emissions as a result of the transport sector (logistics and air freight or airlines, marine, road and rail, and their respective infrastructures).

**Cadmium emissions:** It is a measure of the amount of cadmium (Cd) emissions as a result of the transport sector (logistics and air freight or airlines, marine, road and rail, and their respective infrastructures).

### 5.2 Panel estimations

**Table 7**  
Estimations.

Model: Panel fixed effects model

Dependent variable: In Average annual wage per capita<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.0828	0.0720	1.149	0.2511
In Average annual wage per capita <sub>t-1</sub>	0.9928***	0.0067	146.100	<0.0001
Observations	420			
R <sup>2</sup>	0.9814			
Adjusted R <sup>2</sup>	0.9814			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Insurance coverage<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	1.2911***	0.1024	12.60	<0.0001
In Insurance coverage <sub>t-1</sub>	0.7192***	0.0222	32.25	<0.0001
Observations	420			
R <sup>2</sup>	0.7266			
Adjusted R <sup>2</sup>	0.7202			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Gross domestic product per capita<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.2141***	0.0374	5.726	<0.0001
In Gross domestic product per capita <sub>t-1</sub>	0.9828***	0.0036	269.000	<0.0001
Observations	420			
R <sup>2</sup>	0.9944			
Adjusted R <sup>2</sup>	0.9944			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Ammonia emissions<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	1.1879***	0.1144	10.380	<0.0001
In Ammonia emissions <sub>t-1</sub>	0.9219***	0.0078	118.100	<0.0001
Observations	420			
R <sup>2</sup>	0.9718			
Adjusted R <sup>2</sup>	0.9718			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Consultation of a medical doctor per capita and per year<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.0299	0.0186	1.604	0.1095
In Consultation of a medical doctor per capita and per year <sub>t-1</sub>	0.9819***	0.0103	94.480	<0.0001
Observations	420			
R <sup>2</sup>	0.9568			
Adjusted R <sup>2</sup>	0.9567			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Life expectancy<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.1204***	0.0223	5.398	<0.0001
In Life expectancy <sub>t-1</sub>	0.9729***	0.0051	190.300	<0.0001
Observations	420			
R <sup>2</sup>	0.9889			
Adjusted R <sup>2</sup>	0.9889			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Total population<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.0196***	0.0041	4.698	<0.0001
In Total population <sub>t-1</sub>	0.9990***	0.0002	3958	<0.0001
Observations	420			
R <sup>2</sup>	0.9999			
Adjusted R <sup>2</sup>	0.9999			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Arsenic emissions<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.0205	0.0155	1.319	0.1879
In Arsenic emissions <sub>t-1</sub>	0.9953***	0.0034	289.100	<0.0001
Observations	420			
R <sup>2</sup>	0.9952			
Adjusted R <sup>2</sup>	0.9951			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Fraction of children vaccinated against tetanus<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.7713***	0.1021	7.547	<0.0001
In Fraction of children vaccinated against tetanus <sub>t-1</sub>	0.8311***	0.0224	37.060	<0.0001
Observations	420			
R <sup>2</sup>	0.7770			
Adjusted R <sup>2</sup>	0.7727			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In The proportion of women in the population<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	-0.0655***	0.0181	-3.614	<0.0001
In The proportion of women in the population <sub>t-1</sub>	1.0166***	0.0046	220.700	<0.0001
Observations	420			
R <sup>2</sup>	0.9918			
Adjusted R <sup>2</sup>	0.9917			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

Model: Panel fixed effects model

Dependent variable: In Cadmium emissions<sub>t</sub>

Y <sub>t-1</sub>	Coefficient	Std. Error	t-Statistic	Prob.
Const	0.0094	0.0062	1.511	0.1315
In Cadmium emissions <sub>t-1</sub>	0.9986***	0.0016	620.600	<0.0001
Observations	420			
R <sup>2</sup>	0.9989			
Adjusted R <sup>2</sup>	0.9989			
P-value(F)	<0.0001			

Note: \*\*\* denotes statistical significance at the 1% levels.

### 5.3 Reduction in health expenditures

**Table 8**

Average annual reduction in health expenditures in USD according to different short-term policies.

Country	Average annual reduction in health expenditures per capita in USD over the period 2021–2023					
	10 % reduction in emissions compared to 2020 of each pollutant from the first year.	10 % reduction in Ammonia emissions compared to 2020 from the first year.	10 % reduction in Cadmium emissions compared to 2020 from the first year.	10 % reduction in emissions compared to 2020 of each pollutant from the third year.	10 % reduction in Ammonia emissions compared to 2020 from the third year.	10 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	121.20	37.26	111.61	46.90	16.71	40.07
Czech Republic	79.84	25.28	72.94	31.18	11.44	26.40
Denmark	135.44	44.51	122.21	52.08	20.03	43.19
Finland	114.40	36.15	102.31	45.15	16.39	37.30
France	98.98	11.95	105.91	36.05	4.17	37.31
Germany	91.69	-1.10	115.69	30.90	-2.52	40.44

(continued on next page)

Table 8 (continued)

Average annual reduction in health expenditures per capita in USD over the period 2021–2023						
Country	10 % reduction in emissions compared to 2020 of each pollutant from the first year.	10 % reduction in Ammonia emissions compared to 2020 from the first year.	10 % reduction in Cadmium emissions compared to 2020 from the first year.	10 % reduction in emissions compared to 2020 of each pollutant from the third year.	10 % reduction in Ammonia emissions compared to 2020 from the third year.	10 % reduction in Cadmium emissions compared to 2020 from the third year.
Greece	51.93	14.32	47.95	20.15	6.38	17.21
Hungary	61.18	18.05	58.11	23.86	8.14	21.26
Ireland	226.63	82.29	194.20	89.01	37.49	69.52
Italy	72.77	7.94	83.25	25.59	2.53	29.09
Netherlands	89.94	13.22	110.81	30.57	4.69	38.79
Poland	59.44	8.06	66.48	21.73	2.96	23.97
Portugal	78.10	25.18	69.44	30.91	11.49	25.29
Spain	70.19	15.19	70.94	25.96	6.36	24.88
Sweden	111.79	28.80	109.08	42.78	12.57	39.45
Average annual reduction in health expenditures per capita in USD over the period 2021–2023						
Country	50 % reduction in emissions compared to 2020 of each pollutant from the first year.	50 % reduction in Ammonia emissions compared to 2020 from the first year.	50 % reduction in Cadmium emissions compared to 2020 from the first year.	50 % reduction in emissions compared to 2020 of each pollutant from the third year.	50 % reduction in Ammonia emissions compared to 2020 from the third year.	50 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	579.40	101.25	640.06	203.66	38.62	221.21
Czech Republic	377.09	66.80	415.82	133.41	25.73	144.57
Denmark	651.71	116.57	717.87	228.07	44.60	246.68
Finland	520.75	92.95	571.31	184.43	35.88	198.42
France	559.57	76.31	635.46	194.66	26.35	219.78
Germany	602.28	70.19	701.10	206.49	22.01	241.63
Greece	254.90	42.67	282.01	90.55	16.23	98.56
Hungary	298.19	51.14	331.26	106.33	19.66	116.46
Ireland	1008.67	191.52	1097.74	353.49	74.46	375.94
Italy	444.35	59.80	509.96	154.00	20.45	176.57
Netherlands	572.70	80.50	664.48	195.87	27.72	228.27
Poland	340.56	47.32	389.41	119.64	16.64	136.46
Portugal	360.76	64.67	395.71	128.71	25.17	138.45
Spain	383.47	58.91	431.52	134.12	21.47	149.50
Sweden	549.27	89.93	612.98	192.09	33.45	211.67
Average annual reduction in health expenditures per capita in USD over the period 2021–2023						
Country	100 % reduction in emissions compared to 2020 of each pollutant from the first year.	100 % reduction in Ammonia emissions compared to 2020 from the first year.	100 % reduction in Cadmium emissions compared to 2020 from the first year.	100 % reduction in emissions compared to 2020 of each pollutant from the third year.	100 % reduction in Ammonia emissions compared to 2020 from the third year.	100 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	2482.79	1333.09	2093.58	854.85	460.39	719.47
Czech Republic	1532.79	860.49	1246.40	530.91	298.93	430.82
Denmark	3411.66	1490.62	3058.68	1168.89	513.23	1046.34
Finland	1449.57	1170.80	1065.92	502.80	405.77	368.35
France	3129.36	1442.09	3161.62	1079.56	497.14	1090.18
Germany	3776.67	1653.14	3688.27	1298.16	566.78	1268.26
Greece	1271.43	599.62	1217.72	443.14	209.58	423.74
Hungary	1252.80	694.73	996.76	438.50	243.77	348.40
Ireland	3624.22	2198.46	2785.15	1238.08	753.80	948.22
Italy	2927.35	1168.48	2828.35	1012.14	403.79	977.88
Netherlands	3824.33	1504.77	3292.54	1309.25	515.30	1127.62
Poland	1783.28	876.72	1624.17	622.09	305.71	566.56
Portugal	1389.28	814.14	1180.56	484.61	284.76	410.65
Spain	2396.11	952.05	2315.30	828.98	329.97	800.57
Sweden	1820.85	1300.77	1365.64	626.08	447.16	468.91

Table 9

Average annual reduction in health expenditures in % according to different short-term policies.

Average annual reduction in health expenditures per capita in % over the period 2021–2023						
Country	10 % reduction in emissions compared to 2020 of each pollutant from the first year.	10 % reduction in Ammonia emissions compared to 2020 from the first year.	10 % reduction in Cadmium emissions compared to 2020 from the first year.	10 % reduction in emissions compared to 2020 of each pollutant from the third year.	10 % reduction in Ammonia emissions compared to 2020 from the third year.	10 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	2.24	0.68	1.63	0.86	0.30	0.74

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Table 9 (continued)

Average annual reduction in health expenditures per capita in % over the period 2021–2023						
Country	10 % reduction in emissions compared to 2020 of each pollutant from the first year.	10 % reduction in Ammonia emissions compared to 2020 from the first year.	10 % reduction in Cadmium emissions compared to 2020 from the first year.	10 % reduction in emissions compared to 2020 of each pollutant from the third	10 % reduction in Ammonia emissions compared to 2020 from the third year.	10 % reduction in Cadmium emissions compared to 2020 from the third year.
Czech Republic	2.27	0.72	2.43	0.88	0.32	0.75
Denmark	2.22	0.73	1.74	0.85	0.32	0.70
Finland	2.38	0.75	2.26	0.94	0.34	0.77
France	1.83	0.22	1.93	0.66	0.07	0.69
Germany	1.53	−0.01	1.88	0.51	−0.04	0.67
Greece	2.17	0.59	2.91	0.84	0.26	0.72
Hungary	2.19	0.64	1.96	0.85	0.29	0.76
Ireland	2.45	0.89	1.61	0.96	0.40	0.75
Italy	1.67	0.18	2.73	0.58	0.05	0.66
Netherlands	1.59	0.23	1.80	0.54	0.08	0.68
Poland	1.80	0.24	2.44	0.65	0.08	0.72
Portugal	2.34	0.75	2.05	0.92	0.34	0.75
Spain	1.90	0.41	1.91	0.70	0.17	0.67
Sweden	2.16	0.55	1.87	0.82	0.24	0.76
Average annual reduction in health expenditures per capita in % over the period 2021–2023						
Country	50 % reduction in emissions compared to 2020 of each pollutant from the first year.	50 % reduction in Ammonia emissions compared to 2020 from the first year.	50 % reduction in Cadmium emissions compared to 2020 from the first year.	50 % reduction in emissions compared to 2020 of each pollutant from the third	50 % reduction in Ammonia emissions compared to 2020 from the third year.	50 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	10.72	1.87	9.28	3.76	0.71	4.09
Czech Republic	10.75	1.90	13.92	3.80	0.73	4.12
Denmark	10.70	1.91	10.18	3.74	0.73	4.05
Finland	10.85	1.93	12.89	3.84	0.74	4.13
France	10.34	1.41	11.37	3.60	0.48	4.06
Germany	10.07	1.17	11.37	3.45	0.36	4.04
Greece	10.66	1.78	17.39	3.78	0.67	4.12
Hungary	10.68	1.83	11.30	3.81	0.70	4.17
Ireland	10.91	2.07	9.16	3.82	0.80	4.06
Italy	10.20	1.37	16.04	3.53	0.46	4.05
Netherlands	10.12	1.42	10.86	3.46	0.49	4.03
Poland	10.32	1.43	14.46	3.62	0.50	4.13
Portugal	10.81	1.93	11.80	3.86	0.75	4.15
Spain	10.42	1.60	11.41	3.64	0.58	4.06
Sweden	10.65	1.74	10.74	3.72	0.64	4.10
Average annual reduction in health expenditures per capita in % over the period 2021–2023						
Country	100 % reduction in emissions compared to 2020 of each pollutant from the first year.	100 % reduction in Ammonia emissions compared to 2020 from the first year.	100 % reduction in Cadmium emissions compared to 2020 from the first year.	100 % reduction in emissions compared to 2020 of each pollutant from the third	100 % reduction in Ammonia emissions compared to 2020 from the third year.	100 % reduction in Cadmium emissions compared to 2020 from the third year.
Belgium	45.95	24.67	29.01	15.82	8.52	13.31
Czech Republic	43.72	24.54	43.33	15.14	8.52	12.29
Denmark	56.04	24.48	40.57	19.20	8.43	17.18
Finland	30.21	24.40	35.62	10.47	8.45	7.67
France	57.87	26.67	45.98	19.96	9.19	20.16
Germany	63.19	27.66	58.86	21.72	9.48	21.22
Greece	53.19	25.08	83.94	18.54	8.76	17.73
Hungary	44.89	24.89	38.23	15.71	8.73	12.48
Ireland	39.20	23.78	23.79	13.39	8.15	10.25
Italy	67.22	26.83	64.63	23.24	9.27	22.45
Netherlands	67.62	26.60	55.56	23.15	9.11	19.94
Poland	54.08	26.59	65.36	18.86	9.27	17.18
Portugal	41.66	24.41	39.65	14.53	8.54	12.31
Spain	65.10	25.87	53.01	22.52	8.96	21.75
Sweden	35.32	25.23	32.47	12.14	8.67	9.09

**Table 10**  
Average annual reduction in health expenditures in USD according to different long policies.

Average annual reduction in health expenditures per capita in USD over the period 2021–2040			
Country	10 % reduction in Arsenic emissions compared to 2020 from the fifth year.	10 % reduction in Arsenic emissions compared to 2020 from the tenth year.	10 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	17.04	13.09	1.47
Czech Republic	13.05	10.23	1.19
Denmark	18.63	14.25	1.58
Finland	13.72	10.43	1.14
France	−7.59	−7.94	−1.34
Germany	−1.42	−2.78	−0.65
Greece	2.48	1.45	0.06
Hungary	12.72	10.17	1.24
Ireland	31.45	24.20	2.70
Italy	3.80	2.06	0.04
Netherlands	32.81	26.38	3.19
Poland	6.77	4.88	0.48
Portugal	10.14	7.80	0.88
Spain	3.99	2.41	0.13
Sweden	15.13	11.51	1.26
Average annual reduction in health expenditures per capita in USD over the period 2021–2040			
Country	50 % reduction in Arsenic emissions compared to 2020 from the fifth year.	50 % reduction in Arsenic emissions compared to 2020 from the tenth year.	50 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	80.79	59.54	6.18
Czech Republic	57.18	42.75	4.57
Denmark	87.74	64.26	6.58
Finland	71.45	52.62	5.45
France	60.00	41.78	3.80
Germany	70.36	49.60	4.67
Greece	35.58	26.25	2.72
Hungary	51.36	39.06	4.33
Ireland	128.53	93.46	9.44
Italy	59.78	43.43	4.36
Netherlands	98.04	73.70	7.94
Poland	51.57	38.24	4.01
Portugal	55.58	41.77	4.52
Spain	51.58	37.63	3.82
Sweden	74.11	54.25	5.55
Average annual reduction in health expenditures per capita in USD over the period 2021–2040			
Country	100 % reduction in Arsenic emissions compared to 2020 from the fifth year.	100 % reduction in Arsenic emissions compared to 2020 from the tenth year.	100 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	376.20	274.80	28.02
Czech Republic	242.36	179.23	18.74
Denmark	404.91	293.81	29.55
Finland	365.89	267.79	27.38
France	762.90	558.91	57.32
Germany	719.87	523.61	52.86
Greece	286.70	214.35	22.92
Hungary	194.10	145.78	15.75
Ireland	487.97	349.89	34.39
Italy	491.32	362.33	37.65
Netherlands	151.67	112.60	11.85
Poland	340.18	253.13	26.79
Portugal	298.18	223.08	23.94
Spain	406.68	300.46	31.34
Sweden	357.15	259.33	26.09

**Table 11**  
Average annual reduction in health expenditures in % according to different long policies.

Average annual reduction in health expenditures per capita in % over the period 2021–2040			
Country	10 % reduction in Arsenic emissions compared to 2020 from the fifth year.	10 % reduction in Arsenic emissions compared to 2020 from the tenth year.	10 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	0.25	0.19	0.02
Czech Republic	0.28	0.22	0.02
Denmark	0.25	0.19	0.02

(continued on next page)

Table 11 (continued)

Average annual reduction in health expenditures per capita in % over the period 2021–2040			
Country	10 % reduction in Arsenic emissions compared to 2020 from the fifth year.	10 % reduction in Arsenic emissions compared to 2020 from the tenth year.	10 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Finland	0.22	0.17	0.01
France	−0.10	−0.11	−0.01
Germany	−0.01	−0.03	0.01
Greece	0.07	0.04	0.01
Hungary	0.32	0.26	0.03
Ireland	0.29	0.23	0.02
Italy	0.06	0.03	0.01
Netherlands	0.47	0.38	0.04
Poland	0.15	0.10	0.01
Portugal	0.22	0.17	0.01
Spain	0.08	0.04	0.01
Sweden	0.24	0.18	0.02
Average annual reduction in health expenditures per capita in % over the period 2021–2040			
Country	50 % reduction in Arsenic emissions compared to 2020 from the fifth year.	50 % reduction in Arsenic emissions compared to 2020 from the tenth year.	50 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	1.20	0.89	0.09
Czech Republic	1.25	0.94	0.10
Denmark	1.19	0.87	0.09
Finland	1.18	0.87	0.09
France	0.86	0.60	0.05
Germany	0.94	0.66	0.06
Greece	1.07	0.79	0.08
Hungary	1.32	1.00	0.11
Ireland	1.22	0.89	0.09
Italy	1.04	0.75	0.07
Netherlands	1.42	1.06	0.11
Poland	1.14	0.84	0.08
Portugal	1.21	0.91	0.09
Spain	1.06	0.77	0.07
Sweden	1.18	0.87	0.08
Average annual reduction in health expenditures per capita in % over the period 2021–2040			
Country	100 % reduction in Arsenic emissions compared to 2020 from the fifth year.	100 % reduction in Arsenic emissions compared to 2020 from the tenth year.	100 % reduction in Arsenic emissions compared to 2020 from the twentieth year.
Belgium	5.03	3.65	0.36
Czech Republic	8.08	5.91	0.60
Denmark	3.44	2.54	0.26
Finland	6.68	4.85	0.48
France	5.63	4.12	0.42
Germany	10.15	7.43	0.76
Greece	20.87	15.19	1.53
Hungary	7.24	5.41	0.57
Ireland	2.01	1.50	0.16
Italy	8.53	6.12	0.60
Netherlands	6.81	5.02	0.52
Poland	3.65	2.71	0.28
Portugal	7.39	5.50	0.58
Spain	6.29	4.70	0.50
Sweden	6.47	4.77	0.49

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