Economic Analysis of Health Impacts within the Framework of France's National Air Pollution Control Programme (APCP)

Simone SCHUCHT [1], Elsa REAL [1], Florian COUVIDAT [1], Laurence ROUIL [1], Jean-Marc BRIGNON [1], Nadine ALLEMAND [2], Guillaume LE CLERCQ [3], David FAYOLLE [3]

[1] INERIS, Verneuil-en-Halatte, France

[2] CITEPA, Paris, France

[3] AJBD, Paris, France

Mail address: Simone.schucht@ineris.fr, Elsa.real@ineris.fr

INERIS, DRC/DECI/EDEN, Parc Technologique ALATA, BP2, 60550 Verneuil-en-Halatte, Tel.: 03 44 55 65 14

Key words: Atmospheric pollution, health effects, monetisation, cost-benefit analysis, air quality

Abstract

Within the framework of the 'Decision support for developing the National Air Pollution Control Programme' project PREPA (in French "Programme national de réduction des émissions de polluants atmosphériques", financed by the French Environment Ministry), a multi-criterion assessment was applied to some 50 emission-reduction measures for all sectors of the economy. These programmes are compulsory under the National Emission Ceilings Directive [1, 2], setting air-pollution emission reduction obligations for NOx, $PM_{2.5}$,

SO_2, NH_3 and NMVOCs for each Member State by 2020 and 2030. The article presents the approach implemented for one criterion within the multi-criterion assessment: the economic evaluation of health impacts. Starting from information on the emission reductions associated with each of the measures, their contribution to an improvement of air quality was simulated using the CHIMERE model. Then the French population's exposure to the air pollutants was calculated. By combining these data with concentration-response functions in the ARP-FR model, the health effects avoided thanks to each measure were calculated. The corresponding health benefits were also compared with the direct costs of the measures studied. The research identified numerous measures with a positive benefit-cost ratio. The implementation of the measures selected by political decision for the French Programme should allow a reduction of 40% of air-pollution health costs by 2030 (compared to 2010).

1. Background

Air quality in France is a topical issue from both a societal and a regulatory viewpoint. Societal interest reflects public and media awareness of the health impacts of atmospheric pollution. The media regularly cover premature mortality linked to fine particles ($PM_{2,5}$), peaks of pollution and 'hotspots' (e.g. the Vallée de l'Arve). Indeed, air pollution has significant impacts on human health, in terms of morbidity, mortality and well-being [3, 4, 5, 6, 7]. These health impacts have major economic consequences in terms of the costs of illness to the health system and employers, and willingness to pay (WTP) to avoid suffering and premature death [8, 9, 10, 11]. Estimates suggest that in France in 2010, air pollution was responsible for the loss of about 430,000 years of life due to chronic exposure of the population to $PM_{2,5}$, and about 2,300 premature deaths due to acute exposure to ozone (O_3) [12].

On the regulatory side, limits for concentrations of PM_{10} et $PM_{2,5}$ particles and nitrogen dioxide (NO_2) continue to be exceeded, as do target levels for O_3 laid down in the Air Quality Directive [13]. The European Commission has begun pre-litigation proceedings against the

French authorities with the supply of reasoned opinions related to PM_{10} and NO_2 for different areas of France. Neither is France in compliance with emission ceilings for nitrogen oxides (NOx) imposed since 2010 by the National Emission Ceilings Directive [1].

The national Air Pollution Control Programme (APCP, French acronym PREPA) is intended to manage these two areas of regulation. The obligation to establish, adopt and implement national APCPs is laid down in the European Directive on the reduction of national emissions of certain atmospheric pollutants [2][1]. This Directive, which defines commitments to reduce anthropic atmospheric emissions (in %) by 2020 and 2030 (compared to 2005) of 5 pollutants – sulphur dioxide (SO_2), NOx, non-methane volatile organic compounds (NMVOCs), ammoniac (NH_3) and $PM_{2,5}$ – also describes the aims of these programmes. Each Member State must anticipate measures to reduce the emissions of all economic sectors (agriculture, energy, industry, transport, domestic heating, non-road mobile machinery, solvents, etc.) and so contribute to a twofold goal of compliance with:

- national air-pollution control objectives ($PM_{2,5}$, SO_2, NOx, NH_3 and NMVOCs);
- air-quality objectives (levels of PM_{10}, $PM_{2,5}$, NO_2 and O_3 in ambient air).

It is in this context that the Ministère de la Transition Énergétique et Solidaire[2] (MTES - Ministry for an Ecological and Solidary Transition) commissioned a group of service suppliers[3] to conduct research entitled 'Decision support for developing the National Air Pollution Control Programme.

The project process was as follows:

- identification by the group of service suppliers (in cooperation with the MTES) of a set of emission-reduction measures; assessment of these measures according to a multi-criterion table (individually and combined in multi-measure scenarios); presentation of the results in a series of stakeholder consultations and the reconstitution of all results (September 2014 – July 2016);

[1] It presents the revised version of Directive 2001/81/EC on national emission ceilings [1].
[2] The Air Quality Agency (BQA) of the Energy and Climate General Directorate (DGEC) of the Ministry for an Ecological and Solidary Transition (MTES).
[3] CITEPA (Inter-professional Technical Centre for Air Pollution Research), INERIS (National Institute for Industrial Environment and Risks), Energies Demain (Energies Tomorrow) and AJBD (research and consulting firm specialising in the environment).

- selection in a political process of air-pollution reduction measures to be chosen for the APCP regulatory text;
- an '*ex ante*' assessment of the scenario including the APCP measures chosen for the 2020 and 2030 deadlines, conducted by the group of service suppliers (start of 2017);
- publication of a decree [14] establishing national objectives for the reduction of emissions of certain atmospheric pollutants and an order [15] establishing the APCP (May 2017).

This article presents the economic assessment of the health impacts of measures to reduce atmospheric emissions implemented as part of the 'Decision support for developing the National Air Pollution Control Programme' project, as well as some analysis results provided as a guide.

2. Methods

Included in the 'Decision support for developing the National Air Pollution Control Programme' project, economic assessment of the health impacts of air pollution was one criterion of evaluation among others. The set of calculations (grey background), criteria (orange background) and analysis flows are shown in the diagram of Figure 1. In addition to the usual criteria (costs of measures, impact on air quality and health), the assessment takes into account other aspects relevant to the feasibility of emission reductions: the social acceptability of measures and the potential need for legal leverage [16, 17, 18, 19].

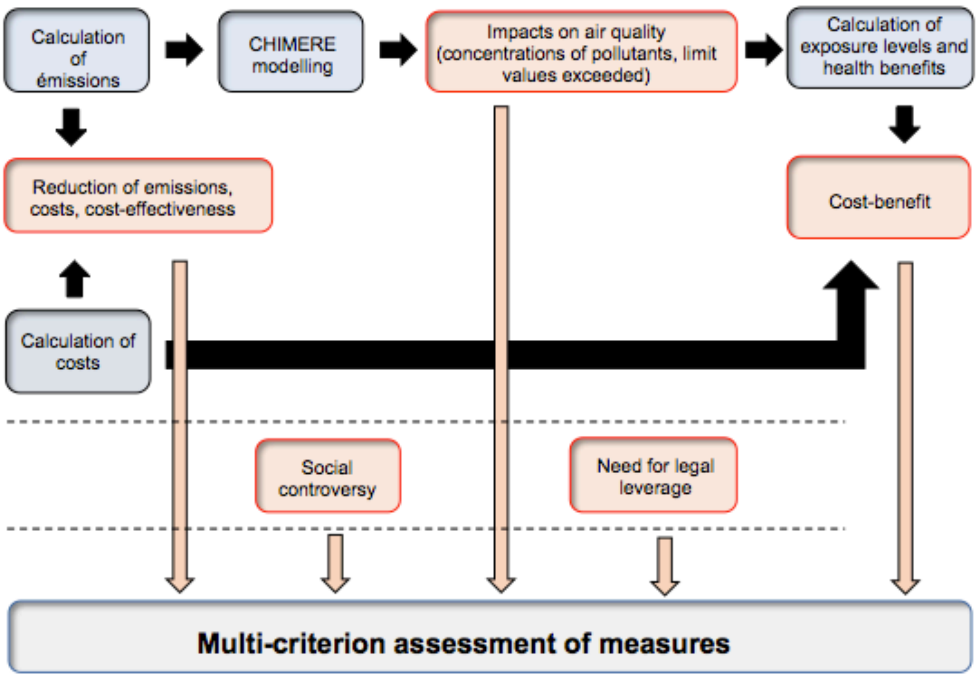

Figure 1. Multi-criterion characterisation of emission-reduction measures [source: adapted from 16]

The emission reduction potential of each measure analysed, together with the costs of these measures, were determined on the basis of emission-inventory data and specific technical and economic data. The CHIMERE air-quality model [20] was then applied to calculate the impacts of each of these measures on air quality, especially on levels exceeded locally and on the exposure of the French population to air pollutants. The health impacts due to an exposure of the French population to concentrations of $PM_{2,5}$, O_3 and NO_2 were quantified and monetised using the ARP-France model[4] which applies methodologies developed as part of the Clean Air For Europe[5] (CAFE) programme and the WHO/Europe 'Health Risks of Air Pollution in Europe' (HRAPIE) survey [21]. In a cost-benefit approach, the health impacts avoided were also compared to the costs of the measures studied.

The choice was made to assess France's APCP programme using methods directly comparable with those used to evaluate Directive 2016/2284/EU on a European level [22, 12]. To do this, approaches to an estimation of the costs of emission reduction and the assessment of health impacts matched those used on a European level.

[4] ARP was developed par M. Holland and J. Spadaro, EMRC (Ecometrics Research and Consulting).
[5] https://www.eea.europa.eu/themes/air/links/research-projects/clean-air-for-europe-programme-cafe

With regard to the evaluation of health impacts, the methodological choices made for CAFE and HRAPIE and applied to the APCP included concentration-response functions, linking levels of pollutant exposure to specific health impacts, as well as monetary indicators and their values. **Erreur ! Source du renvoi introuvable.** summarises the health indicators taken into account (in brackets, the age categories of the population for which the concentration-response functions were developed on the basis of epidemiological studies), the pollutant behind the impacts, the unit of impact, the concentration-response functions used and the monetary values per unit of impact.

Table 1: Health-impact indicators with associated concentration-response functions and monetary unit values

Health impact indicators	Pollutants	Unit	Concentration-response functions (relative risk)	Unit of monetary values used (price year 2013)
Acute Mortality (All ages) median VOLY	O_3	Life years lost	1,0029, 95%CI 1,0014 to 1,0043 per 10 µg.m-3	66 286 €
Respiratory hospital admissions (>64)		Cases	1,0044, 95%CI 1,0007 to 1,0083 per 10 µg.m-3	2 550 €
Cardiovascular hospital admissions (>64)			1,0089, 95%CI 1,0050 to 1,0127 per 10 µg.m-3	2 550 €
Minor Restricted Activity Days (MRADs all ages)		Days	1,0154, 95%CI 1,0060 to 1,0249 per 10 µg.m-3	48 €
Chronic Mortality (All ages), median VOLY	$PM_{2.5}$	Life years lost	1,062, 95%CI 1,040 to 1,083 per 10 µg.m-3	66 286 €
Infant Mortality (0-1yr) median VSL		Premature deaths	1,04, 95%CI 1,02 to 1,07 per 10 µg.m-3	1 878 288 €
Chronic Bronchitis (27yr +)		Cases	1,117, 95%CI 1,040 to 1,189 per 10 µg.m-3	61 576 €
Bronchitis in children aged 6 to 12			1,08, 95%CI 0,98 to 1,19 per 10 µg.m-3	675 €
Respiratory Hospital Admissions (All ages)			1,0019, 95%CI 0,9982.to 1,0402 per 10 µg.m-3	2 550 €
Cardiac Hospital Admissions (>18 years)			1,0091, 95%CI 1,0017 to 1,0166 per 10 µg.m-3	2 550 €
Restricted Activity Days (all ages)		Days	1,047, 95%CI 1,042 to 1,053 per 10 µg.m-3	106 €
Asthma symptom days (children 5-19yr)			1,028, 95%CI 1,006 to 1,051 per 10 µg.m-3	48 €
Lost working days (15-64 years)			1,046, 95%CI 1,039 to 1,053 per 10 µg.m-3	149 €
Bronchitis in children aged 5 to 14	NO_2	Cases	1,021, 95%CI 0,99 to 1,06% per 1 µg.m-3	675 €
Respiratory Hospital Admissions (All ages)			1,018, 95%CI 1,0115 to 1,0245 per 10 µg.m-3	2 550 €
Chronic Mortality (All ages), median VOLY		Life years lost	1,055, 95%CI 1,031 to 1,08 per 10 µg.m-3	66 286 €

The monetary values take into account market costs (e.g. health care) and non-market costs (e.g. years of life lost). The non-market costs applied to mortality are based on contingent assessments (stated preferences) where individuals (a representative sample of a heterogeneous population) are asked about their willingness to pay for measures that modify the risk of death [8, 18].

The health impacts quantified are the chronic or acute effects[6] of exposure of the population to concentrations of $PM_{2,5}$, l'O_3 and NO_2 in terms of morbidity and mortality.

Chronic mortality can be expressed either in terms of years of life lost or in terms of premature deaths. Years of life lost are monetised by the VOLY (Value of Life Year) indicator; premature deaths by the VSL (Value of Statistical Life) indicator. An argument in favour of the use of the years of life lost indicator is the fact that those years of life lost are calculated taking into account the age at which death occurs and life expectancy at the age

[6] Acute effects: effects due to variation in exposure over a few days; chronic effects: effects due to variations in exposure over the longer term, sometimes throughout one's life.

of death, while the premature-death indicator will always show an additional premature death, independently of the length of time by which air pollution shortens life (e.g. 3 months or 10 years).

In analyses currently conducted by the European Commission, the second indicator is also used, especially because in the CAFE methodology, willingness-to-pay (WTP) research was carried out to estimate the value of VSL and not VOLY [11, 23]. Calculation of the VOLY value was based on these VSL estimations. Average and median values of estimated WTP are available for both indicators. Monetisation of health impacts used to draw up the APCP was based on calculations of mortality (for the entire population) in terms of years of life lost, with monetisation by VOLY and the use of the median value, which consequently corresponds to the lower bracket of assessments conducted in Europe [12, 22].

In compliance with the recommendations of the WHO, all aerosols making up $PM_{2,5}$ are considered to display the same degree of noxiousness independently of their source and chemical makeup. Indeed, precise quantification of the effects of individual fine-particle components is not yet possible given our present state of knowledge [20, 24, 25].

More details of the ARP-FR model, its use and bibliographical sources for the health-impact indicators and calculations are provided in [16, 18, 26, 27].

3. Results

In this way, it was possible to assess the contribution to the reduction of health impacts and the cost-benefit performance of fifty or so measures to reduce emissions in all economic sectors. These measures and their results in terms of net health benefits (calculated as health benefits minus costs) by 2020 are presented in **Erreur ! Source du renvoi introuvable.**. In the table, measures related to existing regulations (already approved but not necessarily implemented) are presented on a blue background. The additional measures (not part of the regulations approved when the research was conducted) are presented on a green background. A certain number of measures primarily aimed at reducing emissions of greenhouse gases and tending to be part of climate policy were assessed with regard to their effects (co-benefits) on air quality. The costs of these measures were not taken into account in the analysis because they were seen as being more closely linked to energy and climate policy. Such measures are displayed on a pink background in the table.

Table 2: Summary of the health benefit and cost results (expressed in € million, price base 2013) of the measures analysed in the "Decision support for developing the APCP" project

Sectors	Measures analysed		Health benefits (*)	Costs	Net benefit
			in 2020 in € million (price year 2013)		
Measures in the industrial and energy-production sectors	PROC-IC1$_{ME\ SO2\ NOx\ PM}$	Order of 26 August 2013 relative to combustion plants of > 50 MWth	349	176	173
	PROC-IC2$_{ME\ SO2\ NOx\ PM}$	Decree of 2 May 2013 on the application of the general terms and Chapter II of the IED directive for energy processes (emission limits annex V or BAT-AEL high values)	2	45	-43
	PROC-IC3$_{ME\ SO2}$	Decree of 2 May 2013 on the application of the general terms and Chapter II of the IED directive for oil refining (BAT-AEL high values)	0	82	-82
	PROC-IC4$_{ME\ SO2\ NOx\ PM}$	Order of 26 August 2013 relative to combustion plants of 20 to 50 MW and order of 25 July 1997 modified for those of 2 to 20 MW	1006	228	778
	PROC-IC5$_{MA\ SO2\ NOx\ PM}$	Application of intermediate values between the low and high values of BAT-AELs for energy processes and oil refining	8	51	-43
Measures related to transport	TR1$_{ME}$	Euro 5 and V norms related to light and goods vehicles	1594	229	1365
	TR2$_{ME}$	Euro 6 and VI norms related to light and goods vehicles	2186	565	1621
	TR3$_{ME}$	Penetration of hybrid and electric vehicles	18	587	-569
	TR4$_{MA}$	Euro 6c stage with Real Driving Emissions cycle	4	129	-125
	TR5$_{MA}$	Regulation no.168/2013 of 15 January 2013 relative to two and three-wheel vehicles	0,5	9	-8
	TR6$_{MA}$	Replacement of part of public-vehicle pools with low-emission vehicles	2	14	-11
	TR7$_{MA}$	Traffic restrictions when air-quality warning thresholds are reached in urban areas	0	-31	31
	TR8$_{MA}$	Promotion of the development of clean urban public transport	6	312	-307
	TR9$_{MA}$	Tax increases on fuel	408	-1417	1826
	TR10$_{MA}$	Restricted access to town centres for the most polluting vehicles (ZCR - restricted traffic zone)	275	-107	383
	TR11$_{MA}$	Limitation of brake-abrasion emissions TR11MA (2) (3) Measures related to	282	693	-411
Measures related to combined transport	TC1$_{MA}$	Development of combined rail-road transport	3	-97	100
Measures related to non road mobile machinery for industry and farming	THR1$_{ME}$	Phases IIIB and IV of regulations for non-road mobile machinery for industry and farming	505	596	-91
	THR2$_{MA}$	Proposed regulations for internal combustion engines for NRMMs dated 25/09/2014	3	5	-2
Measures related to the residential and tertiary sectors	RT1$_{ME\ CO2}$	Residential sector - Private housing aid: renovation and heating systems	356	0	356
	RT2$_{ME\ CO2}$	Residential sector - Renovation of social housing	20	0	20
	RT3$_{ME\ CO2}$	Residential and tertiary sectors - Thermal insulation regulations for new buildings	3	0	3
	RT4$_{ME\ CO2}$	Tertiary sector - Renovation and changes in trend system	23	0	23
	RT5$_{ME\ CO2}$	Urban heating - Heating Fund, change in energy mix	50	0	50
	RT6$_{MA}$	New Flamme verte (Green flame) requirements / low hypotheses	252	-25	277
	RT7$_{MA}$	New Flamme verte (Green flame) requirements / high hypotheses	531	-18	549
	RT8$_{MA\ CO2}$	Residential sector - Compulsory thermal-insulation renovation when refurbishing facades and roofs	118	0	118
	RT10$_{MA\ CO2}$	Residential sector - Objective of 500,000 major renovations annually	256	0	256
	RT11$_{MA\ CO2}$	Tertiary sector - Decree for compulsory tertiary renovation by 2020 and consolidation by 2030	3	0	3
	RT12$_{MA\ CO2}$	Tertiary sector - Renovation of all public resources	8	0	8
	RT13$_{MA\ CO2}$	Tertiary sector - Objective of a reduction of 60% in tertiary-sector consumption by 2050	11	0	11
Measures related to agriculture	AGRI1$_{MA}$	Total ban on crop residue burning	15	0	15
	AGRI2$_{MA}$	Replacement of urea by other fertilisers	380	9	370
	AGRI3$_{MA}$	Increased grazing time (+20d)	55	-24	79
	AGRI4$_{MA}$	Two-phase feeding in pig production	4	0	4
	AGRI5$_{MA}$	Air cleaning in pig-production buildings	3	3	1
	AGRI6$_{MA}$	Frequent removal of slurry – V scraping	2	11	-9
	AGRI7$_{MA}$	Frequent removal of slurry – Gravity draining every fortnight	9	0	9
	AGRI8$_{MA}$	Covering of slurry trenches - high technology	7	22	-15
	AGRI9$_{MA}$	Covering of slurry trenches - low technology	8	0	8
	AGRI10$_{MA}$	Slurry-spreading by drop pipe	5	0,9	4
	AGRI11$_{MA}$	Slurry-spreading by injection	9	0,8	8
	AGRI12$_{MA}$	Immediate post-spreading incorporation of slurry and/or manure	278	83	195
	AGRI13$_{MA}$	Post-spreading incorporation of slurry and/or manure within 12 hrs	116	81	35
	AGRI14$_{MA}$	Post-spreading incorporation of slurry and/or manure within 24 hrs	69	57	12
	AGRI15$_{MA}$	Removal of battery-chicken droppings by belt with forced-air drying before storage	9	28	-19
	AGRI16$_{MA}$	Scraping of cattle manure in buildings	3	405	-402
	AGRI17$_{MA}$	Vaporisation in pig-production buildings	3	71	-68

The research identified measures whose health benefits were estimated to exceed costs (positive net benefit) and others whose costs exceeded health benefits (negative net benefit).

As an example, in the farming sector [19], the measure ‘replacement of urea by other mineral fertilisers’ (measure $AGRI2_{MA}$) leads to health benefits that exceed the additional cost[7] of the measure. Indeed, given that urea can emit more NH_3 than other mineral fertilisers, with the same dose of nitrogen spread, its replacement can reduce emissions of ammoniac and so the formation of ammonium nitrate, secondary aerosols. This ensures a major reduction in concentrations of fine particles and the related health impacts. The additional cost is limited to the price difference between the fertilisers. However, a measure such as ‘Removal of battery-chicken droppings by belt with forced-air drying before storage’ (measure $AGRI15_{MA}$) involves major investment for low reductions in NH_3 emissions, so with minor effects on the formation of fine particles and health. The costs of this measure are estimated to be greater than the health benefits.

Looking at the poor result for the ‘Penetration of hybrid and electric vehicles’ measure (measure $TR3_{ME}$), it should be noted that this can be explained by - among other factors - choices made according to the calculation of emission reductions on the one hand and benefits on the other. The reductions in emissions attributed to a measure are calculated in relation to a referential measure. Here, the referential measure represents the situation in 2020, with a greater share of vehicles as a whole complying with the Euro 6 norm than in the current technological mix. In fact, the potential for reducing air-polluting emissions beyond that which can already be achieved by the Euro 6 measure is relatively limited. However, the measure will certainly contribute to major reductions in greenhouse-gas emissions, whose benefits have not been quantified in the project (outside the perimeters of research). Their inclusion in cost-benefit analysis will necessarily improve the cost-benefit ratio of the $TR3_{ME}$ measure.

[7] In cost-effectiveness and cost-benefit research, the impacts and costs attributable to a given measure are generally calculated in relation to a referential measure. Such studies, therefore, look at the reduction of emissions and the costs that occur in addition to those of the referential technique.

Additional information explaining the hypotheses and so the results for all the APCP measures are provided in detail in [16, 17].

Following political processes of dialogue and the final selection of additional measures to be implemented as part of the APCP, the assessment of health impacts was applied to the scenario bringing together the measures listed in the order [15][8] for the 2020 and 2030 deadlines. This *'ex ante'* analysis [28] considers that the implementation of all the measures included in the APCP would enable annual health costs related to air pollution to be reduced to €23.5 billion euros in 2030 (expressed in 2013 €) compared to €40 billion in 2010 (-40%). This reflects costs avoided (benefits) of about €17 billion/year in 2030 compared to 2010[9]. This is a low estimate of the health benefits. The reasons for this are:

- calculation using the years of life lost indicator for chronic mortality (lower values than for premature deaths);
- calculation using median values for mortality (lower than average values);
- only 66% of chronic mortality linked to NO_2 taken into account in order to minimise any risk of double counting[10].

Also, other benefits related to reduced air pollution (reduction of the soiling and corrosion of buildings and materials; reduction of impacts on crops and ecosystems) were not monetised in the analysis and neither were benefits linked to greenhouse-gas reductions.

4. Conclusions

For each sector of activity and between sectors, the research compared different measures to reduce emissions according to different assessment criteria, and also their overall performance was evaluated using a multi-criterion analysis table. Scenarios including different combinations of measures analysed were also assessed according to their ability to

[8] The scenario also includes other existing measures which were not assessed within the project framework and are not listed in the APCP order, but in other plans (measures related to the National Low Carbon Strategy, for instance).
[9] Also, as an example, the reduction in exposure of the population to fine particles would – in 2030 compared to 2010 - avoid 180,000 years of life lost, almost 5 million work days lost, 12,000 cases of chronic bronchitis and 59,000 cases of bronchitis in children.
[10] According to HRAPIE, double counting of chronic mortality attributed to NO_2 on the one hand and $PM_{2,5}$ on the other could be as high as 33%.

reduce emissions to comply with emission ceilings and improve air quality. These results were used in the stakeholder consultation process that was implemented and the political decision-making process for the drawing up of the APCP.

The health benefits assessment approach applied is coherent with the one used in the evaluation of European Directives governing the APCP. Despite the fact that the health-benefit assessment was based on indicators leading to a certain underestimation of these benefits, it identified major health benefits that could be achieved through the implementation of additional emission-reduction measures.

Thanks to: The authors of the 'Decision support for developing the National Air Pollution Control Programme' project, who, aside from the co-writers of this article, included Simon Mariani (Énergies Demain), Jean-Marc André, Romain Bort, Sandra Dulhoste, Anaïs Durand, Céline Gueguen, Édith Martin, Étienne Mathias and Laetitia Nicco (CITEPA), together with Antoine Chaux, Jérôme Drevet, Sophie Hubin, Myriam Merad and Charline Pennequin (INERIS). The project was funded by the Marché MEDDE 1100025000 relative to support for the drawing-up of France's future Air Pollution Control Programme.

5. References

[1] Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants.

[2] Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants. The Directive amends Directive 2003/35/*EC* and repeals Directive 2001/81/EC.

[3] Pope C.A., Burnett R.T., Thun M.J. *et al.*, Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, Journal of the American Medical Association, 2002, 287 (9), 1132-1141.

[4] Curtis L., Rea W., Smith-Willis P. *et al.*, Adverse health effects of outdoor air pollutants. Environ. Int., 2006, 52(6), 815-830.

[5] Dockery D.W., Pope C.A., Xu X. et al., An association between air pollution and mortality in six US cities. N. Engl. J. Med., 1993, 329 (24), 1753-1759.

[6] Jerrett M., Burnett R.T., Pope C.A. *et al.*, Long-Term Ozone Exposure and Mortality. N Engl J Med, 2009, 360, 1085-1095.

[7] RCP, Royal College of Physicians, Every breath we take: the lifelong impact of air pollution. Report of a working party. London, 2016,124p.

[8] CGDD (General Commission for Sustainable Development), Report of the Commission des comptes et de l'économie de l'environnement (Commission of finances and

environmental economics) – Santé et qualité de l'air extérieur, dans MEDDE (dir.) (Health and quality of outdoor air, in the Ministry of Ecology, Sustainable Development and Energy), Service de l'économie, de l'évaluation et de l'intégration du développement durable (Economics, Assessment and Integration of Sustainable Development Department), 2012, 102p.

[9] CGDD (General Commission for Sustainable Development), Estimation des coûts pour le système de soins français de cinq maladies respiratoires et des hospitalisations attribuables à la pollution de l'air (Estimation of costs to the French Health System of five respiratory diseases and hospital treatment attributable to air pollution), Commissariat général au développement durable, Economics and documents, 122, April., 2015, 36p.

[10] WHO/OECD, Economic cost of the health impact of air pollution in Europe – Clean air, health and wealth, WHO Regional Office for Europe, OECD, Copenhagen, 2015, 66p.

[11] Hurley F., Hunt A., Cowie H. *et al.*, Methodology for the Cost-Benefit analysis for CAFE, volume 2: Health Impact Assessment', Service Contract for Carrying 134 out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme, 2005, 149p.

[12] Holland M., Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package, version 2, Corresponding to IIASA TSAP Report n° 11, Version 1, EMRC, 2014, 67p.

[13] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

[14] Decree no. 2017-949 of 10 May 2017 setting national objectives for the reduction of emissions of certain air pollutants pursuant to article L. 222-9 of the Code of the Environment.

[15] Order of 10 May 2017 establishing the National Air Pollution Control Programme.

[16] CITEPA et al., Aide à la décision pour l'élaboration du PREPA, rapport principal, Le Plan national de réduction des émissions de polluants atmosphériques (Decision support for developing the National Air Pollution Control Programme, main report, National Air Pollution Control Programme), AJBD, CITEPA, ÉnergiesDemain and INERIS, MEEM, 2016a, 189p. Available at: http://www.developpement-durable.gouv.fr/Le-Plan-national-de-reduction-des

[17] CITEPA et al., Aide à la décision pour l'élaboration du PREPA, annexe C, Fiches mesures détaillées, (Decision support for developing the National Air Pollution Control Programme, annex C, presentations of detailed measures, National Air Pollution Control Programme), AJBD, CITEPA, ÉnergiesDemain and INERIS, MEEM, 2016b, 484p. Available at: http://www.developpement-durable.gouv.fr/Le-Plan-national-de-reduction-des

[18] CITEPA et al., Aide à la décision pour l'élaboration du PREPA, annexe D, Méthodologie employée, Le Plan national de réduction des émissions de polluants atmosphériques (Decision support for developing the National Air Pollution Control Programme, annex D, methodology employed, National Air Pollution Control Programme), AJBD, CITEPA, ÉnergiesDemain and INERIS, MEEM, 2016c, 55p. Available at: http://www.developpement-durable.gouv.fr/Le-Plan-national-de-reduction-des

[19] Schucht S., Colette A., Brignon J.-M., Bessagnet B. & Rouïl L., Aide aux décideurs - Évaluation des coûts et des bénéfices sanitaires de politiques de lutte contre la pollution de l'air (Decision support – Assessment of the costs and health benefits of air-pollution control policies), Pollution atmosphérique no. 235, July - September 2017, 15p, Evaluer les bénéfices sanitaires des actions de réduction de la pollution de l'air (Assessing the health benefits of initiatives to reduce air pollution).

[20] Menut L., Bessagnet B., Khvorostyanov D., et al., CHIMERE 2013: a model for regional atmospheric composition modelling, Geosci. Model Dev., 6, 981-1028, https://doi.org/10.5194/gmd-6-981-2013, 2013.

[21] WHO, Health risks of air pollution in Europe – HRAPIE project – Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide, WHO Regional Office for Europe, 2013a, 60p.

[22] Amann M., Borken-Kleefeld J., Cofala J. *et al.*, The Final Policy Scenarios of the EU Clean Air Policy Package, TSAP Report #11, Version 1.1a, International Institute for Applied Systems Analysis (IIASA), Laxenburg/Austria, 2014, 43p.

[23] Krupnick A., Ostro B., Bull K., Peer Review of the Methodology of Cost-Benefit Analysis of the Clean Air For Europe Programme, 2005, 43p.

[24] Miller B., Hurley F., Shafrir A., Health Impact Assessment for the National Emission Ceilings Directive (NECD), Methodological Issues, IOM, Research Report TM/11/03, 2011, 83p.

[25] WHO, Review of evidence on health aspects of air pollution – REVIHAAP – First results. Dans Europe, W.R.O.f. (dir.), 2013b, 33p.

[26] Schucht S., Colette A., Rao S. et al., Moving towards ambitious climate policies: monetized health benefits from improved air quality could offset mitigation costs in Europe, Environmental Science and Policy, 2015, 50, 252-269.

[27] Schucht S., Avancement des travaux de mise en œuvre du modèle ARP-France (Progress of work on implementing the ARP-France model), INERIS, DRC-15-149349-09296A, 2016, 17p.

[28] Évaluation ex-ante des émissions, concentrations et impacts sanitaires du projet de PREPA (Ex-ante assessment of emissions, concentrations and health impact of the APCP project), CITEPA, INERIS, Ministère de l’Environnement, de l’Energie et de la Mer (Ministry of the Environment, Energy and the Sea, 2017, 42p.