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Abstract

Climate change is now a global issue that no one can deny. Visible through all the extreme weather events (cyclones, floods, droughts) that have occurred in recent years, global warming remains the main cause. This global rise in temperature, due to the greenhouse effect, has become everyone's business. The members of the Intergovernmental Panel on Climate Change (IPCC) predict that only strong joint action plans would be likely to reduce greenhouse gas emissions and limit, in a very optimistic way (RCP 2.6 scenario), the rise in temperatures to 2°C compared to the pre-industrial era. The impact is such that today, an increase of about 1°C is already observed compared to temperatures in 1850. In addition to the classic Natural Catastrophe guarantee applied to the Property & Causality (P&C) perimeter, life insurance companies could be impacted by these risk factors. These impacts, taken into account through mortality tables calculated on a historical basis, were not directly attributed to climate change until now. The challenge now is to identify what additional risks might be attributable to climate variations and to quantify their consequences.

In this sense, the ACPR launched in July 2020 a climate pilot exercise in the form of a stress test with two scenarios (pollution and vectorial diseases) of shocks on Health & Protection risks provided by AON. As the pollution scenario in the case of a death benefit is the most unfavorable for the AXA Group, Group Risk Management (GRM) Life decided to launch a study on this subject. This study showed that 3 pollutants (PM2.5, PM10, NOx) out of the 4 studied by AON had a decreasing trend in recent years, both in terms of emissions and concentrations. As the objective is to measure the impact of climate change that could be responsible for a possible additional pollution, these 3 pollutants do not appear as an added risk compared to the current risk.

GRM Life has therefore focused on the 4th pollutant (Ozone) and has calculated its own additional mortality shock (with a certain degree of conservatism) on the basis of the Intergovernmental Panel on Climate Change (IPCC) RCP 8.5 high emission scenario. For this purpose, the number of additional deaths due to climate change is calculated as the difference between the current premature deaths due to pollution in this study and those after a temperature increase.

In terms of results, using the age distribution of AXA France's insured sums instead of the French national population significantly reduces the shock due to the low exposure of those aged 65 and over in the portfolio. Overall, the additional mortality attributable to AXA France in 2050, calculated with the presented methodology, will be lower than the one provided by AON, confirming the relative resilience of the perimeter to climate change demonstrated during the climate pilot exercise.

Keywords: climate change, temperature, IPCC, quantify, ACPR, pollution, additional mortality, premature deaths.

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Résumé

Le changement climatique est aujourd'hui un sujet planétaire que nul ne peut nier. Visible au travers de tous les évènements climatiques extrêmes (cyclones, inondations, sécheresses) survenus au cours de ces dernières années, le réchauffement climatique en reste la principale cause. Cette hausse mondiale des températures, en raison de l'effet de serre, est devenue l'affaire de tous. Les membres du Groupe d'experts Intergouvernemental sur l'Évolution du Climat (GIEC) prévoient que seuls de forts plans d'action communs seraient susceptibles de réduire les émissions de gaz à effet de serre et de limiter, de manière très optimiste (scénario RCP 2,6), la hausse des températures à 2°C par rapport à l'ère préindustrielle. L'impact est tel, qu'aujourd'hui, une augmentation d'environ 1°C est déjà observée par rapport aux températures de 1850. Outre, la garantie classique Catastrophe Naturelle appliquée au périmètre IARD (Incendie, Accidents et Risques Divers), les compagnies d'assurance vie pourraient être impactées par ces facteurs de risque. Ces impacts pris en compte au travers des tables de mortalité calculées sur un historique, n'étaient jusqu'à présent pas attribués directement au changement climatique. L'enjeu est désormais d'identifier quels pourraient être les risques supplémentaires imputables aux variations du climat et de quantifier leurs conséquences.

En ce sens, l'ACPR a lancé en juillet 2020 un exercice pilote climatique sous la forme d'un stress test avec deux scénarios (pollution et maladies vectorielles) de chocs sur les risques Santé & Protection fournis par AON. Le scénario pollution dans le cas d'une garantie décès étant le plus défavorable pour le groupe AXA, le Group Risk Management (GRM) Life a décidé de lancer une étude à ce sujet. Cette dernière a montré que 3 polluants (PM2.5, PM10, NOx) sur les 4 étudiés par AON avaient une tendance à la baisse ces dernières années, tant aux niveaux des émissions qu'aux niveaux des concentrations. L'objectif étant de mesurer l'impact du changement climatique pouvant être responsable d'une éventuelle pollution supplémentaire, ces 3 polluants n'apparaissent donc pas comme un risque ajouté par rapport au risque actuel.

Le GRM Life s'est ainsi concentré sur le 4^{e} polluant (Ozone) et a calculé son propre choc de mortalité additionnelle (avec une certaine prudence) sur la base du scénario à fortes émissions RCP 8.5 du Groupe d'experts Intergouvernemental sur l'Évolution du Climat (GIEC). Pour cela, le nombre de décès supplémentaires dus au changement climatique est calculé par différence entre les décès prématurés actuellement, dus à la pollution dans la présente étude, et ceux après une augmentation de la température.

En termes de résultats, l'utilisation de la distribution par tranches d'âge des sommes assurées d'AXA France au lieu de la population nationale française réduit considérablement le choc en raison de la faible exposition des personnes âgées de 65 ans et plus du portefeuille. Globalement, la mortalité additionnelle imputable à AXA France en 2050, calculée avec la méthodologie présentée, sera plus faible que celle fournie par AON, ce qui confirme la résilience relative du périmètre au changement climatique démontrée lors de l'exercice pilote climatique.

Mots clés : changement climatique, température, GIEC, quantifier, ACPR, pollution, mortalité additionnelle, décès prématurés.

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AASQA: Associations Agréées de Surveillance de la Qualité de l'Air

ACPR: Autorité de Contrôle Prudentiel et de Résolution

AOT 40: Accumulated Ozone exposure over a Threshold of 40 ppb

CépiDc: Centre d'épidémiologie sur les causes médicales de Décès

CH4: Methane

CO2: Carbon dioxide

EEA: European Environment Agency

EIOPA: European Insurance and Occupational Pensions Authority

FFA: Fédération Française des Assurances

INERIS: Institut National de l'Environnement Industriel et des Risques

INSEE: Institut National de la Statistique et des Etudes Economiques

INSERM: Institut National de la Santé et de la Recherche Médicale

IPCC: Intergovernmental Panel on Climate Change

LCSQA: Laboratoire Centrale de Surveillance de la Qualité de l'Air

NGFS: Networking for Greening the Financial System

NO2: Nitrogen Dioxide

NOx: Nitrogen Oxide

O3: Ozone

ORSA: Own Risk and Solvency Assessment

PM: Particulate matter

Ppb: Part per billion

Psas: Programme de surveillance air et santé de Santé Publique France

QHIA: Quantitative Health Impact Assessment

RR: Relative Risk

SOMO 35: Sum of Ozone Means Over 35 ppb

SPF: Santé Publique France

TCFD: Task-force on Climate-related Financial Disclosures

VOC: Volatile Organic Compound

WHO: World Health Organization

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Introduction

"Growing concern about climate change indicates that our work is just beginning" - Telegram written on September 1, 1976 by American meteorologists

Climate change refers to variations in the climatic characteristics of a geographical area over time. The first traces of this problem were found in diplomatic correspondence dating from the 1970s. The first climate conference in Geneva in 1979 informed the 138 member countries (today 185) of the World Meteorological Organization of the urgency of the problem. That same year, the Charney Report commissioned by U.S. President Carter from the National Academy of Sciences concluded, "We have irrefutable evidence that our atmosphere is changing and that we are contributing to it". It includes an estimate of global warming: if the concentration of carbon dioxide (CO_2) in the atmosphere doubles, the temperature will increase by 1.5°C to 4.5°C. This result, which was published some 40 years ago, corresponds to the range we are facing today!

The main driver of climate change is the global warming observed for several decades with the greenhouse effect. Some forms of pollution, especially air pollution, resulting from human activities, in this case called anthropogenic pollution, threaten to significantly alter the climate with serious consequences, sometimes irreversible. An increase in greenhouse gases due to human activities traps part of the sun's radiation in our atmosphere, which causes an increase in the average temperature at the Earth's surface. The first effects are already visible with the melting of ice that has accelerated since 2007 - 6.4 million square kilometers of ice surface in the northern hemisphere in 1990 to 4 million in 2020, the rise in sea level - 9 cm in 30 years - and increasingly extreme weather phenomena - category 5 hurricane Irma in 2017.

Several institutions have been created since the end of the 20th century in order to better manage the problem and to ensure that countries respect the commitments made collectively in the various forums. The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 with the mission of methodically evaluating the best scientific, technical and socio-economic information on climate. Since 1990, the organization has been publishing assessment reports in collaboration with scientists from around the world, which serve as a support for public decisions but also as a target. The first part of their sixth report published in early August 2021 is a real alert. After 30 years of warnings, the report is unanimous: some changes are already irreversible and limiting global warming to 1.5°C compared to the pre-industrial era (1850) by 2050 will require colossal and urgent efforts to change our lifestyles and public policies. To date, human activities have caused global warming of about 1°C above pre-industrial levels. In addition to the impacts of climate change on ecosystems, they are now pointing to impacts on health, agriculture, water supply and the livelihoods of certain populations.

"What is being discussed today could have been discussed 30 years ago" - American scientist (2009)

For many years, only scientists felt concerned by the issue of climate change. It wasn't until 2006 with the film "An Inconvenient Truth" and the quantified report by the former chief economist of the World Bank, Nicholas Stern, revealing that in the absence of significant regulatory measures, global warming could cost the world economy 7,000 billion dollars that politicians and financiers took an interest.

In this regard, France has spurred a decisive movement with the adoption of the law on the energy transition for green growth in August 2015. Article 173 of this law requires companies, investors and asset managers to publish annual information on how they take into account the risks associated with climate change and the objectives of the low-carbon transition.

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The AXA Group, as an insurer, understood very early on that climate change would be a potential threat to the long-term sustainability of its business - "a 4°C world is not insurable" Henri De Castries, 2015 - and committed to climate leadership. As early as 2015, the alarm bells rang with an initial divestment from coal and an ambitious green investment program. It thus decided to act responsibly towards its customers and society, believing that it has a role to play towards its stakeholders. As a pioneer in the field, it participates in the Taskforce on Climate-related Financial Disclosures (TCFD), the international reference for climate-related risks and opportunities, supported by governments and supervisors, and is proposing a "portfolio alignment" - "temperature metrics" - from 2018.

AXA's driving progress 2023 plan places for the first time the climate transition as a distinct strategic priority. The main goal is to sustain its climate leadership position by:

- Reducing the carbon footprint of AXA's portfolio by 20% by 2025
- Increasing AXA's Green investments to reach €25 billion by 2023
- Providing inclusive insurance protection to vulnerable population
- Committing to a Green Business Target & "Build Back Better" to promote the adoption of responsible behaviors in post-damage situations and in claims management

AXA is committed in several climate coalitions named Net-Zero Alliances aiming for "climate neutrality". Since September 2021, it is also an official member of the "Task-force on Nature-related Financial Disclosures" (TNFD) whose objective is to define a reporting framework by 2023 for organizations to address both now nature may impact the organizations and how the organization impacts nature.

The entity writes each year an AXA Group Climate Report in which we can find some quantitative metrics as:

- Contribution to global warming expressed in Celsius degree
- Impact of extreme weather events expressed in percentage of enterprise value
- Impact of CO_2 emissions reduction expressed in percentage of enterprise value
- Green revenues expressed in percentage of revenues
- Carbon footprint of AXA's portfolio
- Absolute carbon emissions pro-rated per AXA's holdings

The growing complexity of the regulatory framework surrounding climate risks is pushing businesses to anticipate the inclusion of these risks in their model, and especially the potential impact on their business. In line with the Group's strategy, AXA participated, on a voluntary basis, in a climate change pilot exercise initiated by the *Autorité de Contrôle Prudentiel et de Résolution* (ACPR). The objectives of this exercise, in the form of a climate stress test, are to identify potential vulnerabilities and to prepare the various financial institutions for the risks associated with climate change. The idea is also to extend the perimeters concerned other than the classic Property & Causality (P&C) with the Natural Catastrophe (Cat Nat) guarantee. This involves integrating the Protection and Health perimeters as well as certain balance sheet asset and liability items.

This totally innovative impact study in life insurance will upset the usual stress-testing schemes since it involves a long-term time horizon extending to 2050. To guide the participants in this exercise, the ACPR has provided, through AON, two scenarios, Pollution and Vector-borne diseases, concerning Death, Medical expenses and Work stoppage. In this report, particular attention was paid to the

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development of the following issue: What are the impacts of climate change, in our case through the pollution scenario, on health, particularly mortality?

Despite the scientific dominance of the answer to this question, the work of the actuary is important. In life insurance, particularly on the health/life perimeter, it will be a question of calibrating an additional mortality shock due to atmospheric pollution resulting from the climate change to be applied to the AXA portfolio and then to quantify this impact from a financial point of view.

First, the context and the framework of the climate pilot exercise will be repositioned, and then each of the steps that allowed the calibration of the additional mortality shock on the "Pollution/Death" scenario will be detailed.

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1. Climate pilot exercise

The successive warnings about the dangers of global warming since the beginning of the millennium have led public authorities and financial players to include climate change-related risks in their supervisory approach.

Launched in July 2020, the climate pilot exercise of the *Autorité de Contrôle Prudentiel et de Résolution* (ACPR) is a pioneering and ambitious step towards the supervision of climate risk. The objectives of this exercise in the form of a climate stress test are to identify potential vulnerabilities and to prepare the various financial institutions for the risk of climate change. The pilot was conducted in working groups with banking and insurance groups.

As a founding member of the Networking for Greening the Financial System (NGFS), the ACPR used the scenarios provided by the network to launch this pilot on a voluntary basis. On the one hand, it should encourage banks and insurers to assess the risks and vulnerabilities related to climate change to which they could be exposed over the long term and under different scenarios. On the other hand, it aims to identify the current gaps in terms of tools, indicators, data and resources that would be needed to ensure a relevant monitoring and assessment of climate change risks for the financial sector.

The challenge lies in the need to match climate scenarios with financial asset valuations in order to be able to analyze the resilience of portfolios to climate shocks. In this context, it is difficult to rely on Monte Carlo type simulations, classically used in finance, because these scenarios have not been explored in the past. It is therefore not possible to rely on historical data. Thus, it seemed more relevant to use climate stress-testing methods that are based on historical and theoretical scenarios.

The combination of a static balance hypothesis up to 2025 and a dynamic balance hypothesis from 2025 to 2050 represents a novelty. The static balance sheet remains within the traditional framework of prudential stress testing exercises. This assumption, based on a balance sheet as of December 31, 2019, is intended to measure short-term risks and vulnerabilities. The dynamic balance sheet assumption makes it possible to integrate management decisions and thus adjust the balance sheet according to the scenario considered. It is thus possible to assess the reaction function of institutions to the materialization of climate risks.

The approach chosen concerns several geographical areas - France, the rest of Europe, the United States and the rest of the world - in order to take into account the global nature of climate change and its differentiated effects in each part of the world. This approach is also multi-sectoral, since 55 sectors of activity have been chosen to capture the highly contrasting effects of transition policies.

1.1. Context and regulator

The legislative framework around climate change has evolved a lot over the years in order to make everyone aware of the importance of acting to limit global warming but also to raise awareness on the impact of climate risks. A "green" way of life, individual and collective, individual and company, is now essential.

1.1.1. French legal impulse

Since August 17, 2015, the adoption of the law on the energy transition for green growth in France commits citizens, businesses and public authorities to mobilization and action to prioritize a green

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economy. This law must enable the country to strengthen its energy independence and reduce its greenhouse gas emissions with the appropriate tools.

Article 173 of the law introduces an obligation for institutional investors to provide their subscribers with information on how their investment policy takes into account criteria relating to compliance with environmental, social and governance (ESG) objectives, as well as on the means implemented to contribute to the energy transition. Although there is no definitive list of factors that are covered by the terms ESG, they are broadly defined as:

- Environmental relates to the quality and functioning of the natural environment and system (climate change, loss of biodiversity, disruption of ecosystems, pollution)
- Social relates to the rights, well-being and interest of people (poverty, racial discrimination, gender inequality)
- Governance relates to the quality of governance (transparency, corporate governance, responsible tax, ethics violation)

Subsequently, provision V of article 173 was added and requires the submission of a report on the implementation of regular stress tests on the risks induced by climate change. Provision VI requires institutional investors to be transparent about whether or not ESG criteria are included in their investment policy. It completes the previous provisions by setting out a standard procedure for presenting the ESG approach of those subject to it, while specifying a certain number of expectations regarding the environmental pillar and more specifically the climate theme. This transparency requirement is intended to raise insurers' awareness and encourage them to take an interest in the opportunities for financing the energy and ecological transition while taking into account the risks inherent in this transition.

Still with the idea of creating a financial system capable of integrating climate issues, Article 29 of the Energy-Climate Law, published in May 2021 and included following Article 173.6, confirms France's strong ambition in terms of sustainable finance. It aims to strengthen the transparency requirement for ESG reporting and ensure better integration of extra-financial issues in the investment decision-making and risk management processes. The information requested is structured around the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD), i.e. to make a clear distinction between governance, strategy, risk management and impact measurements. On limiting global warming, it requires the publication of a quantitative target for 2030, which will be revised every five years until 2050 in order to meet fixed-date targets. It also proposes methodological details to assess the alignment of the investment strategy with the objectives of the Paris Agreement, without imposing any particular methodology.

Even more recently, the Climate and Resilience Law, published in August 2021, translates part of the 146 proposals of the Citizens' Climate Convention (CCC) to reduce greenhouse gas emissions by 40% by 2030. This law aims to accelerate the transition of the French development model towards a carbon-neutral society and anchors ecology at the heart of citizens' daily lives: in public services, in children's education, in urban planning, in travel, in consumption patterns but also in justice. It is based on the following five pillars: consumption, production and work, transportation, housing, food, and strengthening legal protection of the environment. The High Council for the Climate will have to evaluate every year the implementation of the planned measures and, every three years, the action of local authorities in terms of greenhouse gas reduction and adaptation to climate change. The gradual ban on renting out E, F and G-rated housing by 2034 and the ban on domestic flights if the train journey is less than 2.5 hours by 2024 are key measures in this work.

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1.1.2. European regulatory framework

Actions must be collective in order to improve the results of the fight against global warming. Thus, in addition to the French jurisprudence which is evolving, a European regulatory framework is emerging in order to harmonize the strategies of the various member countries and to follow a guideline. The European Union has an action plan to reduce its greenhouse gas emissions, which should lead to carbon neutrality by 2050, with an intermediate step of a 55% reduction by 2030 compared to 1990 levels. To reach this goal, the annual investment value amounts to 350 billion euros.

Among a series of measures aimed at redirecting European financial flows towards more sustainable activities, the European Commission has published its new strategy for financing the transition to a sustainable economy through the European Taxonomy. This regulation aims to create a classification system of what is considered sustainable from an environmental and social point of view. It creates a framework and principles for assessing economic activities around 6 environmental objectives:

- Climate change mitigation
- Adaptation to climate change
- Sustainable use and protection of aquatic and marine resources
- Transition to a circular economy
- Pollution prevention and reduction
- Protection and restoration of biodiversity and ecosystems

An activity can be considered sustainable if it substantially contributes to one of the six environmental objectives, without causing significant harm to any of the other five.

This is a very complex project to redirect financial flows, especially since the Taxonomy Regulation will be applied across several regulations.

All companies subject to the non-financial reporting requirements of the Non-Financial Reporting Directive (NFRD) - i.e. public interest entities with more than 500 employees - as revised by the Corporate Sustainability Reporting Directive (CSRD), which extends the scope of these obligations to all public interest entities, will be subject to the reporting requirements of Article 8 of the Taxonomy Regulation. These companies will be required to disclose the proportion of their revenues derived from products or services associated with economic activities that can be considered sustainable, the proportion of their capital expenditure and the proportion of their operating expenditure related to assets or processes associated with economic activities that can be considered sustainable.

A major advance for the insurance world is the European Commission's proposal to revise the Solvency II directive (not before April 2023) with the following measures to integrate climate change scenario analysis in Own Risk and Solvency Assessment (ORSA), to identify material climate change risk exposure and to specify two long-term climate change scenarios (below 2°C, above 2°C). Moreover, amended Solvency II delegated acts will entry into force in October 2022 with sustainability risk which must be reflected in insurance and reinsurance undertakings' risk management.

1.2. Terms and conditions of the exercise

The climate pilot exercise launched by the ACPR is a continuation of this work, which reflects the increasing complexity that insurers will have to face to support the fight against climate change. The regulator has drafted two documents to provide participants with the main scenarios and assumptions as well as the technical details of the exercise. The scenarios and assumptions for the exercise are provided to institutions in the form of projections of climate, macroeconomic and financial variables

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in 5-year steps from 2020 to 2050. In order to reduce the scope and cost of the exercise, it was decided to focus on a few dates corresponding to the periods where the variability of the scenarios is the most important, namely 2025, 2030, 2040 and 2050.

1.2.1. Definition of climate scenarios and risks

Climate risk is a risk related to the increased vulnerability of companies to variations in climate factors (temperature, precipitation, etc.). It can be broken down into two groups of risks:

- **Transition risk** arises from a change in the behavior of economic and financial agents in response to the implementation of energy policies or technological changes aimed at reducing greenhouse gas emissions. It will affect the profitability of business and wealth of households, creating financial risks for lenders and investors.
- **Physical risk** measures the direct impact of climate change on people and property. There are two types of physical risk:
    - The risk of occurrence (acute impacts) from extreme weather events whose damage can lead to the destruction of physical assets, the collapse of local activity and possible disruption of the value chain in some sectors. These events can increase underwriting risks for insurers, possibly leading to lower insurance coverage in some regions, and impair asset values.
    - Chronic impacts, particularly from increased temperatures, sea level arise and precipitations, may affect labor, capital, land and natural capital in specific areas. They can gradually deteriorate the productivity of a given sector. These changes will require a significant level of investment and adaptation from compagnies, households and governments.

A third risk is gradually being added to the list of climatic risks but is derived from the two previous ones. **Liability risk** is defined as risk of climate-related claims under liability policies, as well as direct actions against insurers for failing to manage climate risk. Still little known to the general public, insurers may be highly exposed to this risk if they are deemed responsible for having contributed directly or indirectly to the consequences of climate change, particularly through their role as investors.

Climate scenarios have specific challenges: a time horizon that can be very long, a granularity that is fine enough to take into account the numerous international and sectoral specificities, a high level of uncertainty, an extreme amplitude of risks and an interdependence of physical and transition risks.

The NGFS Scenarios have been developed to provide a common starting point for analyzing climate risk to the economy and financial system. They are grouped in 4 categories and each NGFS scenario explore a different set of assumptions for how climate policy, emissions and temperatures evolve.

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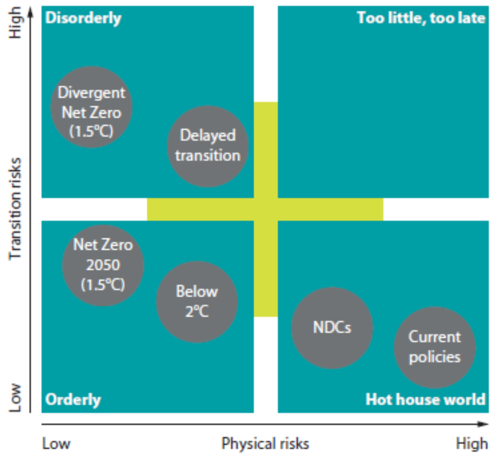
Figure 1-1 : NGFS Scenarios Framework



Source 1 : NGFS

In the "NGFS Climate Scenarios for central banks and supervisors" published in June 2021, there are the following descriptions:

- Orderly scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued.
  - Net Zero 2050 limits global warming to 1.5°C through stringent climate policies and innovation, reaching global net zero CO2 emission around 2050.
  - Below 2°C gradually increases the stringency of climate policies, giving a 67% chance of limiting global warming to below 2°C.
- Disorderly scenarios explore higher transition risk due to policies being delayed or divergent across countries and sectors.
  - Divergent Net Zero reaches net zero around 2050 but higher costs due to divergent policies introduced across sectors leading to a quicker phase out of oil use.
  - Delayed transition assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below 2°C. CO2 removal is limited.
- Hot house world scenarios assume that some climate policies are implemented in some jurisdiction, but globally efforts are insufficient to halt significant global warming. The scenario result in severe physical risk including irreversible impact.
  - Nationally Determined Contributions includes all pledged policies even if not yet implemented.
  - Current Policies assumes that only currently implemented policies are preserved, leading to high physical risks.
- Too little, too late means it is possible that a late transition would fail to contain physical risk, but no scenarios have been specifically designed.

The ACPR has selected three transition risk scenarios and one physical risk scenario based on the work of the NGFS and on an analytical framework determined from a publication by Robert Allen. These scenarios are broken down into forecasts of macroeconomic and financial variables with a fine granularity in terms of geographical areas, sectors of activity and asset classes. All these data allow us to estimate the impact of these scenarios on the balance sheet of banks and insurance companies.

The first scenario, called the orderly transition scenario, is used as a reference because it is very close to the national low-carbon strategy aiming to achieve zero net CO2 emissions by 2050. This is an ambitious scenario where international political commitments are respected, allowing to limit global warming to 1.5°C.

Then, there are two alternative scenarios, known as disorderly transition scenarios. On the one hand, a delayed transition scenario with a brutal revision of the carbon price in 2030 to try to catch up and maintain the carbon neutrality objective in 2050. On the other hand, an accelerated transition scenario with an anticipated and brutal reaction due to a revision of the carbon price and a productivity shock as early as 2025.

All three scenarios incorporate climate policy measures in the form of a carbon tax increase in 2025 and 2030.

The physical risk scenario is based on the IPCC's "Representative Concentration Pathway (RCP) 8.5" scenario, which assumes a temperature increase of between 1.4° and 2.6° in 2050 and between 2.6°C and 4.8°C by the end of the century - an assumption that was revised upwards in their latest report. This scenario is also referred to as "Business as usual", i.e. nothing more would be done between now and 2100 to limit the rise in temperatures. The RCP scenarios (2.6; 4.5; 6.0; 8.5) are four reference scenarios for the evolution of radiative forcing over the period 2006-2300. They are provided to the IPCC by a community of scientists who have selected them from 300 published in the literature. Each scenario is associated with an increase in radiative forcing obtained for the year 2100. Expressed in W/m^2, radiative forcing is a change in the radiation balance - the difference between incoming solar radiation and outgoing infrared radiation - at the top of the troposphere between 10 and 16 km altitude, due to a change in one of the climate drivers such as greenhouse gas concentration. Thus, the RCP 2.6 scenario corresponds to an increasing forcing of 2.6 W/m^2. The higher this value, the warmer the planet Earth becomes. The RCP 8.5 scenario is therefore the most pessimistic.

1.2.2. Scenarios for the Health/Protection perimeter

To assess the impact of the previous scenarios on the Health and Personal Protection perimeter, the ACPR provided the participants with mortality shocks that were calculated by the Life, Accident, Health Department of AON France. The company has presented two scenarios which are pollution and vector-borne diseases. Work has been done on the evolution of mortality tables linked to the development of exotic diseases or chronic pathologies due to exposure to high temperatures or to an increase in the rate of particles present in the air, which have consequences on the guarantees in case of death, medical expenses and work stoppage. Assumptions for changes were provided by geographic area and are associated with the IPCC RCP 8.5 scenario. Organizations are required to provide information on the evolution of premiums and claims as well as the insured values at the level of granularity specified in the scenarios. In the absence of information, data can be provided for the whole territory.

1.2.2.1. Pollution

Air pollution is the combination of high pollutant emissions and specific weather conditions. Climate change has a significant impact on meteorological variables such as temperature, wind and precipitation that affect air quality. In the AON report *(Drif and al., 2020)*[1], pollution phenomena are modeled according to the increase of four pollutants which are fine particles (PM2.5 and PM10), Nitrogen Oxide (NOx) and Ozone (O3), considered the most dangerous for public health. Chronic or long-term exposure to these particles is responsible each year for a certain number of respiratory and cardiovascular diseases, cancers and even premature deaths in the exposed population.

[1] DRIF Y. and al. (2020) "*Conséquences du changement climatique sur la pollution de l'air et impact en assurance de personnes*". *IOP Publishing*

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In order to monitor the evolution of air quality in the future, it is important to use an adequate precursor emission scenario that takes into account the information available at the local level but also the current legislation governing air pollution. The scenario was constructed by materializing the consequences of climate change through pollution phenomena in urban areas over a time horizon between 2020 and 2050. The consequences on the insurability of the guarantees proposed for personal insurance contracts, i.e. death, medical expenses and work stoppage, were analyzed through 5 studies in this report. Most of the studies presented predict a decrease in Ozone in most regions of France, except for Paris intra-muros. The concentrations of fine particles and nitrogen oxides should also decrease.

In order to facilitate the application of these scenarios, presented in percentages, by the participants, they are available at two levels of granularity: a national granularity *(table below)* which does not take into account a precise localization and a granularity by agglomeration allowing a taking into account of the heterogeneity *(appendix)* Companies should only present one granularity, depending on the relevance to their risk profile and the availability of information.

Table 1-1 : Additional shocks for the pollution scenario

		2021 - 2030	2031 - 2040	2041 – 2050
National granularity	Death	0.02%	0.02%	0.03%
	Care costs	0.84%	1.25%	1.65%
	Work stoppage	0.07%	0.10%	0.13%

Source 2 : AON

These rates are interpreted as follows:

- The "Death" line is an additional mortality rate that annually increases the insurer's mortality assumptions for each of the projection years. A death rate of 0.02% between 2031 and 2040 means that for the years 2021 to 2040, a company normally applying a mortality rate of 0.4% will move to a rate of 0.42%.
- The line "Health care costs" corresponds to an additional proportion of the insured who will have to generate health care costs because of the worsening of the pollution, for each projection year. An assumption has been made such that, among these insured, 3% will be hospitalized for an average duration of 6 days and 97% will have a simple consultation. Thus, a health care cost rate of 1.65% for a portfolio of 100,000 insureds, induces that $100{,}000 \times 1.65\% = 1{,}650$ insureds will generate additional health care costs each year. Of these 1,650, $1{,}650 \times 3\% = 50$ will be hospitalized for 6 days and $1{,}650 \times 97\% = 1{,}600$ will generate a consultation.
- The "Work stoppages" line corresponds to an additional proportion of insureds who will be off work for an average of 6 days in each projection year. A work stoppage rate of 0.07% for a portfolio of 100,000 insureds means that each year $100{,}000 \times 0.07\% = 70$ insureds will be off work for an average of 6 days.

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1.2.2.2. *Vector-borne diseases*

Climate change, beyond its environmental impact, can have catastrophic consequences for human life and health. In the AON report *(Drif and al., 2020)*[2], the focus is on the increase in the viability of mosquitoes in ecosystems and therefore the increase in the transmission of viruses spread by them. Temperature change affects the time required for pathogen development in mosquitoes, so the incubation period shortens with increasing temperature. Its gonotrophic[3] cycle decreases but its reproductive cycle increases. The risk of exposure of populations is therefore twofold, firstly by the expansion of geographical areas favorable to their reproduction but also by the increase in the speed of reproduction.

The phenomenon of vector-borne diseases is modeled by the risk of epidemics of viruses transmitted by the Aedes Albopictus mosquito in metropolitan France. A rise of 1°C in January increases the probability of the mosquito's presence by 7%. This scenario materializes the consequences of climate change through the spread of vector-borne diseases (by the mosquito) over a horizon of 2020 to 2050 in terms of the impact on death benefits, medical expenses and work stoppages.

To construct the scenarios for the ACPR shocks, the probability of epidemic occurrence was estimated by region, taking into account the effects of global warming and the colonization of metropolitan France by the tiger mosquito.

In order to facilitate the application of these scenarios, presented in percentages, by the participants, they are available at two levels of granularity: a national granularity *(tables below)* which does not take into account a precise location, and a granularity by agglomeration allowing for heterogeneity *(appendix)*. Companies should only present one granularity, depending on the relevance to their risk profile and the availability of information.

Table 1-2 : Additional mortality for the vector-borne diseases scenario

		2021-2024	2025-2029	2030-2039	2040-2049	2050
National granularity	Additive factor	0.002%	0.002%	0.002%	0.002%	0.002%
	Multiplicative factor	6.3%	3.8%	5.5%	5.5%	

Source 3 : AON

This scenario for the "Death" benefit is broken down into two components:

- An additive factor that corresponds to an additive increase in annual mortality rates. A mortality rate of 0.04% before application of the scenario shock increases to 0.042% with an additive factor of 0.002%.
- A multiplicative factor which corresponds to an annual worsening of the shift of the mortality tables. A multiplicative factor of 3.8% makes that the mortality rates which shift of 0.002% the first year, shift of $0.002\% \times 1.038$ the second year then $0.002\% \times 1.038 \times 1.038$ the third and so on.

[2] DRIF Y. and al. (2020) "*Conséquences du changement climatique pour les maladies à transmission vectorielle et impact en assurance de personnes*". IOP Publishing

[3] The **gonotrophic cycle** is the time required for the mosquito to digest a blood meal and to mature its eggs between two blood meals.

In total, combining the two factors, the shocked mortality rate is of the following form:

$$Shocked\ mortality\ rate_{(A)} = Initial\ mortality\ rate_{(A)} + Additive\ factor_{(A)} \times \prod_{i=1}^{A}(1 + Mulitplicative\ factor_{(i)})$$

Where A is the year and i is the number of years in the period. Thus, a company normally applying a mortality rate of 0.4% in 2020 will move to $0.4\% + 0.002\%$ in 2021, then $0.4\% + 0.002\% \times 1.063$ in 2022 and $0.4\% + 0.002\% \times 1.063 \times 1.063$ in 2023.

Table 1-3 : Additional shocks for the vector-borne diseases scenario

		2021-2024	2025-2029	2030-2039	2040-2049	2050
National granularity	Consultation Emergency	0,7911%	1,047%	1,2408%	1,5808%	1,9208%
	TWD	0,0198%	0,0260%	0,0310%	0,0395%	0,0480%

Source 4 : AON

These rates can be interpreted as follows:

- The "Consultation/Emergency" line represents the additional proportion of policyholders covered by health care benefits who will be required to consult a physician or go to the emergency room each year due to vector-borne diseases. A rate of 0.7911% for Consultation/Emergency means that 0.7911% of the insureds in the portfolio will generate additional claims each year due to a consultation or a trip to the emergency room.
- The "Temporary Work Disability" (TWD) line corresponds to the proportion of policyholders covered by the Work Stoppage benefits who will be off work each year due to a vector-borne disease infection. It has been assumed that 80% of these policyholders will be off work for 8 days and 20% for 20 days. A 0.0260% TWD rate means that 0.0260% of the insureds in the portfolio will generate additional claims each year due to TWD. $0{,}0260\% \times 80\% = 0{,}0208\%$ will be on TWD for 8 days and $0{,}0260\% \times 20\% = 0{,}0052\%$ will be on TWD for 20 days.

1.3. Review of the exercise

The fifteen insurance groups and nine banking groups that participated in the exercise submitted their results in the first quarter of 2021 and these were unveiled by the regulator in June 2021. The strong mobilization around the exercise is a first victory.

1.3.1. Results of the exercise

1.3.1.1. Overall results

From a quantitative point of view, the results show a good resistance of the participating organizations to transition risk. These conclusions should be qualified, however, by keeping in mind that French banks and insurers are mostly exposed to the geographic areas least affected by the shocks imposed. Their exposure to the sectors most affected by transition risk (refining, agriculture, etc.) is relatively low. Moreover, French insurers are already committed to the carbon neutrality strategy, which reflects the good results.

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The dynamic balance sheet hypothesis proved interesting for analyzing participants' strategies and the possible reallocation of their exposures to sectors less affected by the transition.

On the other hand, for physical risk, the results are much more significant with a cost of claims that could be multiplied by 5 to 6 in certain French departments between 2020 and 2050. The increase in the frequency and severity of natural disasters is the main reason for this.

1.3.1.2. Results for the AXA Group's Health & Protection (H&P) segment

Climate is one of the 5 pillars defined in the group's 2023 strategic plan announced in December 2020. The strategy implemented follows the objectives of the Paris Agreements, i.e., limiting the trajectory of global warming to +1.5°C by 2050. For the Health and Protection perimeter, only French activities were studied due to the absence of shocks provided by AON outside France. This is why the exercise was performed on the business of the AXA France Vie domestic entity and then extrapolated to the AXA Group by a multiplicative factor of 2.5. This factor is justified by the fact that the scope of AXA France Vie domestic (business in France only) represents 60% of the business of AXA France Vie, which also operates internationally, but that AXA France represents 65% of the AXA Group. Thus, this scope (AXA France Vie domestic) is representative of 40% of the AXA Group's H&P business. The net written premiums of this perimeter are distributed among the guarantees as follows: 57% for medical expenses, 25% for sick leave and 18% for death. Annual and additive shocks have been applied on the number of policyholders in the scope to measure the additional impact compared to the 2019 situation. The loss ratio is not modified by population growth over 30 years, nor by medical inflation, so these two assumptions have not been taken into account.

The two physical risks that could impact AXA Health & Protection are vector-borne diseases and pollution, which themselves depend on the level of temperature increase. However, the exercise reveals a relatively low overall impact before taking into account a possible future management decision. The maximum deviation in claims between 2019 and 2050 does not exceed 1% for vector-borne diseases and 4% for pollution. It breaks down as follows between scenarios and guarantees:

Table 1-4 : Maximum loss deviation

Scenario/Guarantee	Death	Care costs	Work stoppage	Total claims
Repartition of net written premium	*18%*	*57%*	*25%*	*100%*
Vector-borne disease	5.4%	0.2%	0.07%	1%
Pollution	28%	0.4%	0.11%	4%

Source 5 : GRM Life AXA

The deviation in annual claims is more marked for death benefits than for disability and medical expenses. The main impact would therefore come from pollution, particularly on death benefits, but it would remain very limited because it could be absorbed by managerial actions.

The average costs for each benefit were discussed with AXA France. Recalling that the scope is representative of 40% of the AXA Group's Health and Protection business, the cumulative impact of the two scenarios in terms of losses for the AXA Group is considered as moderate since it represents a cumulative deviation of approximately 10% of the scope's claims over the 30-year period observed. Of these losses, 93% are related to death benefits, 6% to medical expenses and 1% to work stoppages.

However, it is important to remember that realistic repricing of between +0.4% and +4% applied between 2026 and 2050, every 3 years (equivalent to an annual repricing of +0.72%), would allow these shocks to be fully absorbed. Thus, the only remaining impact between 2020 and 2025 would be the static balance sheet for the AXA Group. The scope would therefore be resilient to the impact of climate change.

1.3.2. Limits

1.3.2.1. Time horizon

The time horizon of the assumptions is about 30 years covering the period 2020-2050. The long term is necessary to integrate the effects of climate change, but its length is unusual for stress tests, which are generally 3 to 5 years (short term). Indeed, an insurance company generally defines its strategy over a 4–5-year horizon, for example AXA's strategic plan defined for 2023. This particularity obliged the banking and insurance groups participating in the exercise to adapt their risk quantification methods.

1.3.2.2. Other limits

In contrast to traditional stress tests, none of the scenarios implies an economic recession by 2050, but rather lower growth, particularly in the sectors affected by the climate transition. The choice of the national strategy "Net-Zero 2050" as the reference scenario is debated since it seems less likely than the "business as usual" scenario. A lack of variability between the different transition risk scenarios has also been criticized. In addition, the exercise does not take into account the risk of contagion and intra-sectoral weaknesses, which are generally very strong during financial crises, as seen in the last few crises.

Moreover, the usual stress tests are built on aggregate asset classes, whereas this exercise includes a sectoral dimension with the WIOD[4] nomenclature, which includes 55 sectors of activity. The inability to have a finer granularity is a limitation, since within the same sector of activity, the sensitivity of one company to another can vary according to its own emissions or the nature of its investments.

1.3.2.3. AON Scenarios

Due to the absence of shocks provided by AON for areas outside of France, only the domestic cases carried by AXA France Vie could be studied, which limits the scope of the results.

Moreover, to obtain the impact of the "Pollution/mortality" scenario, the impacts of the different pollutants on mortality were summed up. Santé Publique France stipulates in its Quantitative Health Impact Assessments (QHIA) that "the respective estimates of deaths avoided thanks to decreases in each pollution indicator cannot be added together, as part of these deaths can be attributed to joint exposure to these pollutants." To assess the overall physical risk, the impacts of the pollution and vector-borne disease scenarios were summed.

1.4. Continuation of the exercise

1.4.1. Need for ORSA

This exercise has helped raise awareness of the issue of climate risks among banks and insurers. By integrating this dimension into the regulatory framework, financial market players will gradually be obliged to take it into account in their various internal assessments. It is important to remember that

[4] World Input-Output Database

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the initial pilot exercise does not address the Solvency of the participating institutions, even though it is a prudential supervision tool, as there is no regulatory capital requirement for climate risks to date. Nevertheless, it is important to keep in mind that the Solvency II directive requires companies to take into account in their governance system, their risk management system and their Own Risk and Solvency Assessment (ORSA), all the risks they are and would be facing in the short and long term. In this sense, the European Insurance and Occupational Pensions Authority (EIOPA) expects the competent supervisory authorities to integrate climate change risk scenarios by insurers into their ORSA.

ORSA is an organization's internal risk and solvency assessment process. It should illustrate the ability of the organization or group to identify, measure and manage elements of a nature that could modify its solvency or financial situation. AXA began qualitatively integrating climate risks into its ORSA report starting in 2019. This mainly involved a description of climate change risks that were already considered a significant emerging risk. After participating in the climate pilot exercise, the AXA Group decided to integrate climate risks into its ORSA 2020 report in a more quantitative manner. The results obtained during this study were simply transcribed, but areas for improvement were proposed for the drafting of the 2021 ORSA and the next pilot exercise planned for 2023.

For further work, the Net Zero Carbon objective of the Paris Agreements is not set to be reached in 2050: it could be reached 5 to 10 years later. It is essential to have mortality shocks by age and location to refine the results. Defining shocks specific to each company would be beneficial to improve the accuracy of the shock scenarios. We must not forget the possibility of a scenario other than pollution and vector-borne diseases.

1.4.2. Importance of Life Insurance and Death Benefit

The ACPR was keen to include life insurance companies in this exercise because it should be remembered that even though they represent only a small proportion of the number of players on the market, in France in 2020 they accounted for 54.3%[5] of contributions and 61.7% of benefit expenses.

Health and Protection insurance represent 27% of these contracts. It should not be forgotten that the death benefit is a central product of Life Insurance (9%). The *Fédération Française des Assurances* (FFA) defines it as follows: "Insurance in the event of death is a life insurance contract that allows the payment of a capital or an annuity to a designated beneficiary in the event of the death of the insured before the end of the contract". These contracts can be taken out individually or collectively, and either for a limited period of time (term life insurance) or for the entire life (whole life insurance). They allow the subscriber to ensure the future of his or her loved ones.

Thus, we will focus on the "Pollution" scenario and more particularly on the "Death" guarantee. As the ACPR stress test results show, this is the scenario causing the largest loss at the level of the AXA Group between 2019 and 2050. This corresponds to a deviation shock of 15% in 2025 which will reach 28% in 2050. However, this result seems extreme since it leads to a deviation higher than the application of the bicentennial mortality shock required by the Solvency II directive.

Within the framework of the drafting of the ORSA 2021, it was decided to carry out a more detailed analysis of the shocks proposed by AON concerning the mortality rates for the Pollution scenario in order to understand how these shocks were generated and thus adapt their calibration.

[5] Fédération Française de l'Assurance (2020) "French Insurance - Key Data 2020"

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2. Pollution and inventory of pollutants

Air pollution is defined as "the introduction by man, directly or indirectly, into the atmosphere and enclosed spaces, of substances having harmful consequences of such a nature as to endanger human health, harm biological resources and ecosystems, influence climate change, deteriorate material goods and cause excessive olfactory nuisances". - Air Act, December 1996

Air pollution is a major threat to human health and climate. Everyone has the right to breathe air that is not harmful to their health. Yet, in 2016, an estimated 4.2 million[6] premature deaths worldwide were attributed to ambient outdoor air pollution through stroke, heart disease, lung cancer and acute and chronic respiratory infections. According to the World Health Organization (WHO) in 2016, nearly 91% of the world's population lives in an environment with air quality levels below established limits. The sources of pollution are numerous and vary depending on the context.

Air quality is closely linked to the Earth's climate and ecosystems on a global scale. Many of the drivers of air pollution are also sources of greenhouse gas emissions. Thus, policies to reduce outdoor air pollution will benefit both climate and health by reducing the burden of disease from outdoor air pollution and contributing to climate change mitigation in the short and long term.

For further development, several definitions should be recalled.

A pollution episode is characterized by the exceedance of air quality standards set for the protection of human health in the short term for one or more pollutants. It is considered to be national in scope when the surface area of the territories concerned extends over several regions and the exceedances are measured over several consecutive days.

A quality objective is a level of concentration of pollutants in the atmosphere to be attained in the long term, except where this is not achievable through proportionate measures, in order to ensure effective protection of human health and the environment as a whole.

A target value is the level of concentration of pollutants in the air set with the aim of avoiding, preventing or reducing harmful effects on human health or the environment as a whole, to be attained, as far as possible, within a given period.

A limit value means the level of concentration of pollutants in the atmosphere established on the basis of scientific knowledge which should not be exceeded in order to avoid, prevent or reduce harmful effects on human health or the environment as a whole.

The information and recommendation threshold is defined as a level of concentration of pollutants in the atmosphere above which short-term exposure represents a risk to human health for particularly sensitive groups of the population, making immediate and appropriate information necessary.

The alert threshold is the level of concentration of pollutants in the atmosphere beyond which a short exposure presents a risk for the health of the whole population or for the degradation of the environment justifying the intervention of emergency measures.

Within the framework of the national air quality system, the French ministry in charge of the environment has defined regulations relating to atmospheric pollutants in connection with the

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[6] https://www.who.int/fr/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (the World Health Organization's key air quality benchmarks), site consulted in June 2021

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regulatory provisions taken at the international and European level. There is a list of regulated pollutants that the *Associations Agréées de Surveillance de la Qualité de l'Air* (AASQA) are responsible for monitoring.

In France, a number of institutions are actively involved in the fight against air pollution and climate change. The *Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique* (CITEPA) quantifies, identifies and communicates atmospheric emissions data, explanatory variables and quality indicators. Each year, it estimates the quantity of national anthropogenic emissions of pollutants regulated at the international and/or European level, which it retranscribes through the Secten[7] report - reference report on greenhouse gas and air pollutant emissions in France. Only primary emissions of pollutants, quantities of pollutants emitted directly into the atmosphere, are estimated. This report provides a clear view of the emission trends for each substance studied, the contributing sectors and whether or not the objectives have been met. The French National Institute for the Industrial Environment and Risks (INERIS), under the supervision of the Ministry of the Environment, participates in the prevention of risks that economic activities pose to health, the safety of goods and people, and the environment. At the national level, it aggregates measurements of pollutant concentrations made by the AASQA stations or models them to assess health and environmental risks. These measurements or models, generally expressed in micrograms per cubic meter ($\mu g/m^3$), make it possible to establish estimates of the presence of certain pollutants on the territory and to be able to compare the costs of pollution reduction strategies.

The distinction between air quality and climate change should be mentioned. Surprisingly, greenhouse gases (GHGs) are not included in the list of regulated pollutants because they are not considered as such. Unlike air pollutants, greenhouse gases do not have a local impact on health but on the climate on a global scale since they contribute to global warming. Indeed, the greenhouse effect is not due to air pollutants, even if some of them contribute to it. Despite this distinction, the two issues are closely linked since some pollutants act on climate change (Ozone warms the atmosphere, aerosols cool it) and conversely, climate change impacts air pollution via the rise in temperatures which impacts the levels of some pollutants. Thus carbon dioxide (CO2), the main effect gas and major actor of climate change, will not be part of the following analysis which will be based on the pollutants selected by AON for the Pollution scenario study in the framework of the climate pilot exercise.

2.1. Fine and coarse particles

Atmospheric particles are a mixture of different organic and inorganic chemical compounds suspended in the air. They can be emitted directly into the air, in which case they are referred to as primary particles, or they can be produced by complex chemical reactions from precursor gases, in which case they are referred to as secondary particles. They come in different sizes and are classified according to their aerodynamic diameter. The finer the particles, the more dangerous they are to health because they can penetrate more or less deeply into the respiratory system and reach the pulmonary alveoli. Ultra fine particles can even penetrate the bloodstream. They can be responsible for pathologies such as asthma, allergies, respiratory and cardiovascular diseases, and even cancers.

[7] The "Secten" format report owes its name to the fact that the data is available by issuing SECTor and not Energy hence SECTEN.

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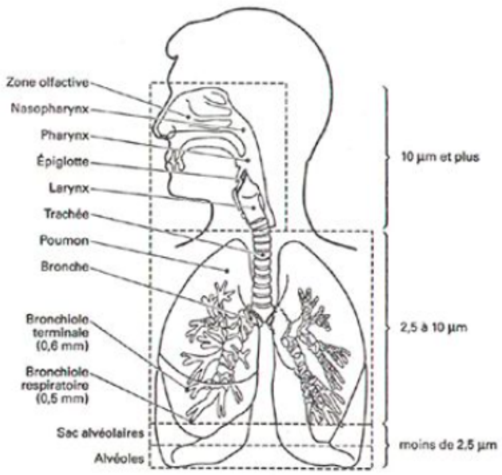
Figure 2-1 : Penetration of particles in the respiratory system



Source 6 : InVS

Particles also have a harmful effect on the environment. When they accumulate on plant leaves, they can smother them and interfere with photosynthesis. They can also cause the transport and deposition of toxic pollutants.

2.1.1. PM 2,5

PM 2.5 are particles with a diameter less than or equal to 2.5µm (microns). They are referred to as fine particles and include ultra fine particles that are less than 0.1µm (micron) in diameter. They contain mainly organic matter and secondary species. They are emitted either directly by natural sources such as wind erosion and sea spray, or they are formed indirectly by secondary pathways resulting from chemical recombination between pollutants in the atmosphere often having an anthropogenic source such as residential/tertiary with the combustion of biomass, industry with construction sites and transport with the exhaust of burned fuels. These fine particles remain in suspension and stagnate in the air for several days or weeks, they can also travel long distances.

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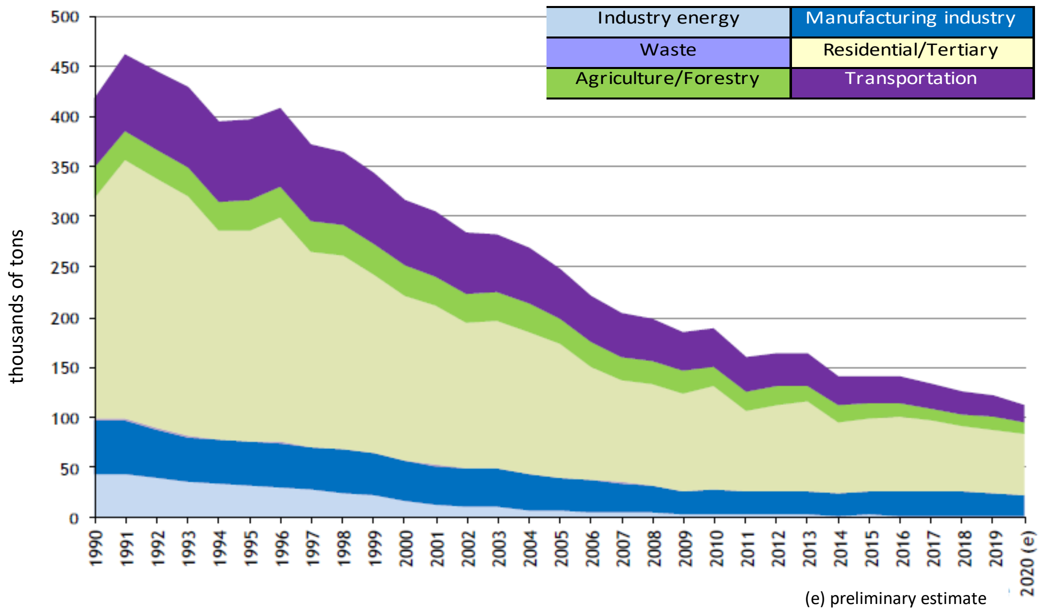
Figure 2-2 : Evolution of PM2.5 emissions in the air since 1990 in metropolitan France



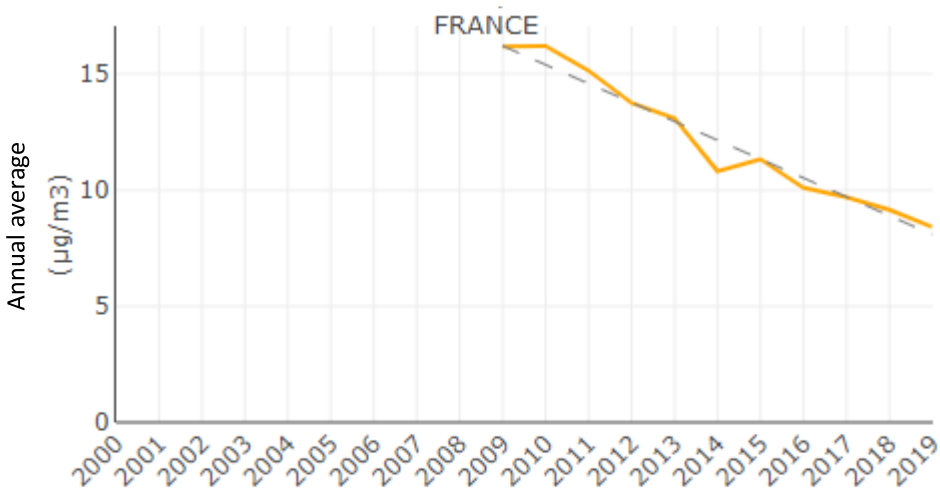
Source 7 : Citepa, Secten report

Over the period studied, a more or less significant decrease in emissions was observed in all sectors. This is explained by the improvement of the technical performances of dedusting, the improvement of technologies for biomass combustion and the implementation of Euro[8] standards for road vehicles. The level of 1991 is exceptionally high due to a particularly harsh winter and therefore a high consumption of wood in the residential/tertiary sector. The objectives for the reduction of PM 2.5 emissions in France compared to the 2005 level are -57% in 2030. In 2019, the level of emissions was already -51% lower than in 2005.

The European Environment Agency (EEA) estimates the number of premature deaths due to exposure to PM 2.5 in France in 2015 at 35,800. However, it estimates that the risk associated with mortality due to air pollution has decreased by half in Europe between 1990 and 2015.

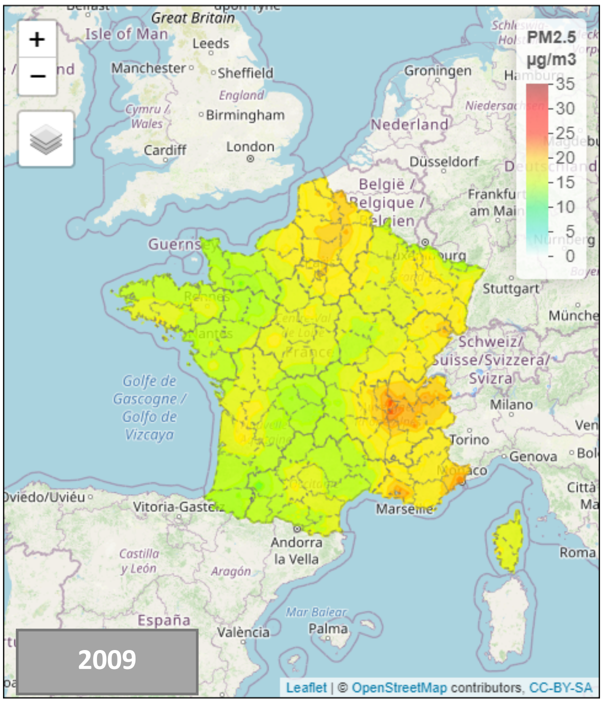
[8] The Euro standards (European emission standards) are a European Union regulation that sets maximum emission limits for new vehicles.

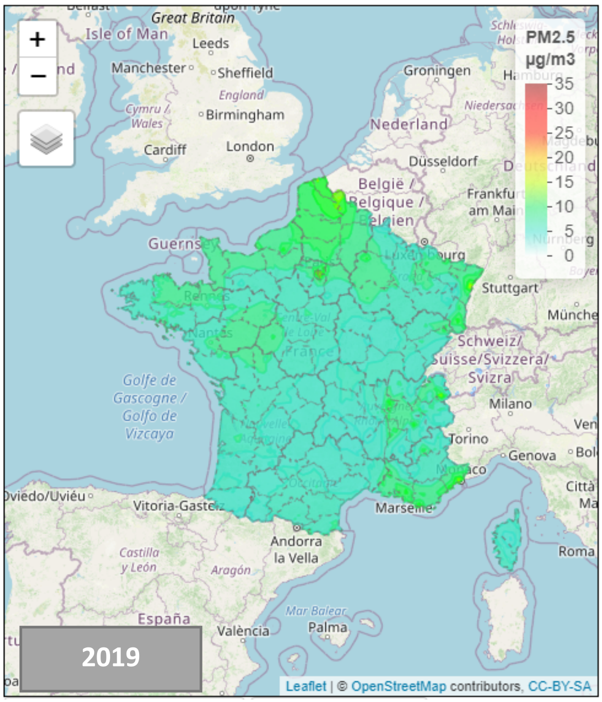
Figure 2-3 : Evolution of PM2.5 concentrations in the air in metropolitan France



Source 8 : INERIS

PM 2.5 concentrations have only been measured and monitored daily since 2009. For this reason, there are no data before this date. The level of concentrations has been decreasing steadily over the observed period. The guide values for levels of daily and annual concentrations defined by the WHO are respectively 25 $\mu g/m^3$ and 10 $\mu g/m^3$. In France, the target value for the protection of human health is set at 20 $\mu g/m^3$ in annual average for a quality objective set at 10 $\mu g/m^3$ in annual average also. Since 2017, this objective is respected. The change in annual average concentration between 2009 and 2019 can be seen on the following maps:



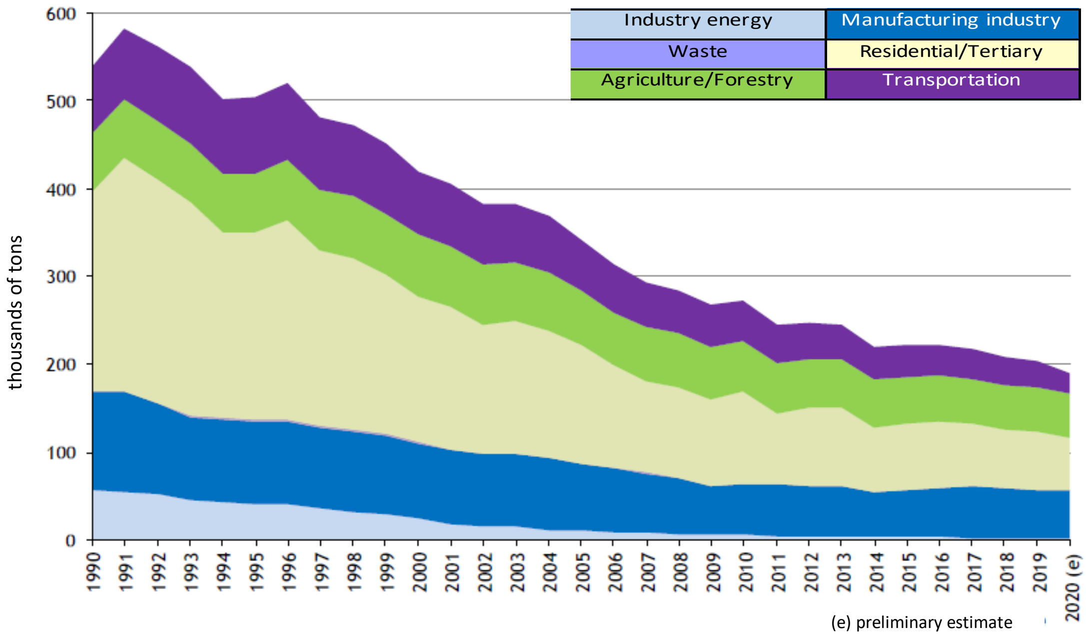


The value of the annual average of PM 2.5 concentrations has improved in all departments of metropolitan France in 10 years.

2.1.2. PM 10

PM 10 is defined as particles with a diameter of 10 µm (microns) or less. Particles with a diameter between 2.5 and 10 µm are called coarse. PM 10 thus includes coarse, fine and ultra fine particles. On average in the ambient air, they are composed of 70% of PM 2.5. The main sectors contributing to PM 10 emissions are the residential/tertiary sector with wood combustion, the manufacturing industry with construction, agriculture with breeding and road transport.

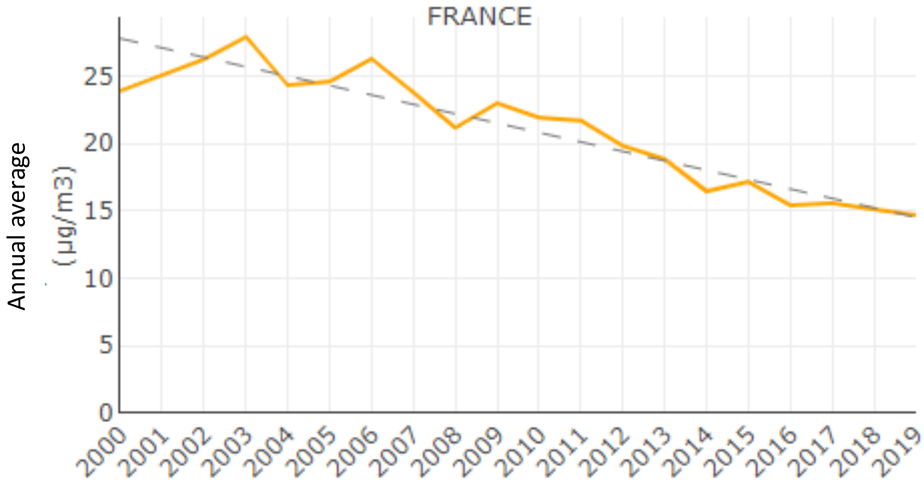
Figure 2-4 : Evolution of PM10 emissions in the air since 1990 in metropolitan France



Source 9 : Citepa, Secten Report

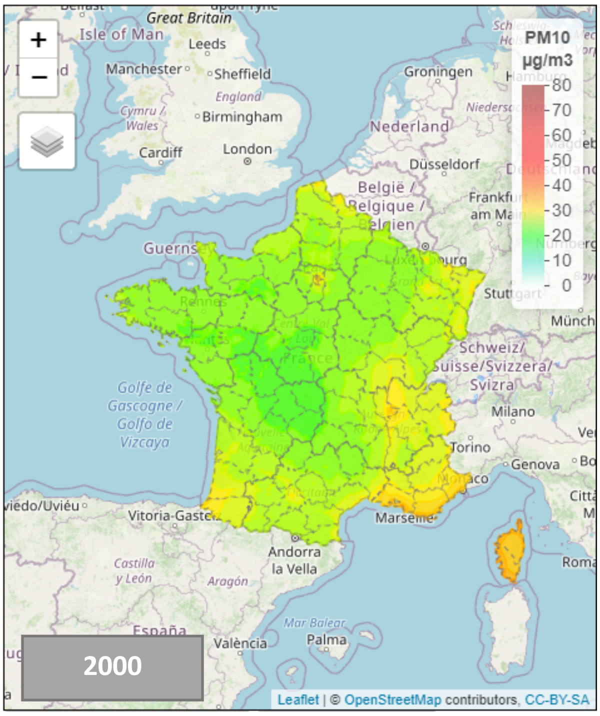
The current level of PM 10 emissions is the lowest observed since 1990. There is no quantified emission reduction target as for PM 2.5 but rather emission limit values imposed in some contributing sectors. The decrease of the emission level is global and observed in all sectors. It can be explained by the improvement of the performance of metallurgy installations, combustion technologies and the implementation of standards for road vehicles. The cessation of open-pit and underground mining operations has contributed significantly to this decrease.

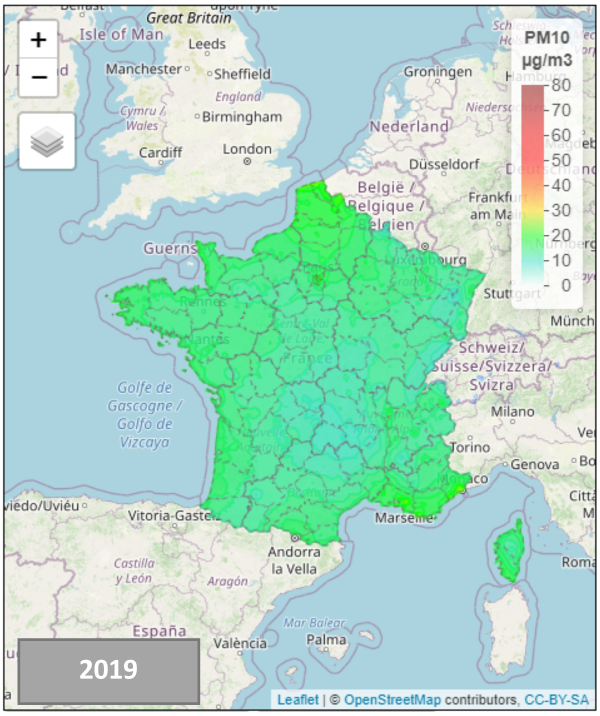
Figure 2-5 : Evolution of PM10 concentrations in the air in metropolitan France



Source 10 : INERIS

The level of the concentrations of PM 10 is regularly measured and supervised in order not to exceed the limit values for the protection of the human health recommended by WHO which are 20 $\mu g/m^3$ in annual average and 50 $\mu g/m^3$ in daily average. The regulatory values of the European Union are 40 $\mu g/m^3$ in annual average and 50 $\mu g/m^3$ in daily average not to be exceeded more than 35 days per year. In France, the threshold of alert and the threshold of information and recommendation are respectively 80 and 50 $\mu g/m^3$ on average on 24 hours for an objective of quality fixed at 30 $\mu g/m^3$ on annual average. The level of the concentrations of PM 10 did not cease decreasing on the observed period and is well lower than the various fixed thresholds. The evolution of the annual average concentration between 2000 and 2019 can be seen on the following maps:



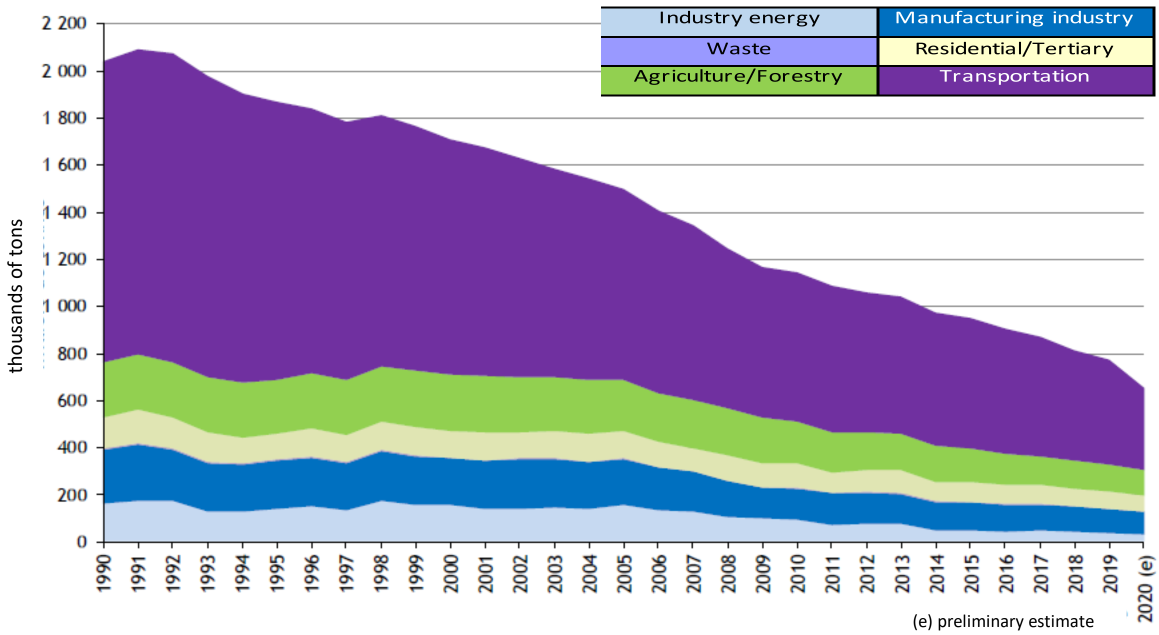


The value of the annual average PM 10 concentration has improved in all departments of metropolitan France in 19 years.

2.2. Nitrogen Oxides

Nitrogen Oxides (NOx) are an air pollutant that includes Nitrogen Dioxide (NO2) and Nitrogen Monoxide (NO). Chemically, it consists of one atom of Nitrogen and one or two atoms of Oxygen (O2). They are emitted by natural sources such as volcanoes, lightning or forest fires, but also by anthropogenic sources with combustion in various sectors. The main contributing sector to NOx emissions is road transport. NOx emissions lead to acidification of the atmosphere and acid deposition, they are also precursors of Ozone. They have an impact on the greenhouse effect.

Figure 2-6 : Evolution of NOx emissions in the air since 1990 in metropolitan France



Source 11 : Citepa, Secten report

Over the period studied, a more or less significant decrease in emissions was observed in all sectors. The share of emissions due to road transport has been falling sharply since 1993 despite an increase in the number of vehicles and traffic. This reduction can be explained in part by the introduction of European standards in 1970 that set maximum pollutant emission limits for vehicles. The development of new technologies and the gradual fitting of catalytic converters to vehicles have contributed to this. The decrease in the other contributing sectors is mainly explained by a better energy performance of industrial installations, the renewal of the fleet of agricultural and industrial machinery as well as the implementation of the nuclear power program and the development of renewable energies.

Nitrogen Oxides (NOx) is harmful to health, particularly Nitrogen Dioxide (NO2), which penetrates deep into the lungs and irritates the bronchial tubes, thus increasing the frequency and severity of asthma attacks, but also altering the development of the lung capacity of young children. As for Nitrogen Monoxide (NO), it passes into the pulmonary alveoli and dissolves in the blood where it limits the fixation of O2 on the hemoglobin and thus reduces the oxygenation of the organs.

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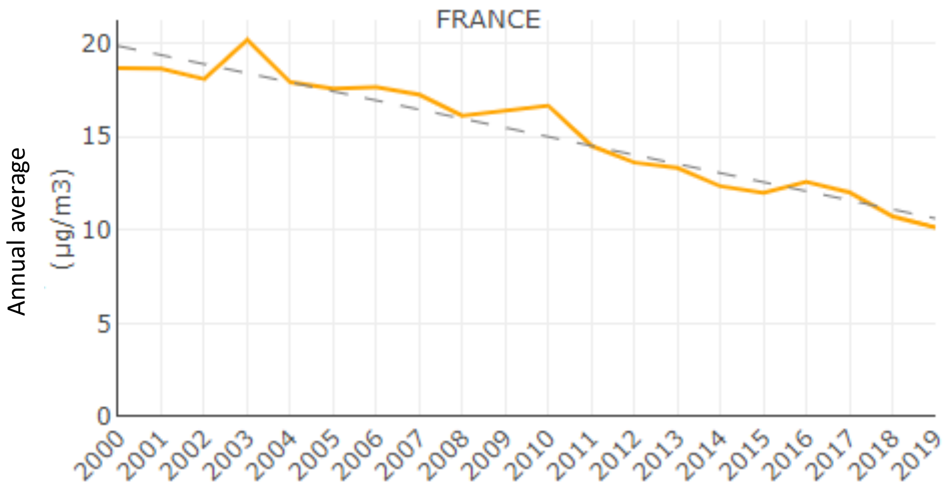
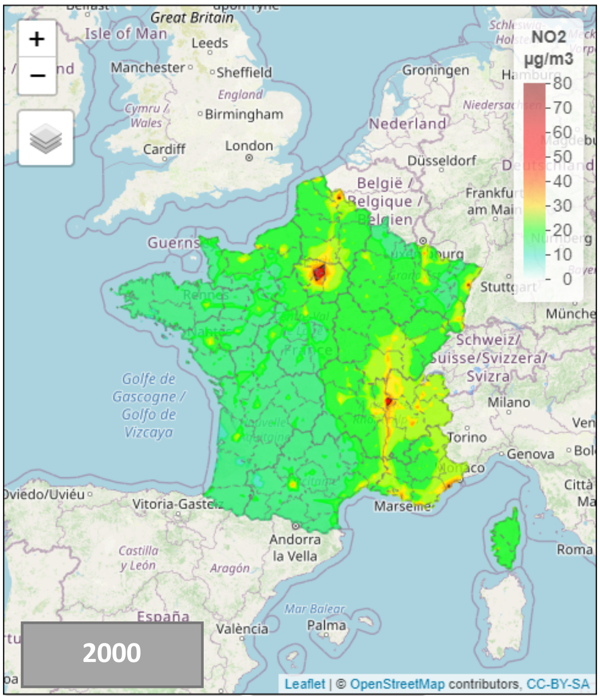
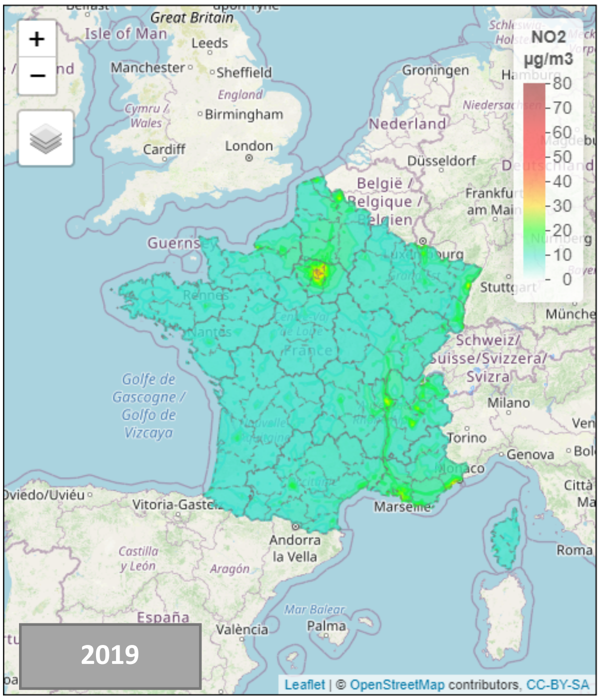
Figure 2-7 : Evolution of NO2 concentrations in the air in metropolitan France



Source 12 : INERIS

The level of NO2 concentrations is regularly measured and monitored in order not to exceed the limit values for the protection of human health recommended by the WHO which are 40 $\mu g/m^3$ in annual average and 200 $\mu g/m^3$ in hourly average and not to be exceeded more than 18 hours per year for the European Union regulatory values. The European threshold of alarm is fixed at 400 $\mu g/m^3$ in hourly average during 3 consecutive hours. In France, the threshold of information and recommendation is 200 $\mu g/m^3$ in average hourly for an objective of quality fixed at 40 $\mu g/m^3$ in average annual. The level of the concentrations of NO2 did not cease decreasing on the observed period, however certain agglomerations still exceed the thresholds in force. The evolution of the annual average concentration between 2000 and 2019 can be seen on the following maps:





The value of the annual average NO2 concentration has improved in all departments of metropolitan France in 19 years.

2.3. Ozone

2.3.1. Precursors and formation

Ozone (O3) is a natural gas present at high altitude in the stratosphere. It forms the Ozone layer which filters and protects us from the sun's ultraviolet rays. However, when it is present at low altitude in the troposphere, or on the ground, this gas becomes a pollutant. O3 is a secondary pollutant, i.e. it is not directly emitted into the ambient air. Its formation is due to photochemistry, which is stronger during the day and in summer, from mid-June to mid-September, following the irradiation of precursor gases such as volatile organic compounds (VOCs), Nitrogen Oxides (NOx) and carbon monoxide (CO) by ultraviolet light (UV), in the presence of oxygen (O2). Thus, the formula of formation and destruction of Ozone is established as follows:

$$NO_2 + O_2 + UV \leftrightarrow O_3 + NO$$

The formation of O3 is a complex process which can last several hours contrary to its destruction which lasts only a few minutes. This equation reflects why O3 concentrations can be higher in rural than in urban areas. As explained in the previous section, NOx are largely emitted by road traffic and a high concentration of these gases favor the formation of O3 during the day but also its destruction at night - a titration[9] phenomenon. Thus, the areas where NO2 is less present will have a less important phenomenon of destruction *(INERIS, September 2020)* because in the absence of volatile organic compounds (VOCs), there is a balance between the formation and destruction of Ozone. But when they are present in the atmosphere, they interact with Nitric Oxide (NO) which is largely oxidized into Nitrogen Dioxide (NO2). At this point, there is no more NO to destroy the Ozone and the NO2 with the ultraviolet rays will form Ozone again.

O3 is one of the pollutants with the greatest impact on human health because it easily penetrates the finest respiratory tract. It can attack the respiratory and ocular mucous membranes and increase asthma attacks as well as sensitization to pollens. It can also promote cardiovascular disorders and impair lung function. Ozone is also harmful to the environment because it disrupts the growth of certain plant species and can lead to a decrease in crop yields. Moreover, it contributes to the greenhouse effect.

2.3.2. Concentrations and indicators

The level of O3 concentrations is measured in $\mu g/m^3$ or parts per billion (ppb), with 1ppb = 2 $\mu g/m^3$.

There is an indicator, developed by the WHO Regional Office for Europe in 2008, to assess the effects of O3 on human health called Sum of Ozone Means Over 35 ppb (SOMO 35). SOMO 35 is defined as the annual sum of the daily maximum of plus 35 ppb (70 $\mu g/m^3$) on an 8-hour basis. It is calculated as follows:

$$SOMO\ 35_{uncorrected} = \sum_i max\{0; C_i - 35\ ppb\}$$

Where C_i is the maximum daily 8-hour average concentration and $i = 1\ to\ 365$ because the sum is annual. It is possible to study only the summer months and therefore to sum for $i = 1\ to\ 180$.

[9] **Titration**: Phenomenon mainly nocturnal of destruction of Ozone by the Oxides of nitrogen in the zones where they are emitted in great quantity.

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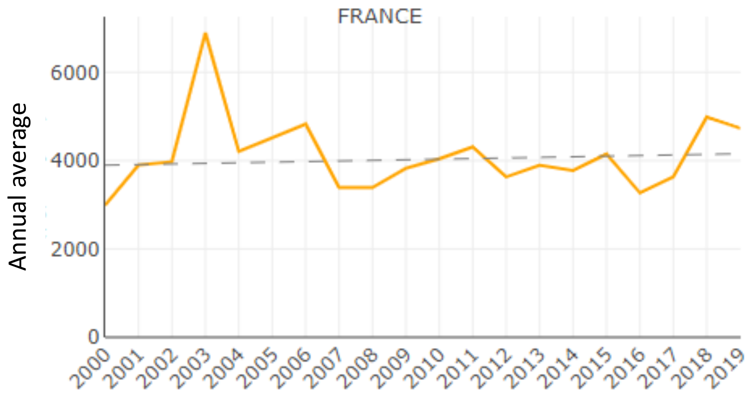
This indicator being sensitive to missing values, days where the maximum daily average concentrations over 8 hours are not available, it is the reason why it is question of uncorrected SOMO 35 in a first time. Indeed, when some daily data are missing, a correction of the following form is necessary:

$$SOMO\ 35 \ = SOMO\ 35_{uncorrected} \times \frac{N_{total}}{N_{valid}}$$

Where N_{total} is the number of days in the period of interest (365 for a year, 180 for summer) and N_{valid} the number of days with valid values *(Miller and al., 2011)*.

Figure 2-8 : Evolution of SOMO35 values in metropolitan France



Source 13 : INERIS

Over the observed period, there are more or less significant variations in SOMO 35 values. The peak in 2003 is explained by the strong summer heat wave of that year. However, there is no recommended or limiting SOMO 35 value.

The authorities have set different thresholds for the protection of human health. In France, the alert threshold for health protection for the whole population and the information and recommendation threshold are respectively 240 and 180 $\mu g/m^3$ in hourly average. The target value for the protection of the human health is set at 120 $\mu g/m^3$ in daily maximum of the average on 8 hours not to be exceeded more than 25 days per annum, on average over 3 year, for a quality objective of the same value. To get an idea, the following maps show the evolution of the number of days of exceedance of the daily threshold of 120 $\mu g/m^3$ between 2000 and 2019:

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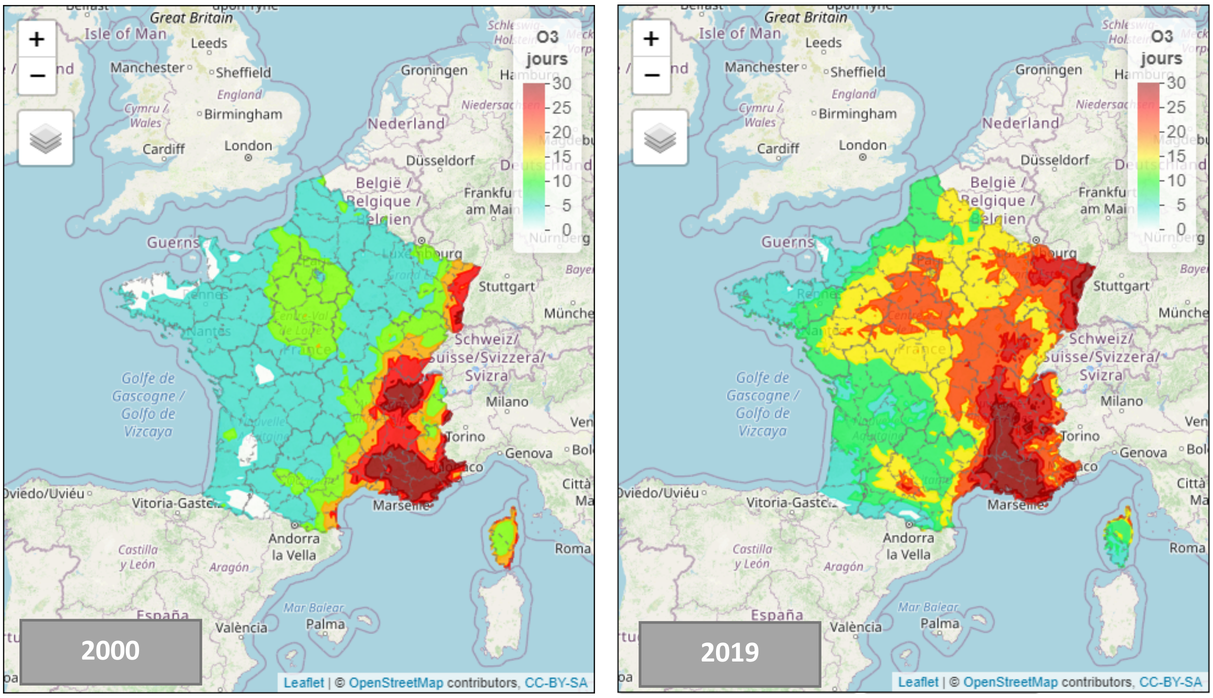
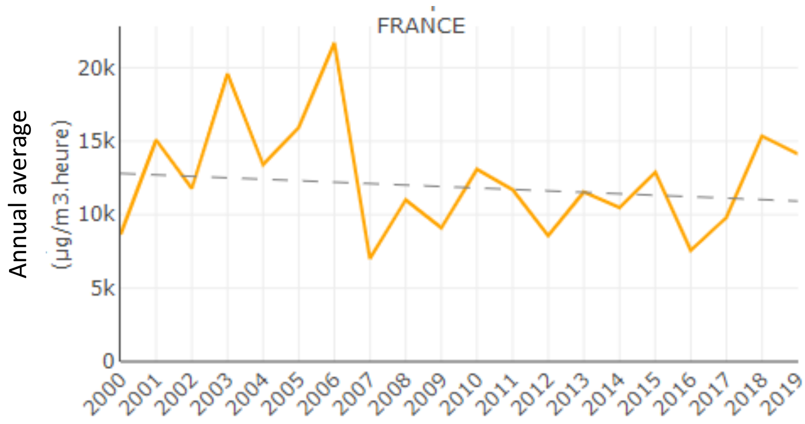


The number of departments with days exceeding the 120 $\mu g/m^3$ threshold has increased over 19 years.

To assess the effects of O3 on vegetation, there is another indicator called Accumulated Ozone exposure over a Threshold of 40 ppb (AOT 40). AOT 40 is defined as the sum of the differences between hourly concentrations above 40 ppb during a given time period, using only the one-hour values measured daily between 8 a.m. and 8 p.m.

Figure 2-9 : Evolution of AOT40 values in metropolitan France



Source 14 : INERIS

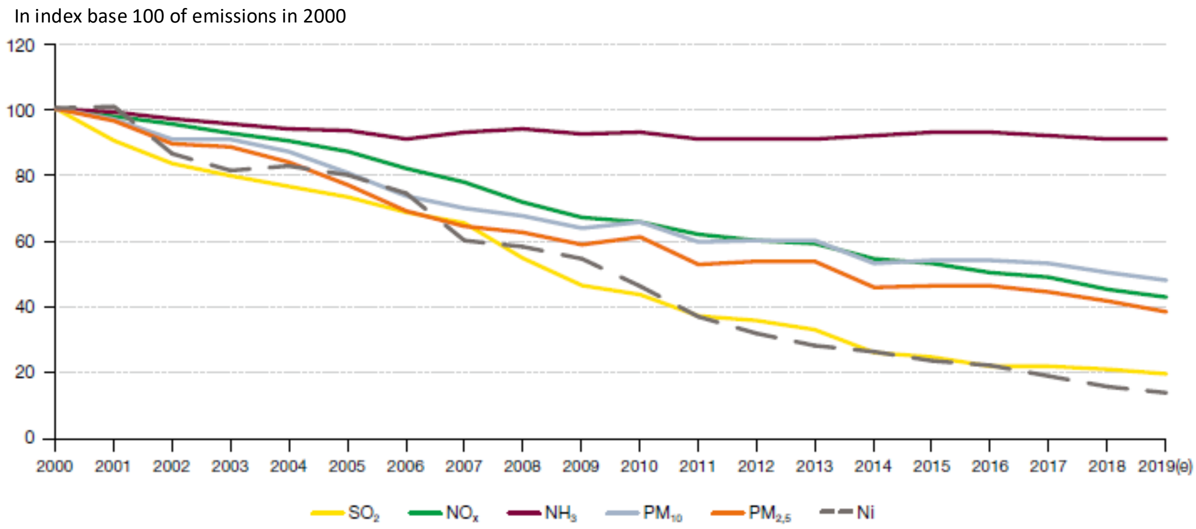
AOT 40 values vary quite significantly from year to year. The target value for the protection of vegetation is set at 18,000 $\mu g/m^3h$, calculated from one-hour values from May to July between 8 and 20 hours (averaged over 5 years), for a quality objective of 6,000 $\mu g/m^3h$.

3. Ozone and Global Warming

Each year, the Ministry of Ecological Transition is obliged to publish a *Bilan de la qualité de l'air extérieur en France* (Report on outdoor air quality in France) in order to report the evolution of the situation on the territory but also to anticipate the effects on health and the environment. To prepare this report, the Ministry's *Service des Données et Etudes Statistiques* (SDES) relies on data on regulated pollutants, presented in part in Chapter 2, which come from the national monitoring system operated at the regional level by the *Associations Agréées de Surveillance de la Qualité de l'Air* (AASQA) and centralized in the national database Géod'Air[10] maintained by the *Laboratoire Central de Surveillance de la Qualité de l'Air* (LCSQA).

In France, the *Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique* (CITEPA) estimates each year the amount of national anthropogenic emissions of pollutants regulated at international and/or European level. Only the primary emissions of pollutants, quantities of pollutant emitted directly into the atmosphere, are estimated. The "*Bilan de la qualité de l'air extérieur en France 2019*", published in September 2020, highlights the significant decrease in primary anthropogenic emissions, which began several years ago following the implementation of various action plans.

Figure 3-1 : Evolution of emissions of some pollutants in metropolitan France



Source 15 : CITEPA

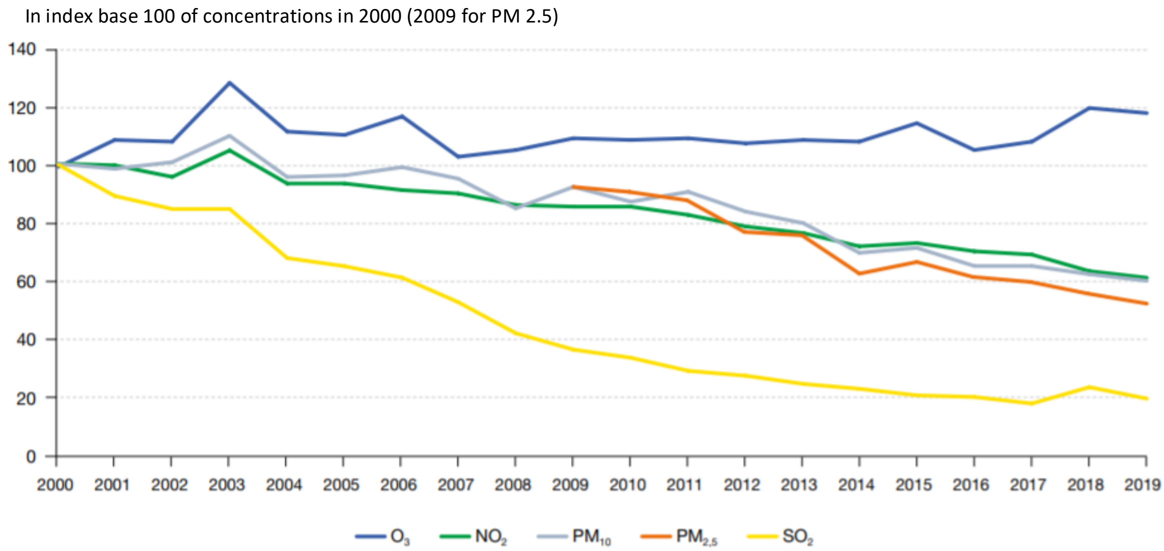
Thus, this graph supports the downward trend in emissions of the pollutants presented in this report already described in Chapter 2. Over the period 2000 - 2019, NOx emissions have decreased by 56% and PM 2.5 and PM 10 emissions have decreased by 61% and 51% respectively.

Air quality does not only depend on primary anthropogenic emissions since there are also primary emissions of natural origin but above all chemical reactions can occur in the atmosphere and produce secondary pollutants. It is therefore important to observe the link between emissions and concentrations which is not necessarily proportional.

[10] **Geod'Air** is the national database of daily air quality. This application managed by INERIS, within the framework of the LCSQA, gathers historical reference statistics but also in real time on air quality in France. The source data come from the AASQA.

In France, the National Institute for Industrial Environment and Risks (INERIS) aggregates at the national level the measurements of pollutant concentrations made by the background or proximity stations of the AASQA. The perimeter may change each year depending on the opening and closing of the stations. These measurements, generally expressed in micrograms per cubic meter ($\mu g/m^3$), are used to establish estimates of the presence of certain pollutants on the territory and to ensure the restitution via maps or a national pollution index in urban areas (Atmo[11] index). *The Bilan de la qualité de l'air extérieur en France 2019* (French Outdoor Air Quality Report 2019) highlights a downward trend in average pollutant concentrations.

Figure 3-2: Evolution of annual average concentrations of pollutants in France (average summer concentrations for O3)



Source 16: Geod'Air

Thus, this graph supports the decreasing trend of the concentrations of the pollutants presented in this report except for Ozone. Average summer O3 levels have been stable since 2007, despite some fluctuations in recent years. However, these trends must be qualified since maximum O3 concentrations are generally observed in rural areas, due to the complex phenomenon of titration explained in chapter 2.3 on the formation and destruction of the pollutant. On the whole of the proximity stations of the national territory, the annual average concentrations are 2 times higher for NO2 than on the background stations and 1.2 times higher for particles.

In view of the decrease in emissions and pollutant concentrations, the strong message of the French Outdoor Air Quality Report 2019 is that air quality has improved in France since the 2000s. However, the LCSQA draws attention to short- and long-term regulatory air quality threshold exceedances for human protection at some locations in the country. A first warning had been given by the Council of State in July 2020, ordering the French Government to act to improve air quality in 8 areas (Paris, Grenoble, Lyon, Marseille - Aix-en-Provence, Reims, Strasbourg, Toulouse and Fort-de-France) of the territory under penalty of a fine of 10 million euros per half year of delay. As the measures taken were deemed insufficient, France was sentenced by the Council of State, in August 2021, to pay the 10 million euros to the association Friends of the Earth, which had initially seized it since 2017, and other

[11] **Atmo index**: "daily indicator of air quality calculated at the scale of each municipality on the whole national territory (metropolis and overseas) from the concentrations in the air of 5 statutory pollutants (sulphur dioxide, NO2, O3, PM 2,5 and PM 10)" Atmo France, 2020

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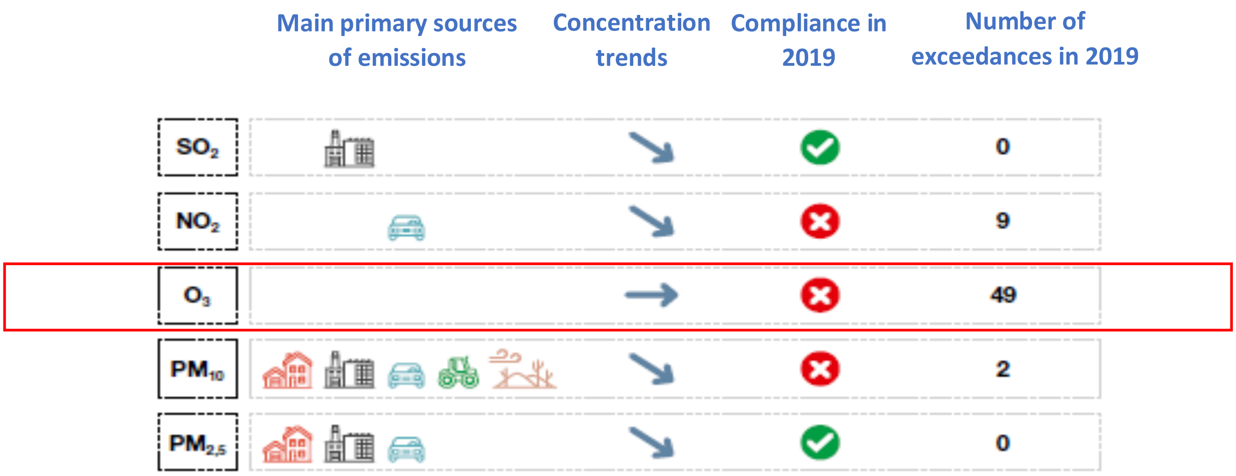
organizations involved in the fight against air pollution. This record fine shows the importance that climate change now occupies on the political level: inactive states against air pollution will be punished.

Figure 3-3: Summary of exceedances of regulatory concentration thresholds for long-term health protection in 2019 in France



Source 17: Geod'Air, CITEPA

The regulatory threshold set for health protection for PM 2.5 has been met since 2015. While threshold exceedances for PM 10 and NO2 are fairly localized, respectively 2 (Cayenne and Paris) and 9 in 2019, O3 is subject to threshold exceedances concerning a significant number of agglomerations in the territory. The regions affected by exceedances for this pollutant are located in the east, south and southeast of metropolitan France as shown on the map below.

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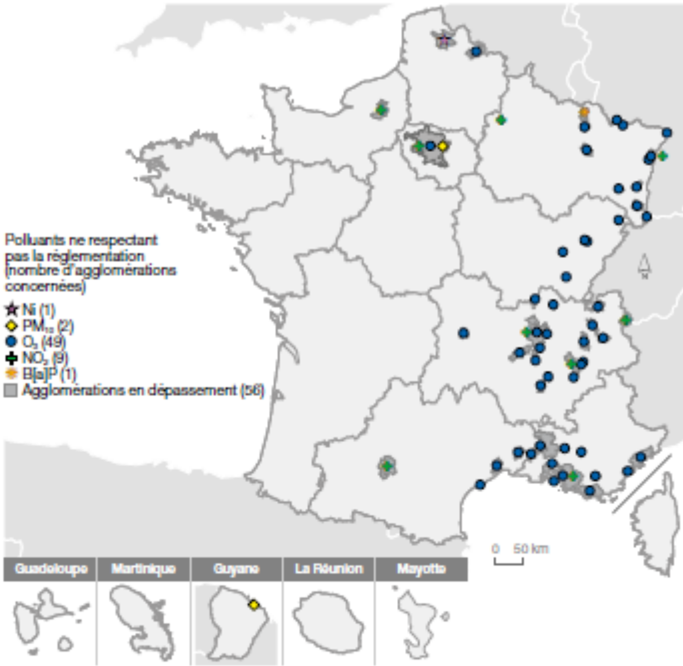
Figure 3-4: Agglomerations with exceedances of regulatory thresholds in 2019 for long-term health protection



Source 18: Geod'Air

Beyond the number of consequent thresholds exceedance for Ozone, the value of the annual average concentration being stagnant since the years 2000, even increasing these last years, the continuation of this report will focus on the pollution due to Ozone, its evolution with the climate change and its impact on health. This choice is also based on the latest IPCC report[12] published last August which, on the health perimeter, emphasizes the fact that the formation of O3 is dependent on temperature, which increases with global warming, and therefore that mortality related to O3 pollution should necessarily increase with climate change.

3.1. Ozone and its precursors

The fight against ozone pollution is a major issue in the field of air quality, given its impact on human health and the environment. The complex process of formation and destruction of this pollutant is based on the balance between the emissions of Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOC) which determines the levels of O3 in the atmospheric air. Emissions and concentrations of NO2, the precursor of O3, are falling sharply, but O3 concentrations are not decreasing, which means that policies must also monitor the evolution of other precursors. While combined actions to reduce emissions of the various precursors appear to be the best way to reduce O3 levels in the atmosphere, it may be necessary to evaluate other potential levers of action. As a reminder, the formula of the process of formation - destruction of the Ozone is the following:

$$NO_2 + O_2 + UV \leftrightarrow O_3 + NO$$

3.1.1. NO2

NO2 is a precursor of O3 which, in the presence of oxygen and ultraviolet rays, promotes the formation of the latter. However, NOx emissions have decreased by 56% between 2000 and 2019. In 2019, only 9 agglomerations have exceeded the regulatory thresholds for long-term health protection for NO2

[12] IPPC (2021) "AR6 Climate Change 2021: The physical science basis"

compared to 37 in 2003. Despite this, a study[13] conducted by ATMO Auvergne-Rhône-Alpes on the effectiveness of actions to reduce NOx emissions (road transport) shows that a decrease in emissions of the precursor of Ozone does not necessarily lead to a decrease in concentrations of the latter, at least not a proportional decrease. These results highlight threshold effects due to the Ozone formation process, below which the reduction of precursor emissions is not very effective.

To this non-proportional decrease is added the temperature factor. Indeed, high temperatures will increase the number of chemical reactions between NO2 and O2, and thus accentuate the formation of O3 while in reality the concentrations of the precursors are lower. The relationship between temperature and Ozone formation reminds us of the objective of this report, i.e., the impact of climate change, translated here by an increase in temperature which can favor the formation of Ozone and thus pollution.

3.1.2. Volatile Organic Compounds (VOCs)

VOCs are molecules formed mainly from bonds between carbon atoms and hydrogen atoms. They are said to be volatile because under normal conditions of temperature and pressure, they can be transported more or less far from their place of emission. VOCs can be classified according to their origin and their toxicity for the environment and/or human health. There are two main categories: Non-methane volatile organic compounds (NMVOCs) on the one hand and methane (CH4) on the other.

3.1.2.1. Non-methane volatile organic compounds (NMVOCs)

NMVOCs are gaseous organic species resulting from combustion, evaporation, chemical or biological reactions. They contain at least one carbon atom associated with other atoms such as hydrogen, oxygen, nitrogen, etc. They are primary air pollutants, i.e., emitted directly from natural sources such as biotic VOCs from forests and crops, or from anthropogenic sources such as the production of alcoholic beverages and bread, petroleum refining, combustion facilities and domestic or industrial use of solvents. As explained in Chapter 2.3, NMVOCs are precursors of Ozone since they react with Nitrogen Oxides under the effect of solar radiation. They can be hazardous to human health as they can cause eye irritation and breathing difficulties.

In 2019, agriculture is the main source of NMVOC emissions (42%[14]) in France, followed by solvent use at 31%.

[13] ATMO Auvergne-Rhône-Alpes (2019) « *Episodes de pollution – Bilan Eté 2019* »
[14] CITEPA (2021) « *Rapport National d'Inventaire / Format Secten* »

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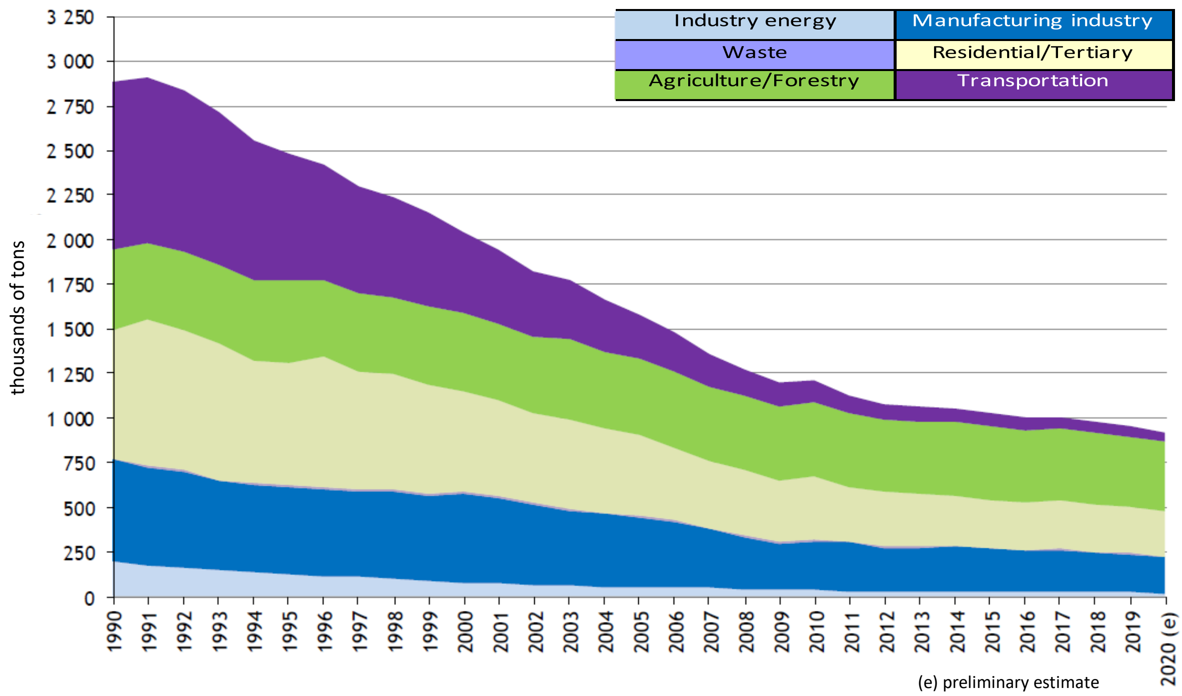
Figure 3-5: Evolution of COVNM emissions in the air since 1990 in metropolitan France



Source 19: Citepa, Secten Report

NMVOC emissions have decreased by 67% between 1990 and 2019 with a 94% decrease in the transport sector thanks to the equipment of gasoline vehicles with catalytic converters and the increasing share of diesel vehicles, 64% in the residential/tertiary sector with progress in the field of combustion and an offer of solvent-free household products, 88% in the energy transformation sector with all coal mines closed.

Thanks to these results, France has already reached the target set by the European Directive 2016/2284. Thus, the same postulate as with NO2 can again be established, namely that a decrease in emissions of the precursor of Ozone does not necessarily lead to a decrease in concentrations of the latter, in any case not a proportional decrease.

3.1.2.2. Methane (CH4)

Methane is a powerful, colorless, odorless and non-toxic greenhouse gas that holds a special place among volatile organic compounds. It is composed of one carbon atom and four hydrogen atoms. It is produced mainly biologically through natural sources such as bacteria in wetlands, volcanoes and forest fires, or through anthropogenic sources such as agriculture mainly cattle breeding and landfills. CH4 is a precursor of Ozone and as a greenhouse gas it is relevant to both climate change and air pollution issues. It is not on the list of regulated pollutants to avoid possible overlaps with EU climate policy.

Methane is the second largest contributor to the total radiative forcing of greenhouse gases (16% in 2019, after 66% for CO2), which explains why the targets for reducing its emissions are defined according to the strategies put in place to limit global warming.

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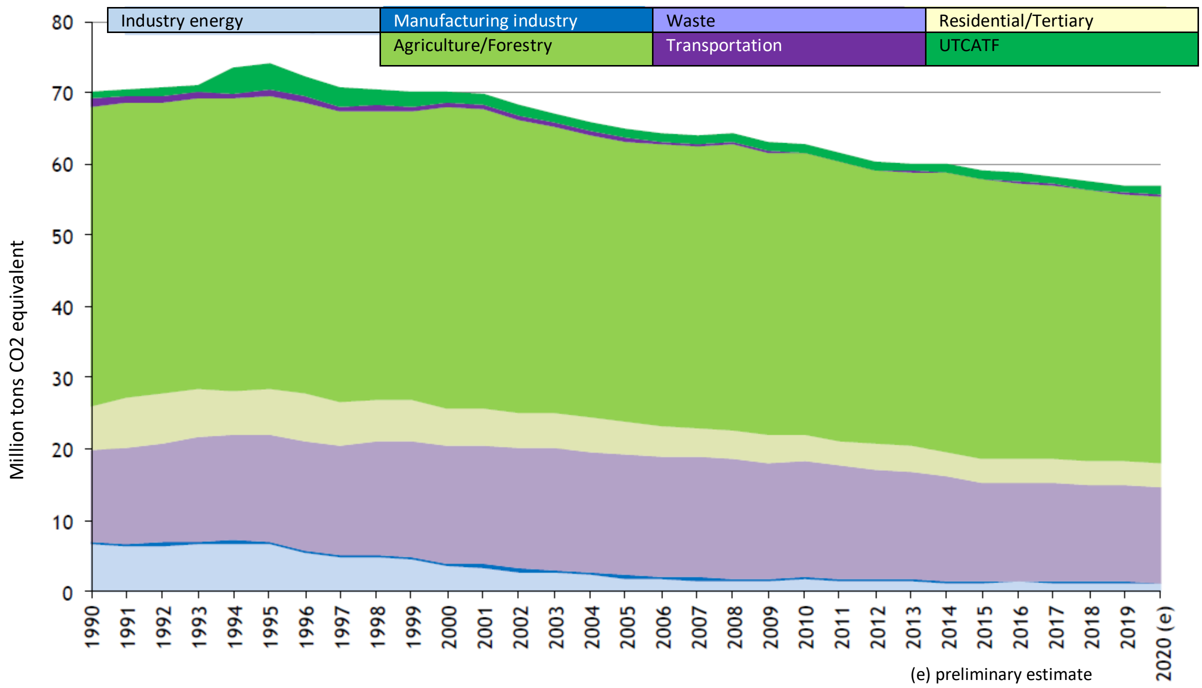
Figure 3-6: Evolution of CH4 emissions in the air since 1990 in France

[15]



Source 20: Citepa, Secten Report

Methane emissions have decreased by about 19% between 1990 and 2019 with a slight decrease of 11% in the agricultural sector, the main source of emissions, and 84% for the energy transformation sector with the gradual cessation of coal mining and the replacement of the gas transport and distribution network. Emissions from the agricultural sector are difficult to reduce since they are intrinsically linked to animal metabolism.

Methane does not deviate from the previous postulate: even if the decrease in its emissions is less than the two pollutants studied previously, it is possible to say that a decrease in the emissions of the precursor of Ozone does not necessarily lead to a decrease in the concentrations of the latter, at least not a proportional decrease.

3.2. Quantitative impact of rising temperatures on Ozone concentrations

The observation is strong: Ozone precursor emissions are decreasing. However, the concentrations of this pollutant are not decreasing proportionally. It is now necessary to analyze the impact that climate change, particularly global warming with rising temperatures, may have on Ozone concentrations. Coates et al.[16] point out that high levels of Ozone concentration are correlated with heat waves, which in turn are characterized by high temperatures and stagnant weather conditions. The increase in temperature therefore influences O3 production through increased chemical reactions and increased emissions of volatile organic compounds.

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[15] UTCAF includes the sectors of land use, land use change and forestry

[16] COATES J. and al. (2016) "The influence of temperature on ozone production under varying NOx conditions – a modelling study". Atmospheric Chemistry and Physics, 16, 11601-11615

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3.2.1. Impact modeling

Several studies attempt to model the correlation between Ozone and temperature using either purely meteorological models or more classical statistical models such as time series. According to the articles, it is possible to find a linear or non-linear relationship between the parameters and a possible integration of the concentrations of the Ozone precursors. The choice of the hypothesis taken for the rest of this report, concerning the quantitative impact of the temperature increase on the level of Ozone concentrations, will be based on and justified by the following literature.

3.2.1.1. Meteorological models

The first study (Colette et al., 2015)[17] is a meta-analysis initiated by INERIS in France with the participation of several environmental organizations from different countries of the European Union (Sweden, Denmark, United Kingdom, Greece, Netherlands and Finland) and the United States. Scientists refer to the risk that climate change will negate the strategies put in place to mitigate ozone pollution as the "ozone climate penalty". Using chemistry-transport models with future climate projections, while keeping Ozone precursor emissions constant, the objective is to quantify this climate penalty on the European continent. They rely on data from 11 previously published papers on the subject, providing them with 25 projection models. They estimate the climate penalty to be plus 1 or 2 ppb per degree Celsius. This estimate is significant for Central and Southern Europe, but the future evolution varies with a projected increase for mid-century in Italy and Spain of one additional ppb against a decrease for the Scandinavian countries. As a reminder, $1ppb = 2\mu g/m^3$. This penalty is even more pronounced for summer days by the end of the century (2071-2100) with at most 5 ppb.

The second study (Coates et al., 2016)[18] is a German analysis that also seeks to quantify the impact of the ozone climate penalty via meteorological models while incorporating the impact of varying NOx emissions unlike the first study which held constant the emissions of the Ozone precursors. In this way, they establish a non-linear relationship between Ozone concentrations, temperature and NOx emissions which they examine using a box model with different meteorological chemical mechanisms. The box model simulations approximating stagnant conditions and the maximal ozone production chemical regime reproduced the 2 ppb increase in ozone per degree Celsius from the observational and regional model data over central Europe. This result coincides with that of the previous article. However, under conditions of high NOx and an increase in temperature from 20 to 40°C, Ozone concentration levels can increase by up to 20 ppb due to the increase in chemical reactions.

More recently, a U.S. study (Porter and Heald, 2019)[19] has established a nonlinear relationship between Ozone and temperature related to Ozone precursor emissions which they analyze using the GOES-Chem chemistry-transport model over the U.S. and Europe. From their model, they estimate that the increase in Ozone concentrations will be about 1.4 ppb per degree Celsius. However, they show that in Europe the temperature dependence of NOx emissions contributes only 7% of the correlation between Ozone and temperature. They thus point out that the major part of the correlation between O3 and temperature is explained by other meteorological phenomena such as humidity and stagnation: « […] models relying on temperature-dependent emissions and chemical mechanisms alone may underpredict the strength of O3-temperature sensitivities by over 60%». This result

[17] COLETTE A. and al. (2015) "Is the ozone climate penalty robust in Europe?". Environmental Research Letters 10 (2015) 084015

[18] COATES J. and al. (2016) "The influence of temperature on ozone production under varying NOx conditions – a modelling study". Atmospheric Chemistry and Physics, 16, 11601-11615

[19] PORTER C. and HEALD L. (2019) "The mechanisms and meteorological drivers of the summertime ozone-temperature relationship". Atmospheric Chemistry and Physics, 19, 13367-13381

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supports the comment in the previous section that justifies the non-proportional decrease in Ozone concentrations with decreasing emissions and concentrations of its precursors.

Thus, the assumption of a 2 ppb increases in Ozone concentrations per degree Celsius up to 5 ppb in summer, based on the literature, seems prudent and consistent.

3.2.1.2. Statistical models

Researchers have tried to quantify the impact of rising temperatures on Ozone concentrations, other than through meteorological models, with the well-known statistical method of time series.

A recent Swiss study (Boleti et al., 2020)[20] attempts to measure the impact of reduced precursor concentrations on Ozone concentrations between 2000 and 2015. Using a non-parametric timescale decomposition methodology, they extracted the variation in ozone observation for long-, seasonal and short-term. Timescale decomposition is based on the decomposition of the mean Ozone concentrations time series into the relevant underlying frequencies by the following equation:

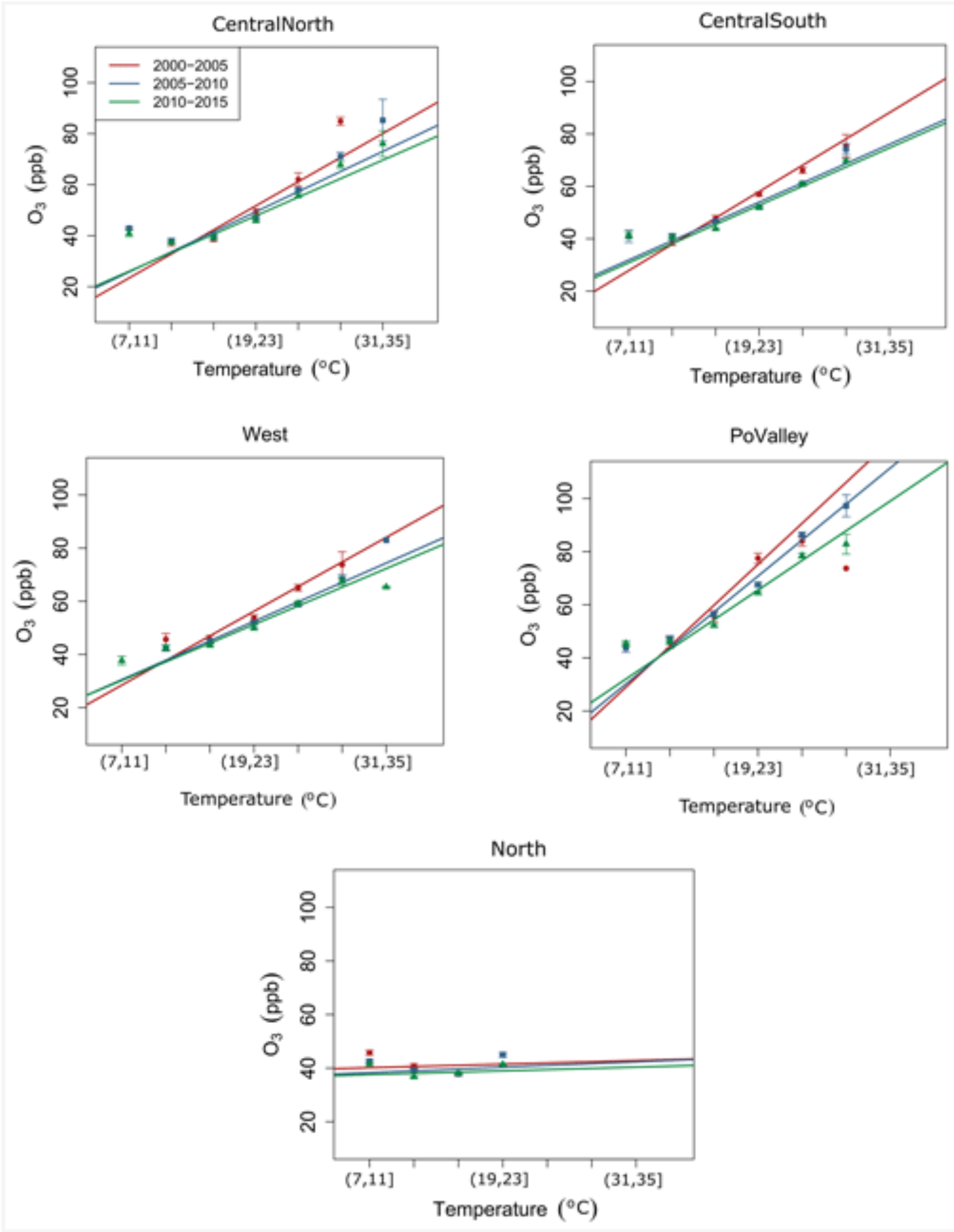
$$O_3(t) = LT(t) + S(t) + W(t) + E(t)$$

Where $O_3(t)$ is a time series of the daily mean observations of Ozone concentrations, $LT(t)$ time series of the long-term variation means variations at multiannual timescales, $S(t)$ time series of the seasonal variation representing variations at monthly to yearly timescales, $W(t)$ time series of the short-term variation means variations at daily to monthly timescales, and $E(t)$ times series of the daily remainder of the decomposition.

They establish a linear relationship between Ozone and temperature using the maximum daily Ozone concentrations and maximum daily temperatures between May and September, again over the observed period of 2000 to 2015, to represent the peak concentrations. The long-term trend of this relationship has been plotted on the following graphs for different regions of Europe.

[20] BOLETI E. and al. (2020) “Temporal and spatial analysis of ozone concentrations in Europe based on timescale decomposition and a multiclustering approach”. Atmospheric Chemistry and Physics, 2020, 9051-9066

Figure 3-7: Linear trends of the slope between O3 and temperature daily maximum values for the warm season



Source 21: Boleti and al.

Following the projections for Europe for the warm season between May and September, it is possible to show, with highly significant trends (p-value below 0.01), that:

- The slope of the Ozone - temperature relation for North Central Europe varies between 2.5 ppb/ degree Celsius between 2000 and 2005 and 1.8 ppb/ degree Celsius between 2010 and 2015.
- The slope of the Ozone - temperature relationship for south-central Europe varies between 2.1 ppb/ degree Celsius between 2000 and 2005 and 1.7 ppb/ degree Celsius between 2010 and 2015.
- The slope of the Ozone - temperature relationship for Eastern Europe varies between 2.1 ppb/ degree Celsius between 2000 and 2005 and 1.4 ppb/ degree Celsius between 2010 and 2015.

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These graphs highlight the increasing relationship between the level of Ozone concentrations and temperature: the higher the temperature, the higher the Ozone concentrations. They support the fact that the correlation between Ozone concentrations and temperature is slightly stronger in Central South Europe than in Central North Europe (Colette and al., 2015): the slope of the "Central South" graph is steeper than that of "Central North". The trend in the "North" graph is not representative (p-value greater than 0.05) given the lower average temperatures in these regions. The increasing relationship between the level of Ozone concentrations and the temperature that these graphs show, allows us to confirm the hypothesis of an increase of 2 ppb of Ozone concentrations per degree Celsius, fixed thanks to the previous articles. The slope of the curves is however decreasing between the three groups of years: the slope of the period 2000-2005 is more marked than that of the period 2005-2010, itself more marked than the period 2010-2015. The decrease in slopes between years is mainly explained by the decrease in Ozone precursor emissions. However, as Porter and Heald explain, precursor emissions contribute less than 50% to the correlation between Ozone concentrations and temperature. Thus, there are other explanatory factors.

A German study (Otero et al., 2020)[21] supports the previous results. They examine the climate penalty through a linear relationship between Ozone and temperature for the periods 1999 to 2008 and 2009 to 2018. They try to show the involvement of NOx emissions in the Ozone-temperature relationship and consequently the impact of the decrease of the latter. For this purpose, they use generalized additive models (GAM), which are well known in the statistical world, to model the rates of Ozone production from hourly observations at German monitoring stations as a function of NOx emissions and temperature. The rates of change of hourly Ozone concentrations are approximated as follows:

$$\Delta O_3(t) = O_3(t) - O_3(t-1)$$

From a linear regression model, they project the daily maximum of the 8 hours running mean based on hourly mean concentration as follows:

$$Y(t) = N(\mu(t), \sigma^2)$$

With

$$\mu(t) = T(t) \times P(t)$$

Where $T(t)$ is the time series of daily temperature maximum for the whole period 1999-2018 and $P(t)$ is a categorical variable of two parts: one representing the 1999-2018 period and another for the period 2009-2018.

Thus, they certainly show an increasing relationship between Ozone and temperature, but more importantly a decrease in Ozone production rates and a decrease in temperature sensitivity between the first and second observation periods that can be explained by the reduction in NOx emissions. However, they caution that decreases in precursor emissions and concentrations alone cannot explain the dependence of Ozone on temperature, which is consistent with the previously mentioned literature.

[21] OTERO N. et al. (2020) “Observed changes in the temperature dependence response of surface ozone under NOx reductions”. Atmospheric Chemistry and Physics, not published

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For the sake of transparency with the reader, it is important to specify that this last article has been cited because it seems relevant and is in agreement with those previously mentioned, but that following a revision, the author did not obtain the recognition of his peers, so it has not been published.

The hypothesis of an increase of 2 ppb of Ozone concentrations per degree Celsius, which can go up to 5 ppb in summer, will be kept for further development.

3.2.2. Projection of SOMO 35

Once the assumption of an increase in Ozone concentrations of 2 ppb per degree Celsius is justified, it must be applied to the indicator for the protection of human health, which is SOMO 35. It is important to remember that SOMO 35 is the annual sum of the daily maximum of plus 35 ppb (70 $\mu g/m^3$) on the basis of 8 hours and it is calculated as follows:

$$SOMO\ 35 = \sum_i max\{0; C_i - 35\ ppb\}$$

Where C_i is the maximum daily 8-hour average concentration and $i = 1\ to\ 365$ because the sum is annual.

Strictly speaking, applying an increase of 2 ppb to the level of Ozone concentrations would mean having the level of concentrations of each day over a whole year, then adding to each of them the increase of 2 ppb to calculate the SOMO 35. As we do not have the daily concentration values, but only the SOMO 35 values retrieved from the online map library[22] published by INERIS allowing to trace the evolution of the air quality in France, from 2000 to 2019, the following methodology has been used.

Using the IPCC RCP 8.5 scenario, which projects a temperature increase of up to 4.8°C in 2100, to define the temperature increase due to climate change *(following table)* and assuming that the impact of the temperature increase is constant over a whole year, applying an increase in the level of Ozone concentrations amounts to adding to the SOMO 35 value studied the impact in terms of ppb multiplied by 2 and by 365. Recalling the conversion $1ppb = 2\mu g/m^3$, the projection assumption translates as follows:

Table 3-1: Projection assumption

Temperature increase since today (celsius)	+0.5°	+1°	+1.5°	+3°
Ppb	1	2	3	6
$\mu g/m^3$	2	4	6	12

Source 22: GRM Life AXA

It is important to remember that between the pre-industrial era (1850) and today, temperatures have already risen by more than 1°C (IPCC) and when institutions that fight against global warming warn that it must be limited to a rise of 1.5°C, it is in comparison to the temperatures of 1850. Adding one degree Celsius to current temperatures is therefore equivalent to adding 2°C compared to pre-industrial temperatures.

[22] https://www.ineris.fr/fr/recherche-appui/risques-chroniques/mesure-prevision-qualite-air/20-ans-evolution-qualite-air (20 years of air quality evolution mapped by Ineris), site visited from July to November 2021

Table 3-2: Comparaison temperature increase by reference year

Temperature increase since 1850 (celsius)	+1°	+1.5°	+1.5°	+2.5°	+4°
Temperature increase since today (celsius)	Current	+0.5°	+1°	+1.5°	+3°

Source 23: GRM Life AXA

Thus, the SOMO35 value after an increase of x degrees Celsius compared to the 2019 level is projected as follows under the assumption of a 2 ppb increase per degree Celsius:

$$SOMO\ 35\ after\ increase\ of\ n°C = \sum_{i=1}^{365} \max\{0; C_i + 2ppb \times x - 35\ ppb\}$$

$$= \sum_{i=1}^{365} \max\{0; C_i + 4 \times x - 70\}$$

$$\approx \sum_{i=1}^{365} [max\{0; C_i - 70\} + 4x]\ \ (see\ below)$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 365 \times 4x$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 1\,460x$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 35\ ppb\} + 730x$$

The projection method is based on the strong assumption that all daily concentrations C_i were implicitly greater than 35 ppb (70 $\mu g/m^3$). This is what allows the multiplication by 365 to be performed. The approach is therefore conservative since it tends to overestimate the SOMO 35 value. With this methodology, SOMO 35 increases linearly with temperature.

For example, an initial SOMO 35 with a value of 4,732.831 $\mu g/m^3$ (INERIS, 2019), following an increase of one degree Celsius, increases to a value of $4{,}732.831 + 1{,}460 \times 1 = 6{,}192.831 \mu g/m^3$. For an increase of three degree Celsius, the initial SOMO 35 increases to value of $4{,}732.831 + 1{,}460 \times 3 = 9{,}112.831 \mu g/m^3$.

Table 3-3: Projection of SOMO 35 (assumption of 2 ppb per degree year-round)

Année	2019	Climate change impact				
		Increase in °c since 1850*	1,5	2	2,5	4
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3
4732,831		Corresponding SOMO35	5462,83	6192,83	6922,83	9112,83
		** Between 1850 and today the temperature has already increased by about 1°C*				

Source 24: GRM Life AXA

Although conservative, since one additional degree today already exceeds the policy goal of plus 1.5°C, the assumption of a 2 ppb increases in Ozone concentrations per degree Celsius applied linearly throughout the year is debatable. Indeed, Ozone is certainly known for its interannual variations, complicating the comparison from one year to another, but this pollutant is especially known for its

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intra-annual variations, with frequent peaks of concentrations in summer depending on heatwave episodes. In order to remain cautious and to prepare for possible extreme situations, still based on the literature presented in the previous section, another projection of SOMO 35 was made with the assumption of an increase of up to 5 ppb in the level of Ozone concentrations during the summer months (June, July and August), i.e. 92 days over the year, and an increase of 2 ppb in the level of Ozone concentrations during the rest of the year, i.e. 273 days.

For example, an initial SOMO 35 with a value of 4,732.831 $\mu g/m^3$ (INERIS, 2019), following an increase of one degree Celsius, increases to a value of $4\,732{,}831 + 2 \times 2 \times 273 + 5 \times 2 \times 92 = 6\,744{,}831 \mu g/m^3$.

Table 3-4: Projection of SOMO 35 (assumption of 5 ppb per degree during summer)

Année	2019	Climate change impact				
		Increase in °c since 1850*	1,5	2	2,5	4
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3
4732,831		Corresponding SOMO35	5738,83	6744,83	7750,83	10768,83
		***Between 1850 and today the temperature has already increased by about 1°C**				

Source 25: GRM Life AXA

This second assumption is doubly conservative since a pollution episode usually lasts only a few days, concentrations are not as high for the full 3 months.

4. Quantifying the current climate impact of pollution on health

« L'Etat assure […] la surveillance de la qualité de l'air et de ses effets sur la santé et l'environnement. Il confie à l'Agence de l'environnement et de la maîtrise de l'énergie, la coordination technique de la surveillance de la qualité de l'air. » - Article 3 de la loi sur l'air et l'utilisation rationnelle de l'énergie (LAURE), décembre 1996

To guide and justify the implementation of actions to reduce population exposure to air pollution, decision makers often need information on the magnitude of the potential health impact of pollution on the population in their area. They may also want to assess the expected health impact of an intervention to reduce emissions in their area. Thus, quantifying the public health effects of exposure to air pollution has become an essential part of the policy debate. Indeed, the impact of pollution on health has been scientifically proven by various quantitative studies (Santé Publique France, 2016, 2021) which allow to direct the choice of public authorities on adapted measures. A methodological guide has been written by Santé Publique France, within the framework of the Air and Health Monitoring Program (Psas) created in 1997 in application of the LAURE, in order to provide the different stakeholders with a support element for the realization of Quantitative Assessment of the Health Impact of Air Pollution.

In this sense, WHO has developed, for Europe, a free software called AirQ+ operating under Windows or Linux systems that performs calculations to quantify the burden of disease due to air pollution and its impact, including estimates of reduced life expectancy. The first version of the program, AirQ, was distributed in a Microsoft Excel spreadsheet program in 1999, followed by another version for Windows in 2000. A substantial difference between AirQ and AirQ+ is that the second contains a new graphical user interface with several help texts and various features to input and analyze data and illustrate results. The main calculation methods use scientific data generated by epidemiological cohort studies, showing the existing relationships between average concentration levels found in polluted air over the long term and mortality risks in exposed populations. It is suggested that the impact of air pollution be assessed when evaluating the consequences of hypothetical policies, interventions or scenarios.

This section will focus on the analysis of the current impact of pollution: the existing quantitative methods and the existing studies in the literature.

4.1. Quantitative methods

4.1.1. Quantitative Health Impact Assessment (QHIA)

An QHIA is a tool to support decision-making and raise public awareness that allows the magnitude of the impact of air pollution on health to be calculated and the potential benefits of action to reduce pollution to be assessed. It is a method originally developed by the WHO and is based on the assumption of a causal link between exposure to air pollution and its health effects. There are three categories of QHIA the type of which depends mainly on the objective pursued and also on the air pollution exposure data available to the stakeholders:

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- The QHIA with measured exposure is the best known and most widely used. It allows to quantify the impact of air pollution on health on a territory equipped with measuring stations. Two categories of measurement stations can be distinguished:
    - The proximity stations collect information on the maximum levels of exposure of the population in the vicinity of traffic routes and industrial zones.
    - The background stations monitor an average level of exposure of the population in all the areas away from any direct source of pollution (urban centers, periphery of the urban center, rural areas).
- The QHIA with modelled exposure allows to quantify the impact of the air pollution burden on a territory with an adapted model. It requires statistical and geoprocessing methods for exposure data since air pollutant concentrations are obtained from pollution models.
- Intervention QHIA quantifies the expected health impact of the change in air pollution levels caused by an action over the study period. It also requires statistical and geoprocessing methods for exposure data since it is the air pollutant concentration differentials (with and without intervention) that are recovered.

Regardless of the type of quantitative assessment chosen, the study area must be co-constructed with the AASQA. Ideally, an area with more than 20,000 inhabitants would be required to make the results interpretable, or a grouping of municipalities. The study period should be determined with the partners according to the available exposure and health data. At least two consecutive years are required and data from years with major climatic and meteorological events should be avoided.

The principle of the QHIA is to rely on scenarios of air pollution change. Three types of scenarios can be used for the first two categories of QHIA described:

- Target value scenario corresponds to the quantification of a decrease in concentration levels to a specific value such as the WHO guide values.
- Pollution reduction scenario is the quantification of a decrease in concentration levels by a fixed amount, for example a percentage.
- Mortality or morbidity reduction scenario is the search for a percentage reduction in health impact, e.g., 10% reduction in mortality.

The results can be expressed in different ways depending on the scenario chosen: number of attributable cases, a certain number of percent reduction in the health indicator, number of years of life lost or gained, reduction in the concentration necessary to achieve a health objective.

An QHIA is based on a quantitative approach that assumes a causal relationship between exposure to a pollutant and the occurrence of a health effect. Its implementation is therefore limited to pollutant-effect pairs for which a causal link has been defined. The choice of the pollutant - health effect pair must be made by avoiding double counting, i.e.:

- Depending on the objective pursued, which may be to assess the health impact attributable to air pollution as a whole or to assess the impact of a particular source or of an action targeting that source.
- Based on available air pollution and health data for the study area.
- Based on available robust relative risks.

A relative risk (RR) or concentration-risk function estimates the magnitude of an association between exposure and disease. It indicates the probability of developing the disease in the exposed group compared to those who are not exposed. An RR is considered robust when it is derived from a well-

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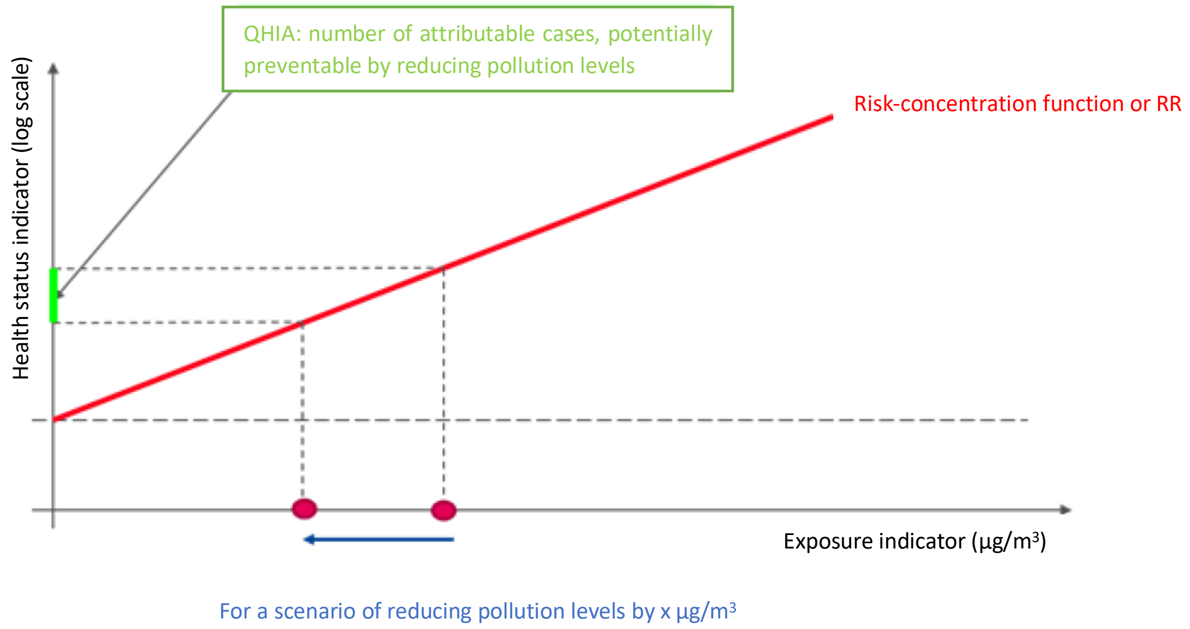
framed meta-analysis[23] and is associated with a confidence interval not containing 1. The RR is one of the most important parameters of the QHIA because it is the RR that is used to select the demographic and health data, and always the objective. Indeed, the data must be determined in a way that is consistent with the data used in the epidemiological study providing the RR. Clauses and age groups must match.

The principle of calculation of an QHIA with measured or modelled exposure for a target value scenario is summarized by the following graph which can be found in the report of the QHIA published in 2021 by Santé Publique France:

Figure 4-1 : Principle of calculation of an QHIA



Source 26 : Santé Publique France

The results of the QHIA presented above will be expressed as an estimate of attributable cases. This concept can be "crudely" interpreted as the number of cases (deaths) that could be avoided if the concentration of the pollutant under study decreases from the mean value to the threshold value, both of which are input.

When the threshold value is zero, any decrease in concentrations results in a decrease in mortality for the exposed population.

The number of avoided cases ΔY from an QHIA, associated with a decrease in pollution levels Δx is calculated from the following equation:

$$\Delta Y = Y_{obs}(1 - e^{-\beta\Delta x}) \quad (\mathbf{1})$$

[23] **Meta-analysis**: a statistical method that combines and integrates the results of different studies concerning similar problems. In the case of air pollution, it gives an overall average value of the effect size of exposure to a specific air pollutant.

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Where

- Y_{obs} the number of observed cases in the population at the current pollution level x_{obs}
- β the slope of the relationship between pollutant concentration and log mortality. For an RR expressed for a 10 $\mu g/m^3$ increase in pollutant, $\beta = ln(RR)/10$.

Δx represents the level of the pollution decrease whose impact is to be estimated. For a scenario with a target value x_{target}, this level of decline corresponds to

$$\Delta x = x_{obs} - x_{target}\ si\ x_{obs} > x_{target}$$

If $x_{obs} \leq x_{target}$, i.e., the observed concentration is below the target value, then $\Delta x = 0$ and there is no health benefit to achieving the target value.

ΔY represents the difference between the number of deaths observed today Y_{obs}, and the number of deaths expected at the scenario pollution level Y_{sce}.

The 95% confidence interval of ΔY is calculated using the upper and lower bounds of the 95% confidence interval of the β.

4.1.2. AirQ+

AirQ+ is a specific calculation tool for air pollution QHIA, developed by WHO and available for free. AirQ+ is intended as a tool to ascertain the magnitude of the burden and impacts of air population on health for a given locality. It performs this function by featuring data analysis, graphing tools, tables and quantitative information for prominent pollutants such as particulate matter (PM), nitrogen dioxide (NO2) and tropospheric ozone (O3). It also has the capacity to perform calculations for black carbon (BC) and provides rough estimates of impacts of households (indoor) air pollution on health. It can be applied to long-and short-term exposure to ambient air pollution and to long-term household air pollution exposure caused by solid fuel use.

4.1.2.1. Analysis

It is possible to perform three types of analysis on the software. To assist users in these, it is accompanied by explanatory manuals:

- An impact assessment allows to perform a simple analysis such as calculating the proportion of adverse health effects attributed to exposure to a particular level of ambient air pollution, in a given population and during a certain time, short or long term. This proportion is used to estimate the number of cases attributable to air pollution. In a slightly more advanced way, it is also possible to perform an impact assessment using data from multiple areas (several countries, regions, cities) in order to obtain a complete assessment. A module allows the inclusion of life tables in an impact assessment. It can estimate years of life lost using calculations for a specific year and the entire follow-up period for all-cause mortality due to specific exposure to ambient air pollution in a given population and area. It also calculates changes in life expectancy that can be attributed to long-term exposure to ambient air pollutants.
- A burden of disease assessment involves combining estimates of air pollution exposure and distribution in the population with results from epidemiological studies specifying the additional burden of disease attributable to different levels of air pollution exposure, based on particular causes of death. The module includes integrated exposure-response (IER) functions to produce estimates of disease burden from cause-specific mortality data. This mode is only

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available for the pollutant PM2.5 and a long-term time perspective. It allows analyses of both ambient and indoor air pollution. It is also useful for global comparisons.
- A risk analysis estimates the risk of cancer occurrence due to lifetime exposure to a carcinogenic air pollutant. It can calculate these risks on the basis of a unit excess risk based on epidemiological studies or toxicological data. The software uses default excess unit risk values for arsenic, benzene, benzopyrene (BaP), chromium, nickel and vinyl chloride.

4.1.2.2. Required inputs

The software asks users to fill in a number of data by themselves:

- The average value of the concentration of the chosen pollutant over the study area. It is expressed in micrograms per cubic meter ($\mu g/m^3$).
- The total population, i.e. the entire population living in the study area.
- The health indicator that he/she wishes to study: he/she can choose from a drop-down list according to the pollutant. For example, for NO2, we find the all-cause mortality and the prevalence of bronchitis symptoms in asthmatic children.
- The gross mortality rate (sometimes referred as incidence) is defined as the number of deaths in a year per 100,000 inhabitants of the population at mid-year, i.e. the arithmetic average of the population on January 1 and December 31 of a year.
- The population at risk represents a percentage, in some cases all, of the total population specific to the study being conducted, usually a specific age group (Adults 30 years and older).

Other fields are filled in by default once the health indicator has been selected but can be modified by the user:

- The default threshold value recommended in the WHO guidelines corresponds to a concentration level below which it is chosen not to quantify health impacts. It corresponds to the quality objective defined at the beginning of the section.
- The relative risk (RR) or concentration-risk function represents the relationship between a population exposure indicator to ambient air pollution and a health indicator. It can be interpreted as the correlation between an exposure dose and a health impact or as the probability of developing a disease in the exposed group (Y) compared to those who are not exposed (Y_0). Thus, the higher the pollution levels, the greater the intensity/probability of the health effect. Relative risks due to air pollution are estimated by epidemiological studies and are usually modeled with the following log-linear function

  $$RR = Y/Y_0 = e^{(\alpha+\beta X)}/e^{(\alpha+\beta X_0)} = e^{\beta(X-X_0)}$$

  Where X is the pollutant concentration expressed in $\mu g/m^3$ and X_0 is the threshold value, β indicates the change in RR for a one unit change in concentration X.

  Each relative risk value is central and associated with a 95% confidence interval. This interval expresses the random error and variability attributed to the heterogeneity of the relative risks from the epidemiological studies.

  From the expression of the RR, it is possible to obtain an equation for the number of avoidable cases, which is in fact an equivalence to the equation for the number of avoided cases presented in the previous section.

  $$Y/Y_0 = e^{\beta(X-X_0)}$$

$$\leftrightarrow Y - Y_0 = Y_0 e^{\beta(X - X_0)} - Y_0$$
$$\leftrightarrow \Delta Y = Y_0(e^{\beta(\Delta x)} - 1)\ \ (\mathbf{2})$$

These two inputs are particularly important because the levels entered into the software can lead to a large variability in the results. The user is reminded that other RRs exist based on new studies and meta-analyses and therefore is advised to always check the robustness of these. The same applies to the cut-off value.

4.2. Premature deaths related to current pollution in the literature

4.2.1. The Santé Publique France study of April 2021

The global health crisis of Covid-19 has had serious consequences for health, societies and the economy. As of September 15, 2021, the virus has affected 226.5 million people worldwide and killed at least 4.7 million, according to the American Johns-Hopkins University. As of the same date, in France, the number of infected people is 6.93 million and the number of deaths is 155,803, according to data from Santé Publique France. In an attempt to contain the spread of the virus, the government was forced to institute a strict lockdown in March 2020, which led to a massive slowdown or even a halt in the activity and mobility of the French population. In addition to the negative consequences that this may have had on economic and social activities, clear improvements in air quality indicators have been noted. At the global level, major decreases in outdoor air pollution levels have been observed in major cities. At the European level, the European Commission's Copernicus Atmospheric Monitoring Service (CAMS) assessed air quality on a daily basis for particulate matter, nitrogen dioxide and ozone. This work was used by the European Environment Agency (EEA) in the drafting of its annual report on air quality. The federation Atmo France, thanks to the regional data of the *Associations Agréées de Surveillance de Qualité de l'Air* (AASQA), reveals that the lockdown has led to a strong decrease of the daily average concentrations of NOx near the roads. Studies carried out by the French National Institute for the Industrial Environment and Risks (INERIS) confirm these decreases. In this sense, Santé Publique France has carried out a study with the objective to evaluate the short and long term impacts on mortality of this decrease in population exposure to air pollution following lockdown but also to re-evaluate the total long term burden of ambient air pollution on annual mortality in metropolitan France in order to update the latest available estimates. In the following, only the second objective will be detailed.

4.2.1.1. Characteristics of the study

Santé Publique France conducted in April 2021 an QHIA with modeled exposure to estimate the total long-term burden of ambient air pollution (PM2.5 and NO2) between 2016 and 2019 on adults aged 30 years and older outside the context of the Covid-19 pandemic measures. The study was conducted in metropolitan France, at the communal scale, based on the 2018 communes reference frame. It covered 35,228 municipalities. The study period runs from January 1, 2016 to December 31, 2019. To refine the accuracy of the results, they are presented at the national level for metropolitan France and also by type of commune:

- Rural municipalities: less than 2,000 inhabitants
- Semi-rural municipalities: 2,000 to 20,000 inhabitants
- Semi-urban communities: 20,000 to 100,000 inhabitants
- Urban municipalities: More than 100,000 inhabitants

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The population data comes from the population census conducted in 2016 by the National Institute of Statistics and Economic Studies (INSEE). This census was done at the IRIS[24] scale and spatialized on residential buildings according to a method established by the *Laboratoire Centrale de Surveillance de la Qualité de l'Air* (LCSQA). This method, often used, allows to take into account the heterogeneous distribution of the population on the territory of a commune.

The total annual all-cause and age-specific mortality data for adults aged 30 and over at the commune level were retrieved from the *Centre d'épidémiologie sur les causes médicales de Décès* (CépiDc) for the most recent year available (2016). This is a service unit of the *Institut National de la Santé et de la Recherche Médicale* (INSERM) in charge of producing statistics on medical causes of death. Attention should be paid to the time lag in the availability of the most recent data, because since 2015, mortality data have been available from the National Health Data System (SNDS).

The choice of relative risks is based on the pairs of pollutants - health effects with which they are associated among those available in the literature. The study focuses on the PM2.5 - mortality and NO2 - all-cause mortality pairs for adults aged 30 years and over in the long term. Thus, the corresponding RRs are as follows:

- For PM2.5: 1.15[1.05; 1.25] from the work of Pascal et al in 2016.
- For NO2: 1.023[1.008; 1.037] from the work of COMEAP in 2018

Annual PM2.5 and NO2 concentration data estimated over the period 2016-2019 by INERIS were used. INERIS models the concentration of pollutants in France using the Chimere model. It is a chemistry-transport model developed by the French National Center for Scientific Research (CNRS) and INERIS in 2001, used for air quality forecasts but also for emission reduction scenario studies. It allows to combine modeling and measurement on a grid of about 4km and thus to have data at the commune.

The reference thresholds (target value under AirQ+) have been set without taking into account anthropogenic pollution because of the lack of modeling data to estimate the share of the latter in France. Thus, for PM2.5 it is the threshold of 5 $\mu g/m^3$ which was chosen because it corresponds to the values estimated in the mountainous zones and is close to the 4.9 $\mu g/m^3$ used in a preceding QHIA of Santé Publique France for continental France. For NO2 it is 10 $\mu g/m^3$ which corresponds to the level used in a sensitivity analysis carried out by the European Environment Agency on the basis of the publication of Raaschou-Nielsen et al.

4.2.1.2. Results of the study

In 2016, there were more than 64 million people in metropolitan France, 47% of whom lived in urban areas, 13% in semi-urban areas, 17% in semi-rural areas, and 23% in rural areas. The all-cause mortality rate for those aged 30 years and older per 100,000 inhabitants was 1,365.07.

[24] **IRIS** stands for "Ilots Regroupés pour l'Information Statistique" and refers to a division of the French territory into grids of uniform size.

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Table 4-1 : Demographic inputs

Urbanization class	Number of municipalities	Total population	30 years and older	Mortality rate per 100 000 inh.
Rural	28,102	14,547,358	9,800,219	1,358.12
Semi-rural	3,743	11,244,685	7,500,861	1,613.96
Semi-urban	1,380	8,650,868	5,669,358	1,549.73
Urban	2,003	30,025,229	18,196,273	1,208.65
metropolitan France	35,228	64,468,320[25]	41,166,711	1,365.07

Source 27 : Santé Publique France

The national mortality rate is obtained by weighted summation of the mortality rates for each area by the weight of adults 30 years and older in each area over the total.

For the study period, the annual average concentration of PM2.5 is 9.6 $\mu g/m^3$ and 12 $\mu g/m^3$ for NO2. The average concentrations of both pollutants are lower in rural communities than in urban communities. The national average concentration rate is obtained by a weighted sum of the average concentrations of each zone by the weight of the number of communes in each zone on the total.

Table 4-2 : Results of the study

Pollutant	Urbanization class	Mean [min ; max]	Number of preventable deaths
PM2.5	Rural	9.5 [6.6 ; 13.5]	7,836
	Semi-rural	9.8 [7.1 ; 13.5]	7,534
	Semi-urban	9.9 [7.2 ; 13.3]	5,721
	Urban	10.9 [7.8 ; 14.4]	18,450
	metropolitan France	9.6 [6.6 ; 14.4]	39,541
NO2	Rural	11.5 [7.4 ; 23.5]	451
	Semi-rural	12.4 [7.6 ; 22.8]	596
	Semi-urban	13.2 [7.9 ; 21.0]	633
	Urban	17.2 [8.0 ; 34.3]	5,110
	metropolitan France	12 [7.4 ; 34.3]	6,790

Source 28 : Santé Publique France

Thus, the study shows that nearly 40,000 deaths would be preventable following a decrease in PM2.5 concentration from 9.6 to 5 $\mu g/m^3$ and 7,000 for NO2 from a concentration of 12 to 10 $\mu g/m^3$.

To show the importance of the impact of the choice of the reference threshold and the relative risks on the variability of the results, sensitivity analyses were carried out. They aim at exploring the influence of the sources of uncertainty of the QHIA. For this, two other relative risks and reference thresholds were chosen for each of the two pollutants.

For PM2.5, we find the RR recommended by the WHO in 2013 which is 1.06 [1.04; 1.08] and the one calculated by the European region in the framework of a meta-analysis of 2020 conducted for the update of the WHO air quality guideline values which is 1.07 [1.03; 1.11]. For NO2, there is another RR from a meta-analysis that is 1.02 [1.01; 1.04].

[25] Summing the column gives 64,468,140, not 64,468,320.

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Table 4-3 : Test of sensitivy

Pollutant	Relative Risk	Reference threshold (µg/m^3)	Number of preventable deaths
PM 2.5	1.15	5	39,541
		2.5	57,382
		0	64,610
	1.06	5	16,866
		2.5	24,707
		0	32,436
	1.07	5	19,532
		2.5	28,582
		0	37,480
NO_2	1.023	10	6,790
		5	12,849
		0	19,025
	1.02	10	5,923
		5	11,212
		0	16,610

Source 29 : Santé Publique France

Regardless of the reference threshold considered, the two RR studied compared to the initial RR for PM 2.5 lead to an estimate of the number of avoidable deaths that is nearly 2 to 2.5 times lower. For NO2, the estimates are quite similar between the two RR regardless of the reference threshold considered. On the other hand, the lower the reference threshold, the higher the number of avoidable deaths, whatever the relative risk considered. This is explained by the principle of calculation of an QHIA which is based on the reduction of pollution levels between an observed level and a target level. Thus, the lower the reference level, the greater the reduction in pollution levels and the greater the number of avoidable deaths.

4.2.1.3. Replication of the results

In order to become familiar with the software, GRM Life attempted to replicate the results of the Santé Publique France study. Each of the inputs used in the study was searched or recalculated to check the consistency of the data:

- As of January 1, 2016, the population of metropolitan France was 64 513 242 according to INSEE.
- Using the INSEE age pyramid[26], also as of January 1, 2016, providing the national population size by sex and age class, it was possible to define the population at risk of adults aged 30 years and older, which amounts to 41 329 938 inhabitants.
- The crude all-cause all-age death rate per 100 000 persons in 2016 in metropolitan France is 895.2 according to CépiDc. Rates are available by age group and sex. Thus, by performing a weighted sum between each death rate by age group from age 30 onward and the weight of each headcount of the population from age 30 onward by age group in the population at risk, it was possible to obtain a crude all-cause death rate of those aged 30 years and older per 100 000 population of 1359.508.

[26] https://www.insee.fr/fr/statistiques/1906664?sommaire=1906743#tableau-TF14032G1 (population by age in the French economy according to INSEE), site consulted in July 2021

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These 3 inputs are very similar to those used in the SPF QHIA, which confirms the traceability and consistency of the data.

The data of the concentration levels of the pollutants by zone modelled by the INERIS being difficult to find under this granularity, the relative risks found in the literature and the reference thresholds will be reused as they are.

The results obtained are presented in the following comparative table:

Table 4-4 : Comparison of results between Santé Publique France and AirQ+

PM2,5	SANTE PUBLIQUE FRANCE							AIRQ+		ANNEX		
	INPUTS					OUTPUTS		OUTPUTS				
Threshol : 5 µg/m3 RR : 1,15(1,05:1,25)	Number of municipalities	Total population	Population at risk (30 + age)	All-cause mortality of people aged 30 and over per 100,000 population	Average concentration	Number of preventable deaths	% annual mortality	Number of preventable deaths	% annual mortality	Gap	Population at risk weight	Nulber of municipalities weight
Rural	28 102	14 547 358	9 800 219	1 358,12	9,50	7 836,00	5,90	8 113,00	6,10	3,53%	23,81%	79,77%
Semi-rural	3 743	11 244 685	7 500 861	1 613,96	9,80	7 534,00	6,30	7 855,00	6,49	4,26%	18,22%	10,63%
Semi-urban	1 380	8 650 868	5 669 358	1 549,73	9,90	5 721,00	6,60	5 816,00	6,62	1,66%	13,77%	3,92%
Urban	2 003	30 025 229	18 196 273	1 208,65	10,90	18 450,00	8,40	17 408,00	7,92	-5,65%	44,20%	5,69%
Metropolitan France	35 228	64 468 140	41 166 711	1 365,06	9,63	39 541,00	7,17	39 192,00	7,05	-0,88%		
		64 468 320		1 365,07	9,60		7,10					

Source 30 : GRM Life AXA

The difference between the outputs obtained on AirQ+ and those of SPF is very small or even negligible. The differences are more marked for the urban municipalities which have the greatest weight in terms of population at risk but among the lowest number of municipalities. The software tends to underestimate the number of avoidable deaths in these municipalities with more than 100,000 inhabitants, whereas it slightly overestimates this variable for the other municipalities. The "Gap" column calculates a rate of change ($(Va - Vd)/Vd$) between the number of avoidable deaths obtained by SPF (Va) and those obtained by AirQ+ (Vd). The two "Weight" columns in the appendix allow the calculation of the all-cause mortality rates of adults aged 30 years and over as well as the average concentration, both at the national scale, by a weighted sum as explained in a previous section. These results provide confidence that the software is well understood and used.

A verification was made by replicating the results using the averted and/or avoidable death equations presented in the first section.

Table 4-5 : Comparaison AirQ+ VS Formulas

	Premature deaths			Mortality rate	Population at risk	Number of cases	Average concentration	SOMO35	Threshold	Relative Risk
	Prevented	Preventable	AirQ+							
Formula	1	2					µg/m3	µg/m3	µg/m3	
O3 2010 LT	8 004	-8 004	8 004	1,32%	39 538 724	523 739	11,1	4 043	0	1,014
O3 2016 LT	6 954	-6 954	6 953	1,36%	41 329 938	561 884	9,0	3 270	0	1,014
O3 2016 CT	1 563	-1 563	1 563	0,89%	64 977 000	576 866	9,4	3 420	0	1,0029
PM2,5 Rural	8 113	-8 113	8 113	1,36%	9 800 219	133 099	9,5		5	1,15
PM2,5 Semi R	7 855	-7 855	7 855	1,61%	7 500 861	121 061	9,8		5	1,15
PM2,5 Semi U	5 816	-5 816	5 816	1,55%	5 669 358	87 860	9,9		5	1,15
PM2,5 Urban	17 408	-17 408	17 408	1,21%	18 196 273	219 929	10,9		5	1,15
NO2 Rural	453	-453	453	1,36%	9 800 219	133 099	11,5		10	1,023
NO2 Semi R	659	-659	659	1,61%	7 500 861	121 061	12,4		10	1,023
NO2 Semi U	637	-637	637	1,55%	5 669 358	87 860	13,2		10	1,023
NO2 Urban	3 571	-3 571	3 571	1,21%	18 196 273	219 929	17,2		10	1,023

Source 31 : GRM Life AXA

The "Prevented" column uses formula (1) for the number of deaths prevented and the "Preventable" column is based on formula (2) for the number of preventable deaths. The inputs used for both formulas have been put in the following columns to facilitate the reader's understanding. The "Number of cases" column is obtained by multiplying the "Mortality rate" column by the "Population at risk" which corresponds to Y_{obs} and Y_0 in both formulas. The Δx is obtained for formula (1) by subtracting

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the "Threshold value" column from the "Average concentration" column and conversely for formula (2).

Example: the 8,113 avoided/preventable deaths due to PM 2.5 exposure in rural communities are obtained by the following equations

$$(\mathbf{1})\ 133\ 098 \times \left(1 - e^{-[ln(1{,}15)/10] \times (9{,}5-5)}\right)$$

$$(\mathbf{2})\ 133\ 098 \times \left(e^{[ln(1{,}15)/10] \times (5-9{,}5)} - 1\right)$$

Both formulas give exactly the same output as if the calculation had been done on AirQ+.

AirQ+ is a software that, at first sight, may seem "button click" and slightly "black box". It allows you to easily carry out an QHIA by entering a certain number of inputs but requires a good understanding of each of the fields requested from the user. However, having access to the tool, but especially having understood and being able to reuse the formulas behind the tool, allows the user to be more independent in the analysis. It is important to know what is calculated and how it is calculated in order to be able to interpret the results as clearly as possible, otherwise an error can quickly occur. As the equation is provided by the WHO, this allows us to confirm the veracity of the methodology used.

4.2.2. Other articles concerning premature deaths related to pollution in the literature

4.2.2.1. Example of short-term impact on mortality

Each year, the European Environment Agency publishes a report on air quality in Europe. It tracks the sources and emissions of regulated pollutants such as particulate matter, nitrogen dioxide, ozone and others. It also studies the exposure of the population to these pollutants but particularly the impacts on health and ecosystems. In the 2019 Air Quality Report, they estimate 14,000 premature deaths in 2016 related to short-term exposure to Ozone for the European Union of 28. This number amounts to 1,400 for France according to the European Environment Agency.

These results are obtained by retrieving population data from Eurostat[27], mortality data from WHO, the population at risk and the relative risk selected from the WHO Health Risk of Air Pollution In Europe (HRAPIE) project recommendations, and by calculating the SOMO 35 values according to the methodology of the European Topic Centre on Air pollution and Climate change Mitigation (ETC/ACM)[28].

The study was carried out on a short-term exposure period with a population of all ages and an all-cause mortality.

4.2.2.2. Example of long-term impact on mortality

Quantifying short-term impacts allows us to assess situations and adjust action plans, but to establish them upstream, it is the long-term impacts that remain the most important to analyze. It is therefore essential to quantify them as well.

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[27] https://ec.europa.eu/eurostat/fr/data/database (European statistics database), site visited in August 2021

[28] The **ETC/ACM** is a consortium of European institutes that provides thematic expertise to the EEA in the fields of air pollution and climate change. It assists EEA in reporting on the progress of EU environmental policy on air quality, air emission and climate change but also with the collection of data concerning the current state of the atmosphere and harmonization of the European monitoring networks and reporting obligations.

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A Scandinavian-American study (Orru et al., 2019)[29] projects the evolution of mortality according to the evolution of Ozone concentrations and, separately, according to the evolution of heat between the periods 1991 to 2000 and 2046 to 2055, with an assumption of a 2° rise in temperatures between the two periods. They present that about 55,000 premature deaths would be due to long-term exposure to Ozone in the European Union of 27 in 2010. They include in this number an estimate of the proportion of premature deaths due to short-term exposure, which they raise to 26 000. Because the sources of the inputs are different, it is not reasonable to make a reliable comparison between the 14,000 avoidable deaths presented by the European Environment Agency in 2016 and the 26,000 in the article in 2010.

By retrieving population data for each European country from the Integrated Assessment of Health Risks of Environmental Stressors in Europe (INTARESE) and the Health and Environmental Integrated Methodology and Toolbox for Scenario Development (HEIMSTA), mortality data from the WHO's European Health for All Database, and relative risk selected from epidemiological studies, the authors present a number of 6,130 premature deaths in France in 2010 that would be attributable to long-term exposure to ozone.

The study was conducted over a long-term exposure period with all-cause mortality rates.

4.3. Limits

There are several sources of uncertainty that can affect the results of a QHIA.

The use of models for exposure estimation can create uncertainty about the quality of the model and its ability to reproduce pollution levels close to reality. The models are dependent on the availability and quality of the input data. The pollution levels that will be input to the QHIA will vary depending on the meteorological model chosen but also on the analysis methods of the QHIA. For this reason, the exposure assessment method used in an QHIA should correspond as much as possible to the one used to define the RR. When this is not the case, it can add an additional source of doubt to the results of the assessment. Moreover, the estimation of population exposure at a fine scale can lead to uncertainties since the use of the average concentration of a municipality as an exposure value for the whole population of the municipality can lead to an underestimation of the real exposure of some inhabitants who would be subjected to a higher pollution level than in their place of residence.

Health indicators can be a source of uncertainties, but they are negligible in the context of this report since the health indicator studied is mortality. The method of producing mortality data is standardized at the international level through the use of the International Classification of Diseases (ICD), which allows for good data consistency.

The greatest source of variation is related to the concentration-risk relationship (RR). The relative risk is calculated from a multitude of studies over fairly large areas. When applied to local data in an QHIA, it is necessary to translate the relationship in space and time. It is therefore essential that not only the air pollution levels but also the living habits of the populations are similar in order to approximate the situation in the study area as closely as possible.

In addition to the different sources detailed above that may impact the results, it should be remembered that in the case of the previously replicated study, the population size dating from 2016 as well as the mortality data may create a slight bias.

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[29] ORRU H. and al. (2019) "Ozone and heat-related mortality in Europe in 2050 significantly affected by changes in climate, population and greenhouse gas emission". Environmental Research Letters, 14 (2019) 074013

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5. Quantifying the climate change impact of pollution on health

Now that we are able, on one side, to translate an increase in temperature in an increase in ozone concentration (chapter 3.2.2), and, on the other side, to calculate the number of premature deaths due to a given pollutant concentration (chapter 4), we are now able to translate the increase in temperature into an increase in premature deaths due to a long term exposure to ozone. And once we have this number of avoidable deaths calculated with the most appropriate parameters, we will get the mortality shock resulting from the climate change.

Indeed, it should be recalled that this report focuses on the study of the impact of Climate Change through the Pollution scenario on the Death benefit. It is important to specify that the impact of the current climate is already taken into account in the existing mortality tables since they are based on a historical number of deaths including naturally those due to pollution. A notable distinction can thus be made between the previous notion and the objective of the present study which is to quantify the impact of climate change in the coming years likely to lead to a possible change in pollution levels and thus to cause additional deaths. The mortality risk, which is defined as the risk of death of a person, is thus at the heart of the analysis. The longevity risk, central to Life Insurance, is the risk of seeing the human life span lengthening in a non-deterministic way and thus the opposite of the mortality risk. The effects of these two systematic risks have opposite consequences in Life Insurance and it is important to anticipate any potential variations in the exposure of either of these two risks for an insurance company.

5.1. AXA additional mortality shock based on French national population

The final aim of this study is to calibrate a mortality shock on the AXA France Vie portfolio and to obtain more precise results than those obtained with the shocks provided by AON which appeared extreme at first sight. However, it would not be legitimate to make a comparison between the shocks provided by AON which apply to the French population and those which would be obtained on the AXA France Vie portfolio since the populations studied are different. This is the reason why, sure of the source of the chosen inputs and of the calibration method of the additional mortality shock due to a long-term exposure to Ozone, a mortality shock has been calibrated on the national population, with more recent data than those of the previous section, in order to compare it to the shock proposed by AON during the ACPR climate pilot exercise and thus, to respect the parsimony of the report.

To do so, the following inputs were selected:

- The estimate of the total population in metropolitan France by five-year age as of January 1, 2021 according to INSEE.
- Using the estimate of the total population by 5-year age groups, it was possible to obtain the population at risk of adults aged 30 years and over on January 1, 2021, again according to INSEE.

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- The individual file containing information on each death in 2020 in metropolitan France according to INSEE. This file has been reworked to obtain an "age" variable that allows the number of deaths to be grouped by five-year age group.
- The SOMO 35 value for 2019 provided by INERIS, 2019 being the most recent data available on the institute's website.
- The relative risk associated with long-term exposure to Ozone provided by WHO of a value of 1.014 [1.005; 1.024].

Using the SOMO 35 projection for the year 2019 presented earlier with an assumption of a 2 ppb per degree Celsius increase throughout the year, the number of premature deaths is calculated for each age band with its own death rate, and the additional mortality is calculated as a relative difference compared to Today situation. The results are:

Table 5-1: Projection of additional mortality shock for French national population

Année	2019	Climate change impact					
		Increase in °c since 1850*	1,5	2	2,5	4	
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3	
4732,831		Corresponding SOMO35	5462,83	6192,83	6922,83	9112,83	
		* Between 1850 and today the temperature has already increased by about 1°C					

*1ppb = 2µg/m3	Rest of the year	Summer
Rise ppb/degree	2	2
Number of day	273	92

Check on French additional mortality									
	Premature deaths					Additional mortality			
Age group	Today	+0,5° since today	+1° since today	+1,5° since today	+3° since today	+0,5° since today	+1° since today	+1,5° since today	+3° since today
5-14	11	12	14	15	20	0,000%	0,000%	0,000%	0,000%
15-24	39	45	51	57	75	0,000%	0,000%	0,000%	0,000%
25-34	68	79	89	99	130	0,000%	0,000%	0,000%	0,001%
35-44	145	168	190	212	278	0,000%	0,001%	0,001%	0,002%
45-54	405	467	528	590	773	0,001%	0,001%	0,002%	0,004%
55-64	937	1 080	1 223	1 365	1 790	0,002%	0,003%	0,005%	0,010%
65-74	1 802	2 077	2 351	2 625	3 441	0,004%	0,007%	0,011%	0,022%
75-84	2 519	2 903	3 286	3 669	4 809	0,010%	0,019%	0,029%	0,057%
85 +	5 718	6 591	7 462	8 330	10 919	0,039%	0,078%	0,116%	0,231%
TOTAL of age 5+	11 644	13 422	15 194	16 962	22 235	0,0029%	0,0057%	0,0086%	0,0171%
TOTAL of age 30+	11 560	13 325	15 084	16 839	22 075	0,0042%	0,0084%	0,0126%	0,0250%

Source 32: GRM Life AXA

The "premature deaths" columns correspond to the number of premature deaths for each temperature increase scenario. The "additional mortality" columns relate the number of additional deaths by age group to the population at risk in each age group, which is the additional mortality shock to be applied to the current mortality rate.

The above table can be interpreted as follows: Currently, in the national population of adults aged 30 years and older, 11,560 preventable deaths would be due to long-term exposure to Ozone. If the temperature increases by 1°C, this number rises to 15,084, an increase of 3,524 avoidable deaths for an additional mortality of 0.0084%.

As a reminder, the additional mortality shocks provided by AON in the Pollution scenario are the following:

Table 5-2: Additional mortality shocks for the Pollution scenario

Time period	2021 - 2030	2031 - 2040	2041 – 2050
Additional mortality	0.02%	0.02%	0.03%

Source 33: AON

To make a consistent comparison between the time horizon defined by AON and the temperature increase scenarios used for the projections, the IPCC RCP 8.5 scenario will be used as a reference. Temperatures are projected to rise between 1.4°C and 2.6°C by 2050 compared to the pre-industrial era. Assuming a rise of up to 2.5°C, which is 1.5°C higher than today, is conservative as it is the worst case scenario. It is therefore possible to compare the following data:

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Table 5-3: Comparison of AON and AXA mortality shocks

AON period	2041 – 2050
Corresponding increase temperature since today	+1.5°C
AON additional mortality	0.030%
AXA additional mortality	0.0126%

Source 34: AON, GRM Life AXA

The shock obtained by GRM Life on the national population is 2,4 times smaller than the one provided by AON. The differences may be for different reasons:

The additional mortality shocks obtained are calculated only on the impact of the temperature increase on the Ozone concentrations. The effects of other pollutants have not been quantified by AXA because emission levels and concentrations have been decreasing for several years, which cannot imply additional risks compared to today. On the contrary, AON assumed mortality shocks for the 4 pollutants (PM 2.5, PM 10, NO2 and O3) and summed up them to obtain a global mortality shock. Plus, Santé Publique France specifies in the summary of its QHIA carried out in April 2021, presented in chapter 4.2.1, that "the respective estimates of deaths avoided by decreases in each pollution indicator cannot be fully summed".

5.2. AXA additional mortality shock based on AXA France vie portfolio distribution

Sure of the source of our inputs and of the calibration method of the additional mortality shock due to a long term exposure to Ozone, we arrive at the final objective of this report, namely to calibrate the mortality shock on the AXA France Vie portfolio.

To do so, the following inputs were selected:

- The population estimate in metropolitan France by five-year age as of January 1, 2021 according to INSEE.
- The individual file containing information on each death in metropolitan France in 2020 according to INSEE. This file has been reworked in order to obtain an "age" variable allowing to group the number of deaths by five-year age group.
- The number of policyholders by five-year age band of the AXA France Vie portfolio for the year 2020. Please note that the total number of insureds includes international scopes in developing countries with high number of insureds and low guarantees compared to other perimeters, so the exposure is mostly in France and the relative distribution in terms of sum insured by age is correct.
- The values of the sums insured net of reinsurance of this same portfolio, also by age class.
- The value of the SOMO 35 for 2019 provided by INERIS, 2019 being the most recent data available on the Institute's website.
- The relative risk associated with a long-term exposure to Ozone provided by the WHO of a value of 1.014 [1.005; 1.024].

Using the SOMO 35 projection for the year 2019 presented earlier with an assumption of a 2 ppb per degree Celsius increase throughout the year, the results are as follows:

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Table 5-4: Projection of additional mortality shock for AXA insured

								*1ppb = 2µg/m3	Rest of the year	Summer
Année	2019	Climate change impact								
		Increase in °c since 1850*	1,5	2	2,5	4		Rise ppb/degree	2	2
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3		Number of day	273	92
4732,831		Corresponding SOMO35	5462,83	6192,83	6922,83	9112,83				
		* Between 1850 and today the temperature has already increased by about 1°C								

	French national population demographics			Current AXA France portfolio				+0,5° since today		
Age group	Population	Deaths	Mortality rate per 100 000	Insured	Sum insured Net Reinsurance	Weights (in sum insured)	Premature deaths	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	3 464 402	2 126		-	-					
1-4		567		-	-					
5-14	7 971 163	594	7	213		0%	0	0	0	0,000%
15-24	7 697 845	2 193	28	11 299 731		4%	58	66	9	0,000%
25-34	7 521 256	3 822	51	26 907 312		25%	244	282	37	0,000%
35-44	8 097 761	8 135	100	22 012 816		31%	395	455	60	0,000%
45-54	8 573 183	22 661	264	15 125 802		27%	714	823	109	0,001%
55-64	8 249 708	52 462	636	7 219 060		12%	820	945	125	0,002%
65-74	7 379 575	100 852	1 367	1 001 138		1%	244	282	37	0,004%
75-84	4 033 345	140 969	3 495	5 728		0%	4	4	1	0,010%
85 +	2 247 605	320 064	14 240	75		0%	0	0	0	0,039%
Total	65 235 843	654 445		83 571 875		100%	2480	2858	378	0,000%
Source:	INSEE	INSEE	Formula	AXA France	AXA France	Formula	Formula	Formula	Formula	Formula
Sum insured weight mortality						Corresponding aditional mortality of AXA France portfolio				0,0006%
						Corresponding aditional mortality of National population (age 5+)				0,0029%
						Corresponding aditional mortality of National population (age 30+)				0,0042%

+1° since today			+1,5° since today			+3° since today		
Premature deaths with increase of T°	Additional deaths	Additional mortality	Premature deaths with	Additional deaths	Additional mortality	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	0	0,000%	0	0	0,000%	0	0	0,000%
75	18	0,000%	84	26	0,000%	110	52	0,000%
319	74	0,000%	356	112	0,000%	466	222	0,001%
516	120	0,001%	576	180	0,001%	754	359	0,002%
932	218	0,001%	1040	326	0,002%	1364	650	0,004%
1070	250	0,003%	1195	375	0,005%	1566	746	0,010%
319	75	0,007%	356	112	0,011%	467	222	0,022%
5	1	0,019%	5	2	0,029%	7	3	0,057%
0	0	0,078%	0	0	0,116%	0	0	0,231%
3236	756	0,001%	3612	1132	0,001%	4735	2255	0,003%
Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula
		0,0012%			0,0017%			0,0034%
5,0		0,0057%	5,0		0,0086%	5,0		0,0171%
7,2		0,0083%	7,2		0,0125%	7,2		0,0248%

Source 35: GRM Life AXA

The projection of the quantitative impact of temperatures on Ozone concentrations, through the SOMO 35 projection, allows to obtain first results in terms of additional mortality on the AXA France Vie portfolio. The "mortality rate per 100,000" column is calculated by dividing the number of deaths of each age group by the number of inhabitants in metropolitan France of the corresponding group and multiplying by 100,000. The "Weights (in sum insured)" column is used to assign a weight to each age group within the total number of insureds in the portfolio based on the sums insured. It is obtained by dividing the value of the sums insured of each age group by the value of the total sums insured, then multiplying by 100 to obtain a percentage. These weights are key to calculate the portfolio global shock. As a reminder, the "additional deaths" column corresponds to the difference between the number of premature deaths due to short-term exposure to Ozone in the current situation and the same number for each temperature increase scenario. The "additional mortality" column relates the number of additional deaths by age group to the population at risk in each age group, which is the additional mortality shock to be applied to the current mortality rate. The total of this column does not take into account the weight of each age group in the insured amounts. In order to correct this bias, a line "sum insured weight mortality" has been added to obtain an additional mortality shock to be applied to the AXA France Vie portfolio which respects the weight of each age group. Thus, the

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additional mortality rate of each age group has been multiplied by the weight of the group in the insured amounts to obtain a global mortality shock to the portfolio.

The table above can be interpreted as follows: Currently, within the portfolio of AXA France Vie policyholders, 2,480 avoidable deaths would be due to long-term exposure to Ozone. If the temperature increases by 1°C, this number rises to 3,236, i.e., an increase of 756 avoidable deaths for an additional mortality of 0.0012%.

A summary comparison table can be drawn up:

Table 5-5: Comparison of projection of AON and AXA mortality shocks

Temperature rise since 1850	+1,5°C	+2°C	+2.5°C
Temperature rise since today	+0,5°C	+1°C	+1.5°C
AON Period	2021-2030	2031-2040	2041-2050
AON	0.0200%	0.0200%	0.0300%
National Population (5+)	0.0029%	0.0057%	0.0092%
National Population (30+)	0.0042%	0.0083%	0.0126%
AXA France Life Portfolio	0.0006%	0.0012%	0.0018%

Source 36: GRM Life AXA, AON

The shocks obtained on the AXA portfolio are almost 18 times smaller than those proposed by AON and this can be explained for different reasons. The portfolio is weighted by the insured sums, which reduces the weight of people over 75 years old, who are the most affected by pollution (Tessier and Bartaire, 2005)[30]. This means that the shocks provided by AON applied as is on the AXA portfolio during the climate pilot exercise have overestimated the additional mortality related to pollution.

The shocks obtained for the AXA portfolio are 7.2 times smaller than those obtained for the national population aged over 30 years and 5 times smaller than those obtained for the national population aged over 5 years. The differences can be explained by the populations at risk which differ in addition to the weighting by insured sums that is applied in the shock calculation for the AXA portfolio.

5.3. Sensitivities

5.3.1. Summer effect: challenging the 2ppb per degree Celsius formula

Using the SOMO 35 projection for the year 2019 presented earlier with an assumption of an increase of 5 ppb per degree Celsius in the summer months and 2 ppb per degree Celsius the rest of the year, the results are as follows:

Table 5-6: Projection of additional mortality shock for AXA insured with an increase of 5 ppb/degree in summer

Année	2019	Climate change impact				
		Increase in °c since 1850*	1,5	2	2,5	4
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3
4732,831		Corresponding SOMO35	5738,83	6744,83	7750,83	10768,83
		** Between 1850 and today the temperature has already increased by about 1°C*				

*1ppb = 2µg/m3	Rest of the year	Summer
Rise ppb/degree	2	5
Number of day	273	92

30 TESSIER J-F. and BARTAIRE J-G. (2005) « Les seniors, une cible privilégiée pour la pollution atmosphérique ». Pollution atmosphérique n°187, Extrapol n°26 – Octobre 2005

	French national population demographics			Current AXA France portfolio				+0,5° since today		
Age group	Population	Deaths	Mortality rate per 100 000	Insured	Sum insured Net Reinsurance	Weights (in sum insured)	Premature deaths	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	3 464 402	2 126		-	-					
1-4		567		-	-					
5-14	7 971 163	594	7	213		0%	0	0	0	0,000%
15-24	7 697 845	2 193	28	11 299 731		4%	58	70	12	0,000%
25-34	7 521 256	3 822	51	26 907 312		25%	244	296	51	0,000%
35-44	8 097 761	8 135	100	22 012 816		31%	395	478	83	0,000%
45-54	8 573 183	22 661	264	15 125 802		27%	714	864	150	0,001%
55-64	8 249 708	52 462	636	7 219 060		12%	820	993	172	0,002%
65-74	7 379 575	100 852	1 367	1 001 138		1%	244	296	51	0,005%
75-84	4 033 345	140 969	3 495	5 728		0%	4	4	1	0,013%
85 +	2 247 605	320 064	14 240	75		0%	0	0	0	0,053%
Total	65 235 843	654 445		83 571 875		100%	2480	3001	521	0,001%
Source:	INSEE	INSEE	Formula	AXA France	AXA France	Formula	Formula	Formula	Formula	Formula
Sum insured weight mortality									*Corresponding aditional mortality of AXA France portfolio*	*0,0008%*
									Corresponding aditional mortality of National population (age 5+)	*0,0040%*
									Corresponding aditional mortality of National population (age 30+)	*0,0057%*

+1° since today			+1,5° since today			+3° since today		
Premature deaths with increase of T°	Additional deaths	Additional mortality	Premature deaths with increase of T°	Additional deaths	Additional mortality	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	0	0,000%	0	0	0,000%	0	0	0,000%
82	24	0,000%	94	36	0,000%	129	72	0,001%
347	103	0,000%	398	153	0,001%	550	305	0,001%
561	166	0,001%	643	248	0,001%	889	494	0,002%
1014	300	0,002%	1163	449	0,003%	1607	892	0,006%
1164	344	0,005%	1336	515	0,007%	1845	1025	0,014%
347	103	0,010%	398	154	0,015%	550	305	0,031%
5	2	0,026%	6	2	0,039%	8	4	0,078%
0	0	0,107%	0	0	0,160%	0	0	0,318%
3520	1041	0,001%	4038	1558	0,002%	5578	3098	0,004%
Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula
		0,0016%			*0,0024%*			*0,0047%*
5,0		*0,0079%*	5,0		*0,0118%*	5,0		*0,0236%*
7,2		*0,0115%*	7,2		*0,0172%*	7,2		*0,0341%*

Source 37: GRM Life AXA

The above rate table can be interpreted as follows: Currently, within AXA France Vie's portfolio of policyholders, 2,480 avoidable deaths would be due to long-term exposure to Ozone. If the temperature increases by 1°C, this number rises to 3,520, i.e., an increase of 1,041 avoidable deaths for an additional mortality of 0.0016%, i.e., 1,3 times the baseline 0.0012% of previous section.

5.3.2. SOMO35 effect: using values between 2000 and 2019

Again with a view to conservatism, several sensitivities on SOMO 35 values were performed.

Projecting the median SOMO 35 of the indicator values between 2000 and 2019, with an assumption of a 2 ppb per degree Celsius increase throughout the year based on the method defined in the previous section, the results are as follows:

Table 5-7: Projection of additional mortality shock for AXA insured with the median SOMO35 value of the last 20 years

Année	Médiane	Climate change impact						*1ppb = 2µg/m3	Rest of the year	Summer
		Increase in °c since 1850*	1,5	2	2,5	4		Rise ppb/degree	2	2
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3		Number of day	273	92
3936,225		Corresponding SOMO35	4666,23	5396,23	6126,23	8316,23				
		** Between 1850 and today the temperature has already increased by about 1°C*								

	French national population demographics			Current AXA France portfolio				+0,5° since today		
Age group	Population	Deaths	Mortality rate per 100 000	Insured	Sum insured Net Reinsurance	Weights (in sum insured)	Premature deaths	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	3 464 402	2 126		-	-					
1-4		567		-	-					
5-14	7 971 163	594	7	213		0%	0	0	0	0,000%
15-24	7 697 845	2 193	28	11 299 731		4%	48	57	9	0,000%
25-34	7 521 256	3 822	51	26 907 312		25%	203	241	37	0,000%
35-44	8 097 761	8 135	100	22 012 816		31%	329	390	60	0,000%
45-54	8 573 183	22 661	264	15 125 802		27%	595	704	109	0,001%
55-64	8 249 708	52 462	636	7 219 060		12%	683	809	126	0,002%
65-74	7 379 575	100 852	1 367	1 001 138		1%	204	241	37	0,004%
75-84	4 033 345	140 969	3 495	5 728		0%	3	4	1	0,010%
85 +	2 247 605	320 064	14 240	75		0%	0	0	0	0,039%
Total	65 235 843	654 445		83 571 875		100%	2065	2445	380	0,000%
Source:	INSEE	INSEE	Formula	AXA France	AXA France	Formula	Formula	Formula	Formula	Formula
	Sum insured weight mortality						*Corresponding aditional mortality of AXA France portfolio*			*0,0006%*
							Corresponding aditional mortality of National population (age 5+)			*0,0029%*
							Corresponding aditional mortality of National population (age 30+)			*0,0042%*

+1° since today			+1,5° since today			+3° since today		
Premature deaths with increase of T°	Additional deaths	Additional mortality	Premature deaths with	Additional deaths	Additional mortality	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	0	0,000%	0	0	0,000%	0	0	0,000%
65	18	0,000%	74	26	0,000%	100	52	0,000%
278	75	0,000%	315	112	0,000%	426	223	0,001%
450	121	0,001%	510	181	0,001%	690	360	0,002%
813	218	0,001%	922	327	0,002%	1247	652	0,004%
934	251	0,003%	1059	376	0,005%	1431	748	0,010%
278	75	0,007%	316	112	0,011%	427	223	0,022%
4	1	0,019%	5	2	0,029%	6	3	0,057%
0	0	0,078%	0	0	0,117%	0	0	0,232%
2824	758	0,001%	3201	1136	0,001%	4327	2262	0,003%
Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula
		0,0012%			*0,0017%*			*0,0035%*
5,0		*0,0058%*	5,0		*0,0086%*	5,0		*0,0172%*
7,2		*0,0083%*	7,2		*0,0125%*	7,2		*0,0249%*

Source 38: GRM Life AXA

The median SOMO 35 is lower than the year 2019 SOMO 35 by nearly 1,000 $\mu g/m^3$. Yet the difference in preventable deaths between the two scenarios is also not immense. For the year 2019 SOMO 35 value, 2,480 preventable deaths were obtained versus 2,065 with the median SOMO 35. The numbers of additional deaths and additional mortality rates are essentially the same between the two scenarios since the projection assumption for SOMO 35 increase is the same.

The above rate table can be interpreted as follows: If the initial SOMO 35 value was 3,936.225, 2,065 preventable deaths would currently be due to long-term exposure to Ozone in the AXA France Vie policyholder portfolio. If the temperature increases by 1°C, this number rises to 2,824, i.e., an increase of 758 avoidable deaths for an additional mortality of 0.0012%, which is the same additional mortality shock obtained with the 2019 SOMO 35 and an assumption of a 2 ppb per degree increase all year.

5.3.3. Combining summer & max SOMO effect

Projecting the maximum SOMO 35 value over the period 2000 - 2019, the value for the year 2003, with an assumption of an increase of 5 ppb per degree Celsius in the summer months and 2 ppb per degree Celsius for the rest of the year, using the method defined in the previous section, the results are as follows:

Table 5-8: Projection of additional mortality shock for AXA insured with the maximum SOMO35 value of the last 20 years and an assumption of an increase of 5ppb/degree in summer

Année	Max	Climate change impact						*1ppb = 2µg/m3	Rest of the year	Summer
		Increase in °c since 1850*	1,5	2	2,5	4		Rise ppb/degree	2	5
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3		Number of day	273	92
6896,241		Corresponding SOMO35	7902,24	8908,24	9914,24	12932,24				
		* Between 1850 and today the temperature has already increased by about 1°C								

French national population demographics				Current AXA France portfolio				+0,5° since today		
Age group	Population	Deaths	Mortality rate per 100 000	Insured	Sum insured Net Reinsurance	Weights (in sum insured)	Premature deaths	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	3 464 402	2 126		-	-					
1-4		567		-	-					
5-14	7 971 163	594	7	213		0%	0	0	0	0,000%
15-24	7 697 845	2 193	28	11 299 731		4%	83	95	12	0,000%
25-34	7 521 256	3 822	51	26 907 312		25%	354	405	51	0,000%
35-44	8 097 761	8 135	100	22 012 816		31%	573	656	82	0,000%
45-54	8 573 183	22 661	264	15 125 802		27%	1037	1185	149	0,001%
55-64	8 249 708	52 462	636	7 219 060		12%	1190	1361	171	0,002%
65-74	7 379 575	100 852	1 367	1 001 138		1%	355	406	51	0,005%
75-84	4 033 345	140 969	3 495	5 728		0%	5	6	1	0,013%
85 +	2 247 605	320 064	14 240	75		0%	0	0	0	0,053%
Total	65 235 843	654 445		83 571 875		100%	3598	4115	517	0,001%
Source:	INSEE	INSEE	Formula	AXA France	AXA France	Formula	Formula	Formula	Formula	Formula
Sum insured weight mortality									Corresponding aditional mortality of AXA France portfolio	0,0008%
									Corresponding aditional mortality of National population (age 5+)	0,0039%
									Corresponding aditional mortality of National population (age 30+)	0,0057%

+1° since today			+1,5° since today			+3° since today		
Premature deaths with increase of T°	Additional deaths	Additional mortality	Premature deaths with	Additional deaths	Additional mortality	Premature deaths with increase of T°	Additional deaths	Additional mortality
0	0	0,000%	0	0	0,000%	0	0	0,000%
107	24	0,000%	119	36	0,000%	155	71	0,001%
456	102	0,000%	507	152	0,001%	657	303	0,001%
738	164	0,001%	820	246	0,001%	1063	490	0,002%
1334	297	0,002%	1482	445	0,003%	1922	885	0,006%
1532	341	0,005%	1701	511	0,007%	2207	1016	0,014%
456	102	0,010%	507	152	0,015%	658	303	0,030%
7	1	0,026%	7	2	0,039%	10	4	0,077%
0	0	0,106%	0	0	0,159%	1	0	0,315%
4630	1032	0,001%	5143	1545	0,002%	6671	3073	0,004%
Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula	Formula
		0,0016%			0,0024%			0,0047%
5,0		0,0078%	5,0		0,0117%	5,0		0,0234%
7,2		0,0114%	7,2		0,0170%	7,2		0,0338%

Source 39 : GRM Life AXA

This scenario is an extreme case: it is the worst case. The maximum SOMO 35 value is higher than the 2019 SOMO 35 by nearly 2,000 $\mu g/m^3$. With the same assumption (a 5 ppb per degree increase in summer and 2 ppb increase the rest of the year), the difference in preventable deaths is more pronounced. For the 2019 SOMO 35 year, 2,480 avoidable deaths were obtained compared to 3,598 with the maximum SOMO 35. Still assuming the same methodology, the numbers of additional deaths and additional mortality rates are roughly the same between the two scenarios since the projection assumption for SOMO 35 is the same. If we compare the two assumptions, in this case there is a slight difference between the scenarios due to the SOMO 35 projection which is not the same.

The above rate table can be interpreted as follows: If the initial SOMO 35 value was 6,869.241, 3,598 preventable deaths would currently be due to long-term exposure to Ozone in the AXA France Vie policyholder portfolio. If the temperature increases by 1°C, this number rises to 4,630, i.e., an increase of 1,032 avoidable deaths for an additional mortality of 0.0016%, which is the same additional mortality shock obtained with the 2019 SOMO 35 and an assumption of a 5 ppb per degree increase in summer and 2 ppb per degree the rest of the year.

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Conclusion

"Climate change happened because of human behavior, so it's natural that it's up to humans to solve this problem. It may not be too late if we take decisive action today." - Ban Ki-moon, Secretary of the United Nations from 2007 to 2016

Climate change is an issue that no one can escape today. The impacts are such that the whole planet is concerned. From one hemisphere to another and depending on the continent, extreme weather phenomena such as category 5 cyclones of unprecedented magnitude (Irma September 2018 in the Caribbean), violent storms causing recurrent flooding (Alex end of 2020 in the South of France), but also heat and cold waves (Argentina and Canada in early 2022) are appearing. These events increase the frequency and severity of claims in the insurance world. They represent an additional cost that companies must now try to anticipate in order to comply with the regulatory solvency standards imposed on them. In addition to the well-known impact on the claims experience of Non-Life insurance companies, the question is now being asked about the impact of this change on human health and thus includes Life insurance companies.

This innovative subject, the impact of climate change on health, requires identification, calibration and finally quantification in order to know which form these climate risks would take and, above all, what the magnitude of the shock in terms of financial losses could be. The ACPR, thanks to its climate pilot exercise, has made it possible to initiate the learning process.

As a pioneer in the field of sustainable development, the AXA Group naturally took part. During the climate pilot exercise, the impact of the additional mortality shock on the AXA France Vie portfolio presented moderate financial losses for the two scenarios combined, stemming notably from the Pollution scenario applied to death benefits alone. However, these losses proved to be absorbable by simple and reasonable repricing applied between 2026 and 2050. Thus, only the small impact between 2020 and 2025 remained. With these shocks, the perimeter was already considered resilient to the scenario. The results obtained in this report are much smaller than those used in the exercise (18 times). Because the impact is smaller, the perimeter would logically remain resilient.

Yet, the methodology used is intended to be prudent and conservative. It is based on the literature for the hypothesis of translating a rise in temperature into a rise in Ozone concentrations and on a cautious approach for the projection of the concentration indicator according to the level of temperature increase.

However, it is neither possible nor feasible to close the "Pollution" file by simply saying that the impact is minimal or even negligible given the importance of climate change in the news. Even if it is proven that air quality has improved in France between the 1990's and today, one should remain cautious. The complexity of the impact of the climate on the various pollutants studied comes into play: increasing the temperature disfavors the formation of particles and thus reduces their concentrations, while conversely, it favors the production of ozone.

It is also not possible to generalize by saying that there will be no more pollution with particles. Indeed, for example mineral dusts such as desert particles represent a potential future risk due to their growth and ease of transport in the air over very long distances. There is no monitoring of the concentration levels of these particles at this time, but for the purpose of quantifying future impacts, they should be kept in mind.

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The issue of climate change is constantly evolving. Action plans are being put in place to try to reduce greenhouse gas emissions with intermediate targets. To follow this logic, the WHO has recently lowered, in September 2021, the guide values of some studied pollutants:

- For PM 2.5, the guide values for daily and annual concentration levels defined were 25 $\mu g/m^3$ and 10 $\mu g/m^3$, respectively. They are now 15 $\mu g/m^3$ for annual concentrations and 5 $\mu g/m^3$ for daily concentrations.
- For PM 10, the recommended limit values for the protection of human health were 20 $\mu g/m^3$ for annual average and 50 $\mu g/m^3$ for daily average. They are now 15 $\mu g/m^3$ for annual concentrations and 45 $\mu g/m^3$ for daily concentrations.
- For NO2, the recommended limit value for the protection of human health was 40 $\mu g/m^3$ as an annual average. It is now 10 $\mu g/m^3$.

The quantitative health impact assessments (QHIA) conducted by Santé Publique France in April 2021 on PM 2.5 and NO2 were already indexed to these new threshold values, which will avoid an increase in the number of current premature deaths due to pollution by these pollutants. Otherwise, the lowering of these thresholds would have necessarily led to an increase in the number of current premature deaths due to pollution because of the adjustment of the parameters. Indeed, the principle of calculating an QHIA is based on the reduction of pollution levels between an observed level and a target level, which means that the lower the reference threshold, the greater the reduction in pollution levels and the greater the number of avoidable deaths.

However, the projection of the impact of rising temperatures would remain the same, given the linear methodology used.

One conclusion could be that, although pollution is responsible for deaths to date and it is important to act against it, climate change, which could be responsible for higher levels of pollution, would not lead to significant additional mortality levels.

The recent inclusion of climate risks in the ORSA reports will allow insurance companies to be more and more aware of these risks on new perimeters and to measure the risks to which they are exposed.

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Executive summary

Climate change is now a global issue that no one can deny. Visible through all the extreme climatic events (cyclones, floods, droughts) that have occurred in recent years, global warming remains the main cause. This global rise in temperature, due to the greenhouse effect, has become everyone's business. The members of the Intergovernmental Panel on Climate Change (IPCC) predict that only strong joint action plans would be likely to reduce greenhouse gas emissions and limit, in a very optimistic way (RCP 2.6 scenario), the rise in temperatures to 2°C compared to the pre-industrial era. The impact is such that today, an increase of about 1°C is already observed compared to temperatures in 1850. In addition to the classic Natural Catastrophe coverage applied to the P&C (Fire, Accident and Miscellaneous Risks) perimeter, life insurance companies could be impacted by these risk factors. These impacts, which are taken into account through mortality tables calculated on a historical basis, have not been directly attributed to climate change until now. The challenge now is to identify what additional risks might be attributable to climate change and to quantify their consequences. The general question that this report attempts to answer is: What are the health impacts of climate change?

In this sense, the ACPR launched in July 2020, a climate pilot exercise in the form of a stress test with two scenarios (pollution and vector-borne diseases) of shocks on Health & Protection risks provided by AON. As the pollution scenario in the case of a death benefit is the most unfavorable for the AXA Group, Group Risk Management (GRM) Life decided to launch a study on this subject. This study showed that 3 pollutants (PM2.5, PM10, NOx) out of the 4 studied by AON had a decreasing trend in recent years, both in terms of emissions and concentrations. As the objective is to measure the impact of climate change that could be responsible for a possible additional pollution, these 3 pollutants do not appear as an added risk compared to the current risk. GRM Life has therefore focused on the 4th pollutant (Ozone). Two sub-problems are emerging, namely

- What are the impacts of climate change on Ozone concentration levels?
- What are the impacts of an increase in Ozone concentration levels on the mortality of the French population?

The climate change scenario used for the study focuses on the rise in temperatures, which remains the main source of concern for specialists. To limit the impacts of global warming, some of which are already irreversible, the IPCC members warn that the temperature increase must not exceed +1.5°C in 2050 compared to the pre-industrial era. However, this very optimistic result would require colossal efforts and joint drastic decisions by the governments of all countries. The choice of the high-emissions scenario Representative Concentration Pathway (RCP) 8.5 as the reference for the projection of temperature increases in the coming years is explained by the need for caution and realism. Indeed, this is the most pessimistic scenario qualified as "Business as usual" where nothing more would be done between now and 2100 to limit the rise in temperatures which would be between 1.4°C and 2.6°C in 2050, and between 2.6°C and 4.8°C by the end of the century.

Based on research in the literature, a hypothesis for translating temperature increases into increases in Ozone (O3) concentrations was set: a one degree Celsius increase results in a 2 ppb (per per billion) increase in Ozone concentration levels. The level of O3 concentrations is measured in $\mu g/m^3$ or part per billion (ppb), with 1ppb = 2 $\mu g/m^3$. The assumption of 2ppb/°C has been applied to an indicator developed by the World Health Organization, to assess the effects of Ozone on human health. This is

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the Sum of Ozone Means Over 35 ppb (SOMO 35) which is defined as the annual sum of the daily maximum of plus 35 ppb (70 $\mu g/m^3$) on an 8-hour basis. It is calculated as follows:

$$SOMO\ 35 = \sum_i max\{0; C_i - 35\ ppb\}$$

Where C_i is the maximum daily 8-hour average concentration and $i = 1\ to\ 365$ because the sum is annual. It is possible to study only the summer months and therefore to sum for $i = 1\ to\ 180$.

Recalling the conversion $1ppb\ =\ 2\mu g/m^3$, the projection assumption translates as follows:

Temperature increase since today (celsius)	+0.5°	+1°	+1.5°	+3°
Ppb	1	2	3	6
$\mu g/m^3$	2	4	6	12

Thus, the SOMO35 value after an increase of x degrees Celsius compared to the 2019 level is projected as follows under the assumption of a 2 ppb increase per degree Celsius:

$$SOMO\ 35\ after\ increase\ of\ n°C = \sum_{i=1}^{365} \max\{0; C_i + 2ppb \times x - 35\ ppb\}$$

$$= \sum_{i=1}^{365} \max\{0; C_i + 4 \times x - 70\}$$

$$\approx \sum_{i=1}^{365} [max\{0; C_i - 70\} + 4x]\ \ (see\ below)$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 365 \times 4x$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 1\ 460x$$

The projection method is based on the strong assumption that all daily concentrations C_i were implicitly greater than 35 ppb (70 $\mu g/m^3$). This is what allows the multiplication by 365 to be performed. The approach is therefore conservative since it tends to overestimate the SOMO 35 value. With this methodology, SOMO 35 increases linearly with temperature.

The answer to the second part of the problem is based on the principle of Quantitative Health Impact Assessments (QHIA), which is a tool to support decision-making and raise public awareness. They allow to calculate the magnitude of the impact of air pollution on health and to evaluate the potential benefits of an action to reduce pollution. This method was originally developed by the WHO and is based on the assumption of a causal link between exposure to air pollution and its effects on health. The results of these assessments are expressed as an estimate of attributable cases. This notion can be "crudely" interpreted as the number of cases (deaths) that could be avoided if the concentration of the pollutant studied were to decrease from the average observed value to the threshold value, both of which are input.

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The number of avoided cases ΔY from an QHIA, associated with a decrease in pollution levels Δx is calculated from the following equation:

$$\Delta Y \ = Y_{obs}(1 - e^{-\beta \Delta x}) \ \ (\mathbf{1})$$

Where

- Y_{obs} the number of observed cases in the population at the current pollution level x_{obs}
- β the slope of the relationship between pollutant concentration and log mortality. For an relative risk expressed for a 10 $\mu g/m^3$ increase in pollutant, $\beta = ln(RR)/10$.

Δx represents the level of the pollution decrease whose impact is to be estimated. For a scenario with a target value x_{target}, this level of decline corresponds to

$$\Delta x = x_{obs} - x_{target} \; si \; x_{obs} > x_{target}$$

If $x_{obs} \leq x_{target}$, i.e., the observed concentration is below the target value, then $\Delta x = 0$ and there is no health benefit to achieving the target value.

ΔY represents the difference between the number of deaths observed today Y_{obs}, and the number of deaths expected at the scenario pollution level Y_{sce}.

This formula provides a number of premature deaths due to pollution according to the concentration levels of the pollutant under study. Applied to Ozone pollution, the pollution decline level whose impact we want to estimate Δx becomes the SOMO 35 value.

Based on the projection methodology presented above and the assumption of 2ppb/°C, a projection of the SOMO 35 value of the year 2019 based on the RCP 8.5 temperature increase scenario is as follows:

Année	2019	Climate change impact				
		Increase in °c since 1850*	1,5	2	2,5	4
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3
4732,831		Corresponding SOMO35	5462,83	6192,83	6922,83	9112,83
		** Between 1850 and today the temperature has already increased by about 1°C*				

**1ppb = 2µg/m3*	Rest of the year	Summer
Rise ppb/degree	2	2
Number of day	273	92

For each of the corresponding SOMO 35 values, it was possible to derive a number of premature deaths attributed to Ozone pollution from the number of avoided cases equation. In this way, an additional number of deaths due to climate change is calculated as the difference between the premature deaths currently due to pollution in this study and those after a temperature increase. From the additional deaths obtained after each temperature increase relative to the current situation, additional mortality rates are calculated by relating the additional deaths to the population at risk studied.

In order to challenge the additional mortality shocks provided by AON during the ACPR climate pilot exercise, shocks were calculated according to the methodology presented in this report with the French national population of adults aged 30 and over as the population at risk.

As a reminder, the additional mortality shocks provided by AON in the framework of the Pollution scenario are the following:

Time period	2021 - 2030	2031 - 2040	2041 – 2050
Additional mortality	0.02%	0.02%	0.03%

To make a consistent comparison between the time horizon defined by AON and the temperature increase scenarios used for the projections, the IPCC RCP 8.5 scenario will be used as a reference. Temperatures are projected to increase between 1.4°C and 2.6°C by 2050 compared to the pre-

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industrial era. Assuming a rise of up to 2.5°C, i.e. an increase of 1.5°C compared to today, is conservative since it is the upper limit of the worst case scenario. It is therefore possible to compare the following data:

AON period	2041 – 2050
Corresponding increase temperature since today	+1.5°C
AON additional mortality	0.03%
AXA additional mortality	0.0126%

The shock obtained by GRM Life on the national population is 2,4 times smaller than the one provided by AON. The differences may be explained by the fact that AON calculated and summed the mortality shocks of all the pollutants studied (PM 2.5, PM 10, NO2 and O3) to obtain an overall mortality shock, which is not recommended, yet this report only presents the impact of rising temperatures on Ozone concentrations.

In terms of results, using the age distribution of AXA France's insured sums instead of the French national population significantly reduces the shock due to the low exposure of the 65+ age group in the portfolio. Overall, the additional mortality attributable to AXA France in 2050, calculated with the presented methodology, will be lower than that provided by AON, confirming the relative resilience of the perimeter to climate change demonstrated during the climate pilot exercise.

A summary comparison table can be drawn up:

Temperature rise since 1850	+1.5°C	+2°C	+2.5°C
Temperature rise since today	+0.5°C	+1°C	+1.5°C
AON Period	2021-2030	2031-2040	2041-2050
AON	0.0200%	0.0200%	0.0300%
National Population (5+)	0.0029%	0.0057%	0.0092%
National Population (30+)	0.0042%	0.0083%	0.0126%
AXA France Life Portfolio	0.0006%	0.0012%	0.0018%

The shocks obtained for the AXA portfolio are 7.2 times smaller than those obtained for the national population aged over 30 years and 5 times smaller than those obtained for the national population aged over 5 years. The differences can be explained by the populations at risk which differ in addition to the weighting by insured sums that is applied in the shock calculation for the AXA portfolio.

The shocks obtained on the AXA portfolio are almost 18 times smaller than those proposed by AON and this can be explained for different reasons. Beyond the fact that we only quantified the impact of rising temperatures on ozone concentrations, we must add that the portfolio is weighted by the insured sums, which reduces the weight of people over 75 years of age, who are the most affected by pollution.

This means that the shocks provided by AON applied as is to the AXA portfolio during the climate pilot exercise overestimated the additional mortality linked to pollution.

In order to compare the results obtained, sensitivity tests were performed according to the SOMO 35 value but also according to the chosen projection hypothesis.

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Note de synthèse

Le changement climatique est aujourd'hui un sujet planétaire que nul ne peut nier. Visible au travers de tous les évènements climatiques extrêmes (cyclones, inondations, sécheresses) survenus au cours de ces dernières années, le réchauffement climatique en reste la principale cause. Cette hausse mondiale des températures, en raison de l'effet de serre, est devenue l'affaire de tous. Les membres du Groupe d'experts Intergouvernemental sur l'Évolution du Climat (GIEC) prévoient que seuls de forts plans d'action communs seraient susceptibles de réduire les émissions de gaz à effet de serre et de limiter, de manière très optimiste (scénario RCP 2,6), la hausse des températures à 2°C par rapport à l'ère préindustrielle. L'impact est tel, qu'aujourd'hui, une augmentation d'environ 1°C est déjà observée par rapport aux températures de 1850. Outre, la garantie classique Catastrophe Naturelle appliquée au périmètre IARD (Incendie, Accidents et Risques Divers), les compagnies d'assurance vie pourraient être impactées par ces facteurs de risque. Ces impacts pris en compte au travers des tables de mortalité calculées sur un historique, n'étaient jusqu'à présent pas attribués directement au changement climatique. L'enjeu est désormais d'identifier quels pourraient être les risques supplémentaires imputables aux variations du climat et de quantifier leurs conséquences. La question générale à laquelle ce rapport tente de répondre est la suivante : Quels sont les impacts du changement climatique sur la santé ?

En ce sens, l'ACPR a lancé en juillet 2020, un exercice pilote climatique sous la forme d'un stress test avec deux scénarios (pollution et maladies vectorielles) de chocs sur les risques Santé & Protection fournis par AON. Le scénario pollution dans le cas d'une garantie décès étant le plus défavorable pour le groupe AXA, le Group Risk Management (GRM) Life a décidé de lancer une étude à ce sujet. Cette dernière a montré que 3 polluants (PM2.5, PM10, NOx) sur les 4 étudiés par AON avaient une tendance à la baisse ces dernières années, tant aux niveaux des émissions qu'aux niveaux des concentrations. L'objectif étant de mesurer l'impact du changement climatique pouvant être responsable d'une éventuelle pollution supplémentaire, ces 3 polluants n'apparaissent donc pas comme un risque ajouté par rapport au risque actuel. Le GRM Life s'est ainsi concentré sur le 4ᵉ polluant (Ozone). Deux sous problématiques se dessinent à savoir :

- Quels sont les impacts du changement climatique sur les niveaux de concentration d'Ozone ?
- Quels sont les impacts d'une hausse des niveaux de concentration d'Ozone sur la mortalité de la population française ?

Le scénario de changement climatique utilisé pour l'étude se focalise sur la hausse des températures qui demeure la principale source d'inquiétude des spécialistes. Pour limiter les impacts du réchauffement planétaire, certains étant déjà irréversibles, les membres du GIEC mettent en garde sur le fait que l'augmentation des températures ne doit pas dépasser les +1,5°C en 2050 par rapport à l'ère préindustrielle. Toutefois, ce résultat très optimiste nécessiterait des efforts colossaux et des décisions drastiques communes des pouvoirs publics de tous les pays. Le choix du scénario à fortes émissions Representative Concentration Pathway (RCP) 8,5 comme référence pour la projection de la hausse des températures dans les années à venir s'expliquent par soucis de prudence et de réalisme. En effet, il s'agit du scénario le plus pessimiste qualifié de « Business as usual » où rien ne serait fait de plus entre aujourd'hui et 2100 pour limiter la hausse des températures qui seraient comprises entre 1,4°C et 2,6°C en 2050, et entre 2,6°C et 4,8°C d'ici la fin du siècle.

A la suite de recherches dans la littérature, une hypothèse de traduction de la hausse des températures en hausse des concentrations d'Ozone (O3) a été fixée : une hausse d'un degré Celsius entraine une

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hausse de 2 ppb (per par billion) des niveaux de concentration d'Ozone. Le niveau des concentrations d'O3 est mesuré en $\mu g/m^3$ ou en part per billion (ppb), avec $1ppb = 2\mu g/m^3$. L'hypothèse de 2ppb/°C a été appliqué sur un indicateur développé par l'Organisation Mondiale de la Santé, pour évaluer les effets de l'Ozone sur la santé humaine. Il s'agit du Sum of Ozone Means Over 35 ppb (SOMO 35) qui se définit comme la somme annuelle du maximum journalier de plus 35 ppb (70 $\mu g/m^3$) sur la base de 8 heures. Il se calcule comme suit :

$$SOMO\ 35 = \sum_i max\{0; C_i - 35\ ppb\}$$

Où C_i est la concentration moyenne journalière maximale sur 8 heures et $i = 1$ à 365 car la somme est annuelle. Il est possible d'étudier uniquement les mois de l'été et donc de faire une somme pour $i = 1$ à 180.

En rappelant la conversion $1ppb = 2\mu g/m^3$, l'hypothèse de projection se traduit de la façon suivante :

Hausse des temperatures depuis aujourd'hui (celsius)	+0,5°	+1°	+1,5°	+3°
Ppb	1	2	3	6
$\mu g/m^3$	2	4	6	12

Ainsi, la valeur du SOMO35 après une hausse de x degrés Celsius comparé au niveau de 2019 se projette de la façon suivante selon l'hypothèse d'une augmentation de 2 ppb par degré Celsius :

$$SOMO\ 35\ apres\ une\ hausse\ de\ n°C = \sum_{i=1}^{365} \max\{0; C_i + 2ppb \times x - 35\ ppb\}$$

$$= \sum_{i=1}^{365} \max\{0; C_i + 4 \times x - 70\}$$

$$\approx \sum_{i=1}^{365} [max\{0; C_i - 70\} + 4x]\ \ (voir\ ci-dessous)$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 365 \times 4x$$

$$\approx \sum_{i=1}^{365} \max\{0; C_i - 70\} + 1\ 460x$$

La méthode de projection est basée sur l'hypothèse forte selon laquelle toutes les concentrations quotidiennes C_i étaient implicitement supérieures à 35 ppb (70 $\mu g/m^3$). C'est cela qui permet d'effectuer la multiplication par 365. L'approche est donc prudente puisqu'elle tend à surestimer la valeur du SOMO 35. Avec cette méthodologie, le SOMO 35 augmente linéairement avec les températures.

La réponse à la seconde partie de la problématique s'appuie sur le principe des Evaluations Quantitatives d'Impact sur la Santé (EQIS) qui est un outil d'appui à la décision et de sensibilisation du grand public. Elles permettent de calculer l'ampleur de l'impact de la pollution atmosphérique sur la santé et d'évaluer les bénéfices potentiels d'une action pour réduire la pollution. Il s'agit d'une

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méthode initialement développée par l'OMS qui repose sur l'hypothèse d'un lien de cause à effet entre l'exposition à la pollution de l'air et ses effets sur la santé. Les résultats de ces évaluations sont exprimés sous forme d'une estimation de cas attribuables. Cette notion peut s'interpréter « vulgairement » comme le nombre de cas (décès) potentiellement évitables si la concentration du polluant étudié diminue passant de la valeur moyenne observée à la valeur seuil, toutes les deux entrées en input.

Le nombre de cas évités ΔY d'une EQIS, associé à une baisse des niveaux de pollution Δx se calcule à partir de l'équation suivante :

$$\Delta Y \ = Y_{obs}(1 - e^{-\beta \Delta x}) \ \ (\mathbf{1})$$

Où

- Y_{obs} le nombre de cas observé dans la population au niveau actuel de pollution x_{obs}
- β la pente de la relation concentration de polluant et logarithme de la mortalité. Pour un risque relatif exprimé pour une augmentation de 10 $\mu g/m^3$ de polluant, $\beta = ln(RR)/10$.

Δx représente le niveau de la baisse de la pollution dont on veut estimer l'impact. Pour un scénario ayant une valeur cible x_{cible}, ce niveau de baisse correspond à

$$\Delta x = x_{obs} - x_{cible} \ si \ x_{obs} > x_{cible}$$

ΔY représente l'écart entre le nombre de décès observés aujourd'hui Y_{obs}, et le nombre de décès attendus au niveau de pollution du scénario Y_{sce}.

Cette formule permet d'obtenir un nombre de décès prématurés dû à la pollution selon les niveaux de concentration du polluant étudié. Appliquée à la pollution à l'Ozone, le niveau de baisse de la pollution dont on veut estimer l'impact Δx devient la valeur du SOMO 35.

En s'appuyant sur la méthodologie de projection présentée plus haut et sur l'hypothèse de 2ppb/°C, une projection de la valeur du SOMO 35 de l'année 2019 basée sur le scénario de hausse des températures RCP 8,5 se présente comme suit :

Année	2019	Climate change impact						*1ppb = 2µg/m3	Rest of the year	Summer
		Increase in °c since 1850*	1,5	2	2,5	4		Rise ppb/degree	2	2
Valeur de SOMO35		Increase in °c since today*	0,5	1	1,5	3		Number of day	273	92
4732,831		Corresponding SOMO35	5462,83	6192,83	6922,83	9112,83				
		** Between 1850 and today the temperature has already increased by about 1°C*								

Pour chacune des valeurs correspondantes du SOMO 35, il a été possible de déduire un nombre de décès prématurés attribués à la pollution à l'Ozone à partir de l'équation de nombre de cas évités. De cette façon, un nombre de décès supplémentaires dus au changement climatique est calculé par différence entre les décès prématurés actuellement, dus à la pollution dans la présente étude, et ceux après une augmentation de la température. A partir des décès additionnels obtenus après chaque hausse de température par rapport à la situation actuelle, des taux de mortalité additionnelle sont calculés en rapportant les décès additionnels à la population à risque étudiée.

Afin de challenger les chocs de mortalité additionnelle fournis par AON lors de l'exercice pilote climatique de l'ACPR, des chocs ont été calculés selon la méthodologie présentée dans ce rapport avec comme population à risque, la population nationale française des adultes de 30 ans et plus.

Pour rappel, les chocs de mortalité additionnelle fournis par AON dans le cadre du scénario Pollution sont les suivants :

Période temporelle	2021 - 2030	2031 - 2040	2041 – 2050
Mortalité additionnelle	0,02%	0,02%	0,03%

Pour effectuer une comparaison cohérente entre l'horizon temporel défini par AON et les scénarios de hausse de température utilisés pour les projections, le scénario RCP 8,5 du GIEC sera utilisé comme référence. Il est prévu que les températures augmentent entre 1,4°C à 2,6°C d'ici 2050 par rapport à l'ère préindustrielle. Prendre comme hypothèse une hausse allant jusqu'à 2,5°C, soit une hausse de 1,5°C par rapport à aujourd'hui, est prudent puisqu'il s'agit de la borne supérieure du pire scénario. Il est donc possible confronter les données suivantes :

Période temporelle fixée par AON	2041 – 2050
Hausse des températures depuis aujourd'hui correspondante	+1,5°C
Mortalité additionnelle obtenue par AON	0,03%
Mortalité additionnelle obtenue par AXA	0,0126%

Le choc obtenu par le GRM Life sur la population nationale est près de 2 fois plus petit que celui qui avait été fourni par AON. Les différences peuvent s'expliquer par le fait que AON ait sommé les chocs de mortalité de tous les polluants étudiés (PM 2,5, PM 10, NO2 et O3) pour obtenir un choc de mortalité global, ce qui est déconseillé, or ce rapport ne présente que l'impact de la hausse des températures sur les concentrations d'Ozone.

En termes de résultats, l'utilisation de la distribution par tranches d'âge des sommes assurées d'AXA France au lieu de la population nationale française réduit considérablement le choc en raison de la faible exposition des personnes âgées de 65 ans et plus du portefeuille. Globalement, la mortalité additionnelle imputable à AXA France en 2050, calculée avec la méthodologie présentée, sera plus faible que celle fournie par AON, ce qui confirme la résilience relative du périmètre au changement climatique démontrée lors de l'exercice pilote climatique.

Un tableau récapitulatif de comparaison peut être établi :

Hausse des températures depuis 1850	+1,5°C	+2°C	+2,5°C
Hausse des températures depuis aujourd'hui	+0,5°C	+1°C	+1,5°C
Période temporelle fixée par AON	2021-2030	2031-2040	2041-2050
AON	0.0200%	0.0200%	0.0300%
Population Nationale (5+)	0.0029%	0.0057%	0.0092%
Population Nationale (30+)	0.0042%	0.0083%	0.0126%
Portefeuille AXA France Vie	0.0006%	0.0012%	0.0018%

Les chocs obtenus sur le portefeuille AXA sont 7,2 fois plus petits que ceux obtenus pour la population nationale âgée de plus de 30 ans et 5 fois plus petit ceux obtenus pour la population nationale âgées de plus de 5 ans. Les différences peuvent s'expliquer par les populations à risque qui diffèrent en plus de la pondération par les sommes assurées qui est appliquée dans le calcul du choc pour le portefeuille AXA.

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Les chocs obtenus sur le portefeuille AXA sont près de 18 fois plus petits que ceux proposés par AON et cela peut s'expliquer pour différentes raisons. Au-delà du fait de n'avoir quantifié que l'impact de la hausse des températures sur les concentrations d'Ozone, il faut rajouter que le portefeuille est pondéré par les sommes assurées ce qui réduit le poids des personnes âgées de plus de 75 ans or ce sont elles qui sont les plus impactées par la pollution.

Cela signifie que les chocs fournis par AON appliqués tels quels sur le portefeuille d'AXA lors de l'exercice pilote climatique ont surestimé la mortalité supplémentaire liée à la pollution.

Afin de confronter les résultats obtenus, des tests de sensibilité ont été réalisé selon la valeur du SOMO 35 mais aussi selon l'hypothèse de projection choisie.

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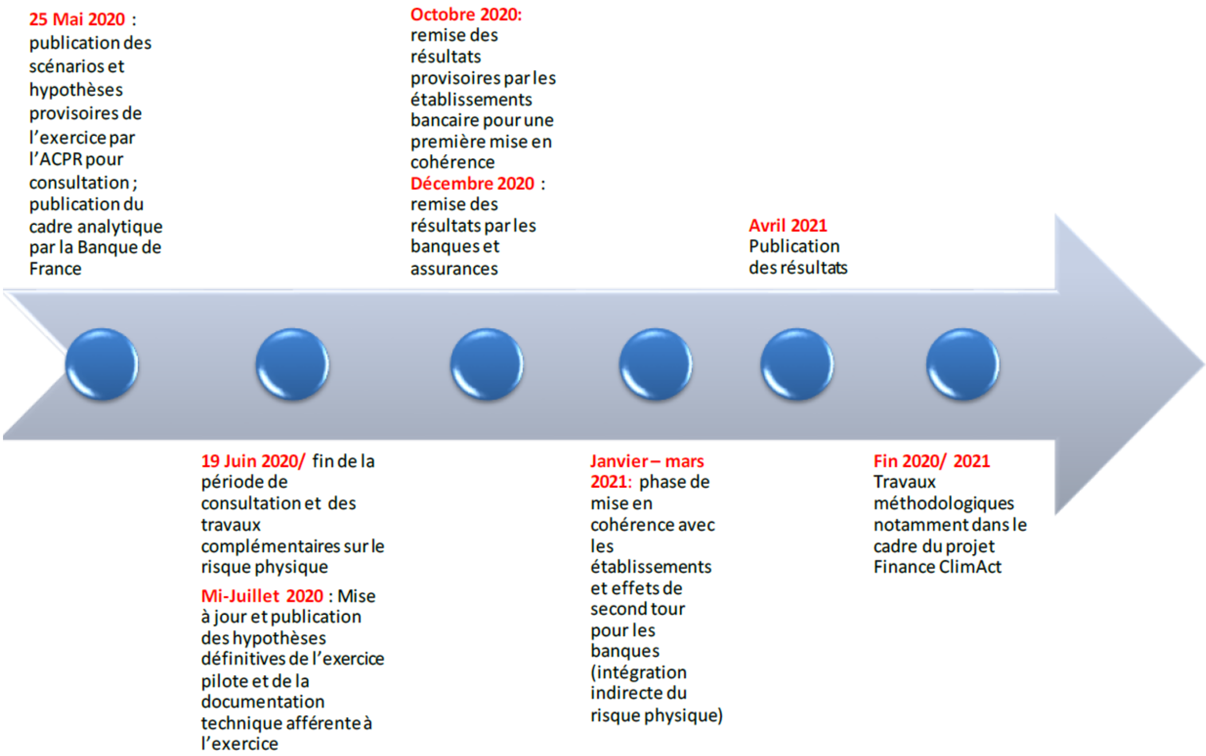
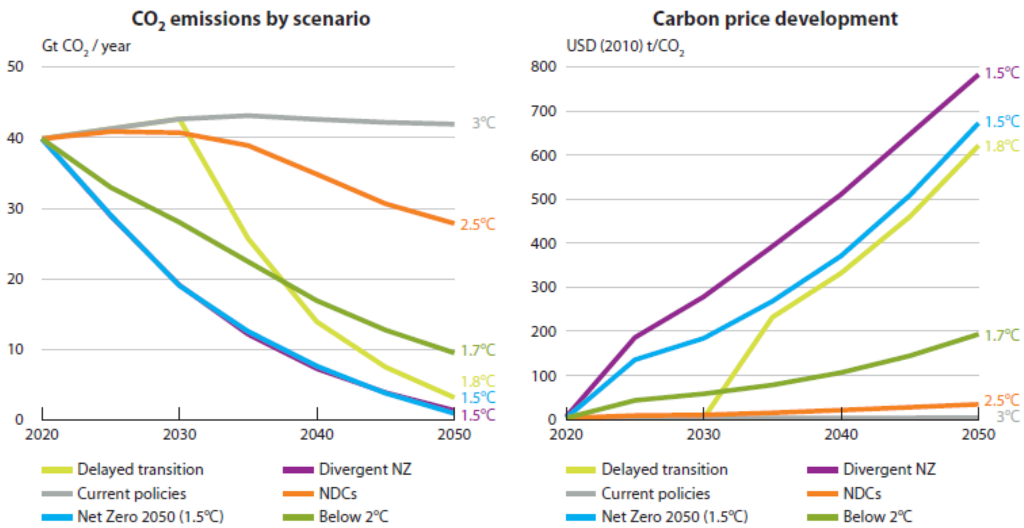
Annex

Annex 1: AXA's driving progress plan

Annex 2: Diagram of the organization of the ACPR pilot exercise



Annex 3: Evolution of CO2 emissions and carbon price



Source: IIASA NGFS Climate Scenarios Database, REMIND model. End of century warming outcomes shown.

Source: IIASA NGFS Climate Scenarios Database, REMIND model. Carbon prices are weighted global averages. End of century warming outcomes shown.

Annex 4: Detailed table by guarantee of the shocks proposed by AON for the pollution scenario

		2021 - 2030	2031-2040	2041-2050
Granularité : Globale	Décès	0,02%	0,02%	0,03%
	Frais de Soins	0,84%	1,25%	1,65%
	Arrêts de Travail	0,07%	0,10%	0,13%
Granularité : Fine				
Bordeaux	Décès	0,01%	0,02%	0,02%
	Frais de Soins	0,68%	1,02%	1,37%
	Arrêts de Travail	0,06%	0,09%	0,13%
Ile de France	Décès	0,02%	0,03%	0,04%
	Frais de Soins	1,09%	1,60%	2,10%
	Arrêts de Travail	0,08%	0,12%	0,17%
Lille	Décès	0,02%	0,03%	0,03%
	Frais de Soins	1,00%	1,47%	1,94%
	Arrêts de Travail	0,08%	0,12%	0,16%
Lyon	Décès	0,02%	0,03%	0,04%
	Frais de Soins	1,09%	1,60%	2,10%
	Arrêts de Travail	0,08%	0,12%	0,17%
Marseille	Décès	0,02%	0,03%	0,04%
	Frais de Soins	1,09%	1,60%	2,10%
	Arrêts de Travail	0,08%	0,12%	0,17%
Montpellier	Décès	0,02%	0,03%	0,03%
	Frais de Soins	0,72%	1,09%	1,47%
	Arrêts de Travail	0,05%	0,08%	0,12%
Nantes	Décès	0,01%	0,02%	0,02%
	Frais de Soins	0,68%	1,01%	1,37%
	Arrêts de Travail	0,05%	0,08%	0,11%
Nice	Décès	0,01%	0,02%	0,02%
	Frais de Soins	0,68%	1,02%	1,37%
	Arrêts de Travail	0,05%	0,08%	0,11%
Strasbourg	Décès	0,01%	0,02%	0,02%
	Frais de Soins	0,68%	1,02%	1,37%
	Arrêts de Travail	0,05%	0,08%	0,11%
Toulouse	Décès	0,01%	0,02%	0,02%
	Frais de Soins	0,68%	1,02%	1,37%
	Arrêts de Travail	0,06%	0,09%	0,13%

Annex 5: Detailed table by collateral of the shocks proposed by AON for the vector disease scenario

		2021-2024	2025-2029	2030-2039	2040-2049	2050
Granularité Nationale	Facteur additif	0,002 %	0,002 %	0,002 %	0,002 %	0,00 2%
	Facteur multiplicatif	6,3%	3,8%	5,5%	5,5%	
Granularité par région						
Auvergne-Rhône-Alpes	Facteur additif	0,005 %	0,005 %	0,005 %	0,005 %	0,00 5%
	Facteur multiplicatif	0,00%	0,3%	0,3%	0,3%	
Bourgogne-Franche-Comté	Facteur additif	0,000 3%	0,000 3%	0,000 3%	0,000 3%	0,00 03%
	Facteur multiplicatif	3,9%	4,2%	17,2%	17,2%	
Bretagne	Facteur additif	0,002 %	0,002 %	0,002 %	0,002 %	0,00 2%
	Facteur multiplicatif	3,872 %	3,033 %	2,193 %	2,193 %	
Centre-Val de Loire	Facteur additif	0,003 %	0,003 %	0,003 %	0,003 %	0,00 3%
	Facteur multiplicatif	0,6%	11,0%	2,2%	2,2%	
Corse	Facteur additif	0,02%	0,02%	0,02%	0,02%	0,02 %
	Facteur multiplicatif	0,9%	2,2%	2,5%	2,5%	
Grand Est	Facteur additif	0,000 3%	0,000 3%	0,000 3%	0,000 3%	0,00 03%
	Facteur multiplicatif	3,9%	3,2%	17,2%	17,2%	
Hauts-de-France	Facteur additif	0,001 %	0,001 %	0,001 %	0,001 %	0,00 1%
	Facteur multiplicatif	0,0%	1%	3%	3%	
Ile-de-France	Facteur additif	0,001 %	0,001 %	0,001 %	0,001 %	0,00 1%
	Facteur multiplicatif	0,0%	1,3%	2,5%	2,5%	
Normandie	Facteur additif	0,005 %	0,005 %	0,005 %	0,005 %	0,00 5%
	Facteur multiplicatif	1,5%	1,4%	3,0%	3,0%	
Nouvelle-Aquitaine	Facteur additif	0,003 %	0,003 %	0,003 %	0,003 %	0,00 3%
	Facteur multiplicatif	0,1%	11,0%	2,2%	2,2%	

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Occitanie	Facteur additif	0,006%	0,006%	0,006%	0,006%	0,006%
	Facteur multiplicatif	0,6%	0,6%	2,5%	2,5%	
Pays de la Loire	Facteur additif	0,001%	0,001%	0,001%	0,001%	0,001%
	Facteur multiplicatif	0,0%	4,2%	2,5%	2,5%	
Provence-Alpes-Côte d'Azur	Facteur additif	0,005%	0,005%	0,005%	0,005%	0,005%
	Facteur multiplicatif	1,4%	1,3%	6,8%	6,8%	

		2021-2024	2025-2029	2030-2039	2040-2049	2050
Granularité Nationale	Consultation / Urgence	0,7911%	1,0407%	1,2408%	1,5808%	1,9208%
	ITT J	0,0198%	0,0260%	0,0310%	0,0395%	0,0480%
Granularité par région						
Auvergne-Rhône-Alpes	Consultation / Urgence	2,1094%	2,1094%	2,1441%	2,1788%	2,2135%
	ITT J	0,0527%	0,0527%	0,0536%	0,0545%	0,0553%
Bourgogne-Franche-Comté	Consultation / Urgence	0,1221%	0,1458%	0,1694%	0,3154%	0,4613%
	ITT J	0,0031%	0,0036%	0,0042%	0,0079%	0,0115%
Bretagne	Consultation / Urgence	0,0611%	0,5985%	0,9272%	1,0288%	1,1305%
	ITT J	0,0015%	0,0150%	0,0232%	0,0257%	0,0283%
Centre-Val de Loire	Consultation / Urgence	1,1600%	1,1970%	1,8543%	2,0577%	2,2611%
	ITT J	0,0290%	0,0299%	0,0464%	0,0514%	0,0565%
Corse	Consultation / Urgence	8,6167%	9,0000%	10,0000%	11,2629%	12,5259%
	ITT J	0,2154%	0,2250%	0,2500%	0,2816%	0,3131%
Grand Est	Consultation / Urgence	0,1221%	0,1458%	0,1694%	0,3154%	0,4613%
	ITT J	0,0031%	0,0036%	0,0042%	0,0079%	0,0115%
Hauts-de-France	Consultation / Urgence	0,3221%	0,0320%	0,3904%	0,4400%	0,4896%
	ITT J	0,0081%	0,0008%	0,0098%	0,0110%	0,0122%
Ile-de-France	Consultation / Urgence	0,3221%	0,0134%	0,3904%	0,4400%	0,4896%

	ITT J	0,008 1%	0,000 3%	0,009 8%	0,011 0%	0,012 2%
Normandie	Consultation / Urgence	2,080 0%	2,240 0%	2,400 0%	2,760 0%	3,120 0%
	ITT J	0,052 0%	0,056 0%	0,060 0%	0,069 0%	0,078 0%
Nouvelle-Aquitaine	Consultation / Urgence	1,189 9%	1,197 0%	1,854 3%	2,057 7%	2,261 1%
	ITT J	0,029 7%	0,029 9%	0,046 4%	0,051 4%	0,056 5%
Occitanie	Consultation / Urgence	2,278 0%	2,348 4%	2,418 8%	2,725 0%	3,031 3%
	ITT J	0,057 0%	0,058 7%	0,060 5%	0,068 1%	0,075 8%
Pays de la Loire	Consultation / Urgence	0,322 1%	0,145 8%	0,390 4%	0,440 0%	0,489 6%
	ITT J	0,008 1%	0,003 6%	0,009 8%	0,011 0%	0,012 2%
Provence-Alpes-Côte d'Azur	Consultation / Urgence	2,027 6%	2,173 3%	2,319 0%	3,110 8%	3,902 7%
	ITT J	0,050 7%	0,054 3%	0,058 0%	0,077 8%	0,097 6%

Annex 6: Assumptions made by GRM Life for the ACPR climate pilot exercise

	Pollution	Maladie vectorielle
Frais de Soin		
Part consultation (%)	97%	40%
Part hospitalisation (%)	3%	1%
Jours hospitalisation	6	10
Cout moyen consultation (EUR)	10	10
Cout moyen hospitalisation 1j (EUR)	1 050	1 050
Deces		
Cout moyen décès (EUR)	100 000	100 000
AT/Autres dommages corporels		
Cout moyen AT 1j (EUR)	33	33
Franchises (moyenne en jours)	73	73
Activation franchises	NON	NON
Part AT 8 J	0%	80%
Part AT 20 J	0%	20%
Part AT 6J	100%	0%

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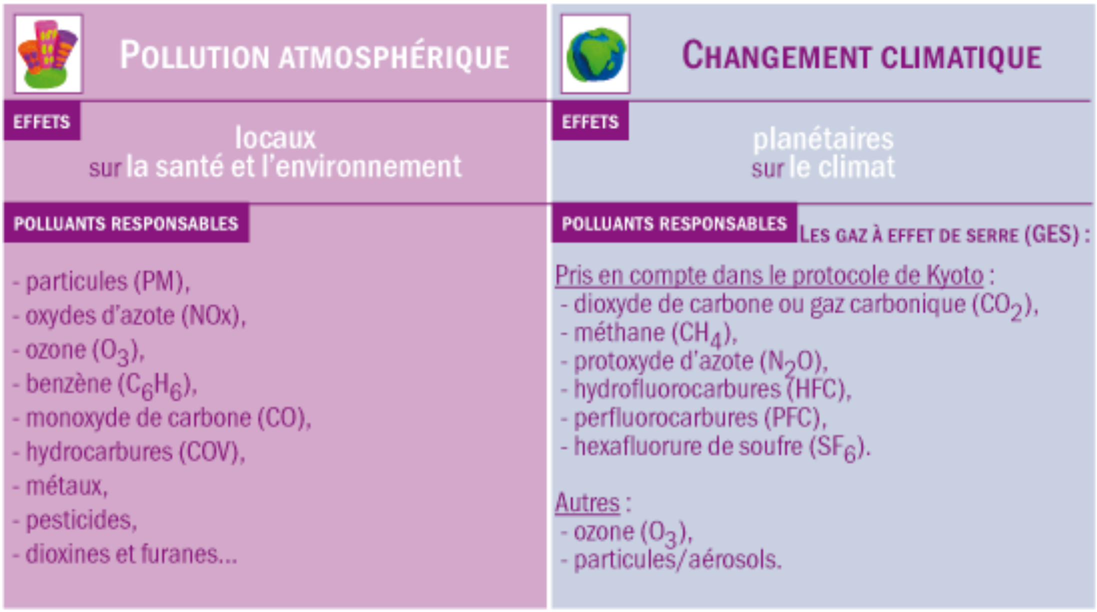
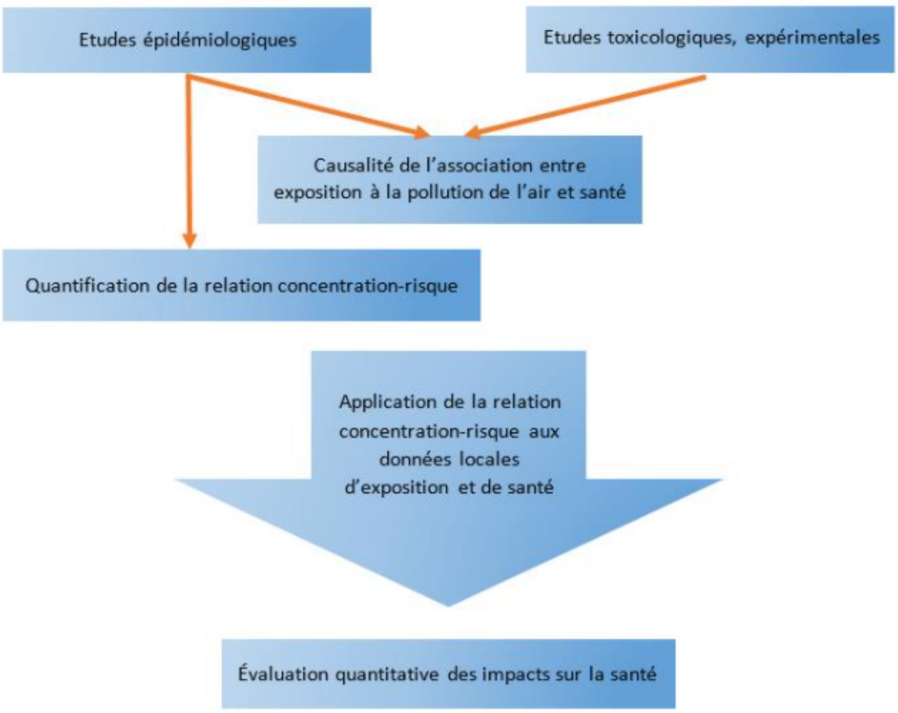
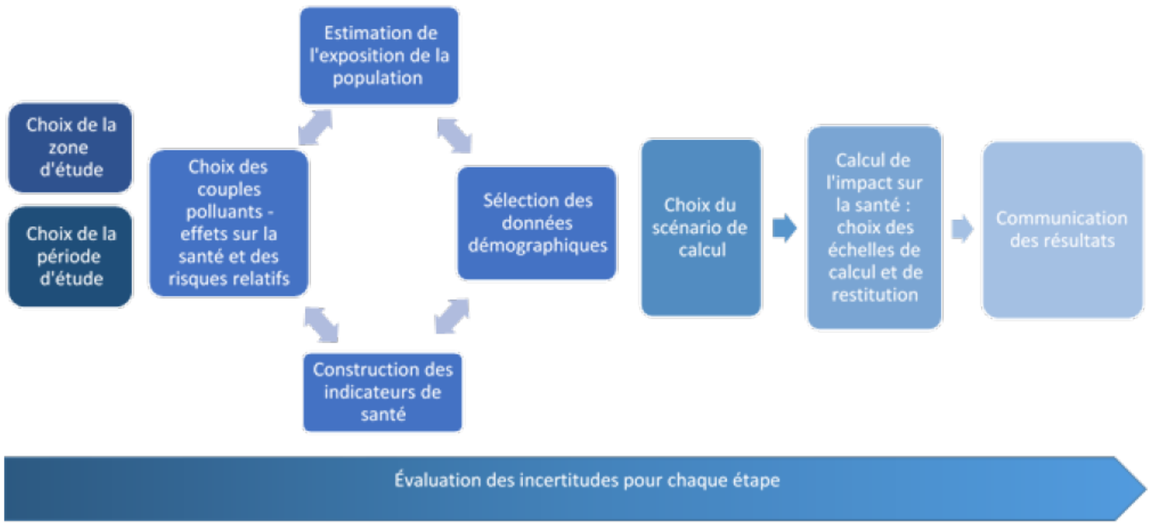
Annex 7: Greenhouse gas pollutant distinction



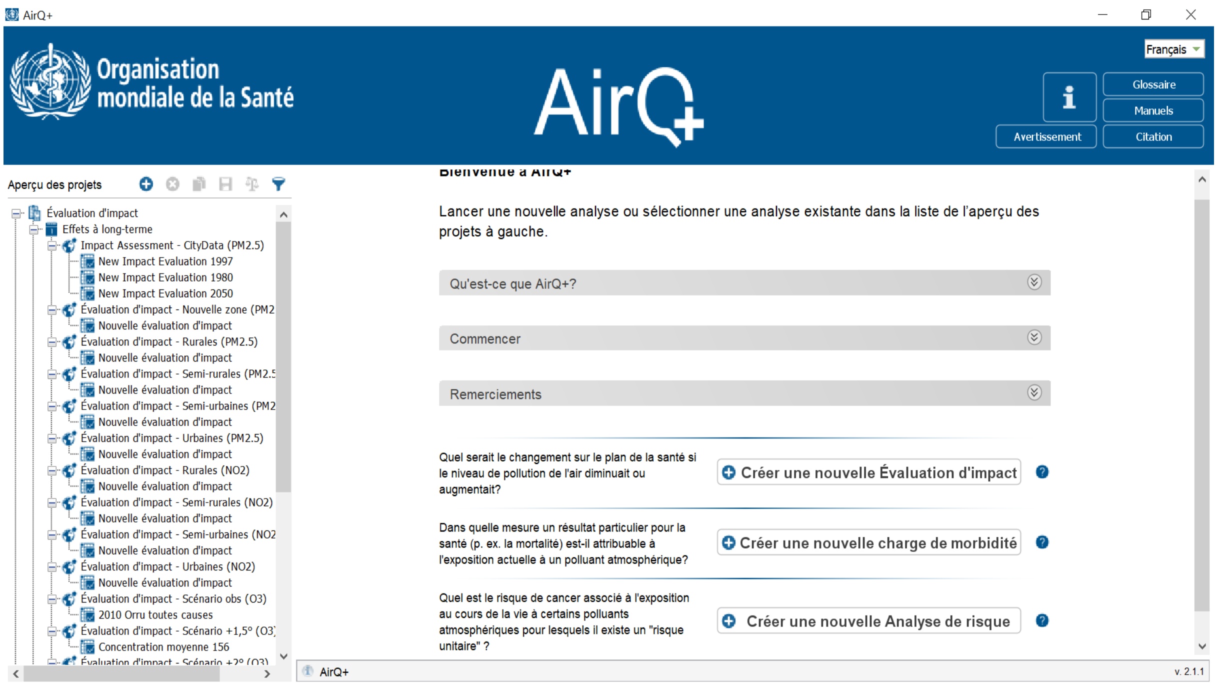
Annex 8: Principle of Quantitative Health Impact Assessments



Annex 9: Steps of a Quantitative Health Impact Assessment



Annex 10: AirQ+ : Homepage



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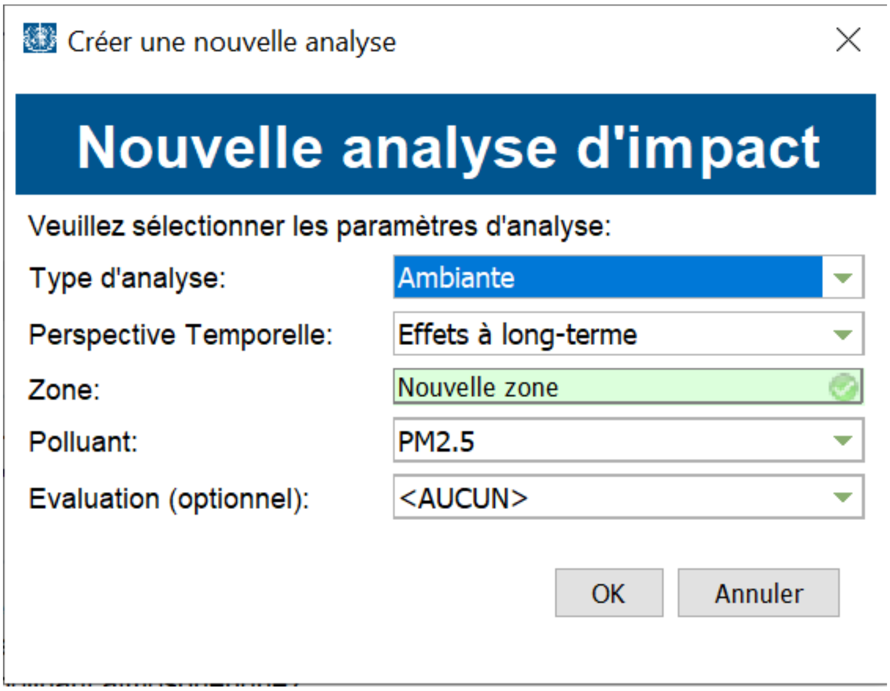
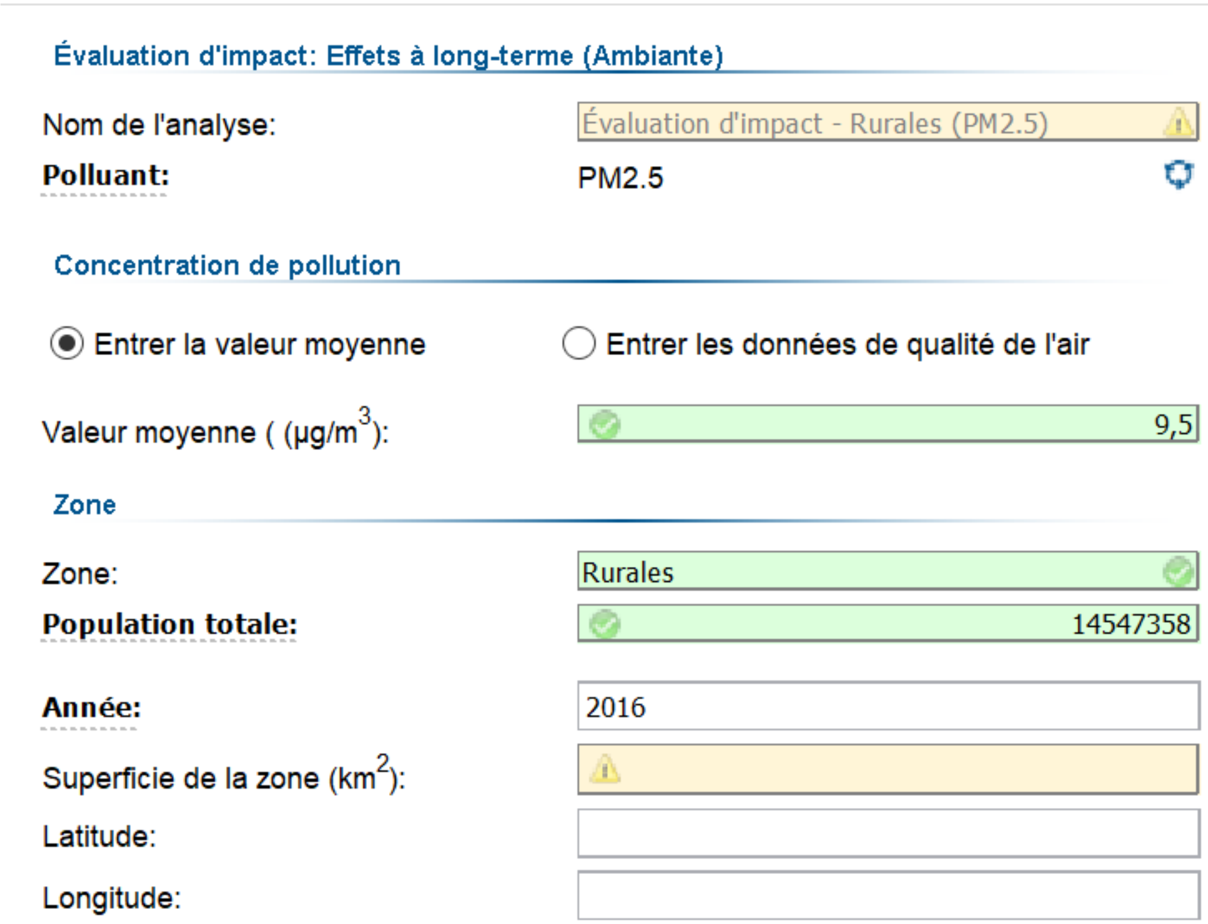
Annex 11: AirQ+ : Impact analysis



Annex 12: AirQ+ : Analysis properties



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Annex 13: AirQ+ : Detailed results

Evaluation d'impact | Résultats détaillés

Évaluation d'impact (PM2.5)

Nom de l'évaluation: Nouvelle évaluation d'impact

Indicateur de santé

Indicateur de santé:	Mortalité, toutes causes (naturelles) (adultes de 30 ans et plus)
Incidence (per 100 000 Population à risque par année):	1358,12
Pop. à risque (67,37 %):	9800219

Paramètres de calcul

Méthode de calcul:	log-linéaire				
Risque Relatif :	1,15	Inférieur:	1,06	Supérieur:	1,25
Valeur seuil X0 (voir formule)	5				
Moyenne des concentrations.X:	9,5				

Avancée

Calculer

Résultats (dernier calcul 2021-11-30 23:49:24)

	Central	Inférieur	Supérieur
Estimation de la part attribuables	6,1 %	2,59 %	9,55 %
Estimation du nombre de cas attribuables	8 113	3 445	12 716

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