MASTER

ACTUARIAL SCIENCE

MASTER´S FINAL WORK

PROJECT REPORT

LONG-TERM IMPACT OF CLIMATE CHANGE ON MORTALITY
A STUDY FOR PORTUGAL

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OCTOBER 2023

Abstract

This work aims to study the long-term impact of climate change on mortality rates in Portugal, having in mind the specific setting of life insurance business in the country.

Life insurance requires, among other factors, accurate mortality forecasts, reason why considering the effects of climate change on mortality in the long-term is essential for correct pricing and reserving of life insurance products.

After a review of the (still scarce) existing literature, it was possible to conclude that only temperature and air pollution will pose a material risk to the population mortality, and consequently to life insurance. Applying models and data already available, the effects of both risk factors were assessed at a regional level, due to the exposure differences among the Portuguese regions, and considering years 2030 and 2050. The option for 2030 and 2050 was made precisely in order to determine the population-weighted mortality shock, resulting from temperature and air pollution variations, in the long-run.

The overall results indicate that the effects of temperature change will vary depending on age (younger population and older population, for instance) and the year (2030 or 2050). For air pollution, and because climate projections suggest the decrease in greenhouse gas emissions, the concentration of the main pollutants affecting health will consequently decrease. This results in the cause related mortality to decrease over time, throughout all ages.

Key words: climate change; life tables; life insurance; mortality risks; climate projections; mortality rates; temperature and air pollution mortality shock.

Acknowledgments

To my family, for always giving me their unconditional support and believing in me and my work. To my mother and my father for always making my education a priority and encouraging me to pursue my goals.

Um enorme obrigada ao Professor Onofre Simões, por todo o tempo investido e todas as orientações e sugestões feitas no decorrer deste trabalho.

To Management Solutions, particularly Efrén and Ingo, for all the guidance and work done in the scope of the project

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Glossary

ADM2 – 2nd administrative level

CO2 – Carbon Dioxide

CRF – Concentration Response Function

EIOPA - European Insurance and Occupational Pensions Authority

GAINS – Greenhouse Gas and Air Pollution Interactions and Synergies

GDP – Gross Domestic Product

NO2 – Nitrogen Dioxide

NUTS – Nomenclature of territorial units for statistics

OECD – The Organisation for Economic Co-operation and Development

ORSA – “Own Risk Solvency Assessment”

PM2.5 - Fine particulate matter

RCP – Representative Concentration Pathways

RR – Relative Risk

SSP – Shared Socioeconomic Pathways

WHO – World Health Organization

1 Introduction

1.1 Motivation

The issue of climate change has long been of interest. The fact that it is presently impacting daily life on several levels, including health, finances, and the environment, prompted the issue of how it would affect the insurance industry. What effect will climate change have on mortality, and how will it influence life insurance? Considering the current impact of climate change on mortality, what will be its change in the future? A few months after starting my professional career an opportunity to join a project related to this matter came up and gave me the chance to further explore this issue.

1.2 Overview of the topic

Life insurance profitability and sustainability depends, amongst other elements, on reliable mortality risk projections and pricing. Therefore, it is crucial to comprehend the primary life insurance products, how they are structured, and how climate change may affect them. The present study focuses on the three main contract variations, (Gatzert, 2009), (term, whole life and endowment) that rely on the survival or death of the insured (the individual or entity named in a certain insurance contract who would receive the predefined amount from the insurance company if a specified event occurred, (Cambridge Dictionary, 2023). In a setting of climate changes, a natural question is: knowing the contracts' fundamentals, how can the impact of climate change on future mortality be assessed?

Regardless of the influence of climate changes, in the scope of this project, the essential issue is how they will alter mortality patterns and the consequences of these alterations on the life insurance industry. To answer this question, it is necessary to understand the function of mortality in life insurance and how changes in mortality patterns may impact the business.

A mortality table, also known as a life table or an actuarial table, displays the rate of fatalities happening in a specific population over a certain time span, as well as survival rates from birth to death. A mortality table often displays, depending on a person's present age, the respective mortality rate, including the probability they will die before their next birthday. Adding the future mortality shock associated to climate change to the death rates will result in a more accurate and updated future life table. So, picking the hazards that will in reality constitute a high danger to mortality is necessary.

To do so, we need to better understand what climate change is and how it impacts the population, as well as the threats it poses with respect to that, in order to comprehend its influence on mortality. The effects of climate change on humanity and biology may occur independently. More often than not, it functions in tandem with other environmental changes, impacting such processes as diverse as the productivity of our food-producing systems, the reproduction of mosquito populations, and functional integrity of ecosystems, among others.

Although exposure to each climate risk varies with geography, the most significant climate hazards are:

- Changes of temperature patterns;
- Air pollution;
- Water Scarcity;
- Wildfires;
- Tropical Storms;
- Floods and sea level rise;
- Vector-borne diseases.

The frequency and intensity of these hazards are changing, which will harm people, property, environment, and the economy. This tendency is projected based on different climate scenarios designed by the climate change research community in order to assist the comprehensive study of future climate effects, vulnerabilities, adaptation, and mitigation. The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5) has designed a global RCP–SSP–SPA (Representative Concentration Pathways–Shared Socioeconomic Pathways–Shared climate Policy Assumptions) scenario architecture to answer this demand (Kebede *et al.*, 2018).

Although there is a list of different risks that may pose an impact on mortality, not all will be material. This means, despite the change in climate patterns, the influence of their future behavior may not significantly alter the mortality rates. EIOPA released a report assessing the materiality of climate risks in the different lines of business, non-life and life, constructing dummy companies that better represent European insurance companies (EIOPA 2022). It determined that only temperature and air pollution would be considered material for the assessment of climate change's impact on mortality, in the long-term exposure to the hazards.

Given this conclusion, in our work we will delve into the long-term effects of these two hazards with respect to Portugal, at a regional level, with the ultimate purpose of including them in the country's life table, by performing the adjustments resulting from our analysis, where these adjustments reflect the long term effects, because the life tables resulting from this process refer to 2030 and 2050.

It is important to note that, since there is no public access to insurance-specific mortality tables, the consequences of these risks will be added individually to the national mortality table to finally obtain the total impact.

To better understand the consequences of temperature changes we need to start by reviewing available studies. The main conclusion is that the higher temperatures of the future will increase morbidity and mortality inherent to heat-stress. In particular, Carleton *et al*. (2022) assesses the direct impact on mortality caused by this climate hazard through a regression, considering age, adaptation, GDP per capita (Gross Domestic Product), temperature and precipitation. This study supplied results at a regional level until 2100.

To assess the air pollution consequences, it is necessary to understand that there are several pollutants impacting health and mortality. Because PM2.5, see WHO (2021), is by far the constituent responsible for more deaths, future concentration projections and correlated mortality are estimated.

IIASA launched a model, GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) (IIASA, 2023) model, that estimates the projections for the overall concentration of several air pollutants, at a resolution of 0.5ºx0.5º cell level (meaning there are projections of the pollutant for every coordinate, latitude and longitude, at scaling of 0.5º), in Europe. Using the pollutant’s relative risk, that is, a shock of the relationship of the variation of the pollutants with the mortality attributable to them, a mortality for this risk is estimated for an intermediate climate scenario.

In a way similar to the existing works, we aim to determine the shocks from the main two climate risks in Portugal.

1.3 Literature Review

1.3.1 Assessment of mortality risk

Climate change and mortality is a relatively recent area of study. When discussing the assessment of this topic within the life insurance sector, the existing research is scarce. (EIOPA, 2022) assessed the risks inherent to climate change, both for non-life and life insurance, using dummy companies for assumptions concluding that most climate risks are not material to assess, in the life insurance business. (Banque the France, 2023) seeks to protect the stability of the financial system by ensuring that financial institutions have clearly recognized the climate change-related risks to which they are exposed and have established adequate governance and risk management techniques. The exercise includes assumptions for both physical and transition risks, that rely on climate scenarios projections, that is RCP4.5 scenario for the methodology (Banque the France, 2023). No results are reported since the report is focused mainly on setting the scenarios and key assumptions.

1.3.2 Effects of temperature change on mortality

When it comes to mortality risk due to temperature, (Gasparrini *et al.*, 2015) gathered data for 384 locations, estimated temperature–mortality associations using a distributed lag non-linear model with a 21-day lag, and then pooled them into a multivariate meta-regression that included country indicators and temperature average and range, calculating the number of deaths attributable to heat and cold. Using a similar methodology (Gasparrini *et al*. 2017) projected the excess mortality due to temperature and their net change in 1990–2099 under each climate scenario (RCPs).

Bressler *et al*. (2021) performed global extrapolation of prior forecasts for the impacts of climate change on heat and cold-related mortality in 23 countries, see (Gasparrini et al. 2017).

Lastly, regarding temperature risk assessment, Carleton *et al.* (2022) used subnational data from 40 countries, estimated age-specific mortality-temperature correlations and extend them to nations lacking data and into a climate-changed future. They have determined a U-shaped connection in which severe cold and heat increase death rates, particularly among the elderly. Critically, this association is weakened by both rising earnings and the ability of the different regions to adapt to the rising temperatures (adaptation). Uncovered a relationship in which severe cold and heat increase death rates, particularly among the elderly, susceptible to both higher incomes and adaptation ability.

1.3.3 Effects of air pollution on mortality

To assess the future impact of air pollution on mortality there are several factors to consider, research tries to include them by modeling PM2.5 concentration and its impact on mortality.

When it comes to the concentration modelling, it is important to cite (Zhai *et al.*, 2017), who have developed a best subsets regression (BSR) enhanced principal component analysis-GWR (PCA-GWR) modeling technique to predict PM2.5 concentration by concurrently taking into account the contributions of all 50 possible variables, outperforming the standard GWR model with clearly higher model fitting- and cross-validation-based R2 53 and 54 adjusted RMSE values. (Wang *et al.*, 2019) Examined the effect of urbanization on national PM2.5 concentrations in emerging, developed, and impoverished countries from 1998 to 2014. Urbanization has a strong link with PM2.5 concentrations, although the strength of this relationship differs across groupings of countries with varying degrees of development.

In terms of the risk's mortality effect, (Chen and Hoek, 2020) assists the development of new recommendations by the World Health Organization (WHO) by conducting a systematic assessment of evidence of links between long-term exposure to PM2.5 and PM10 and all-cause and cause-specific mortality, through a random-effect meta-analysis including a large number of studies. (WHO, 2021) revised worldwide guidelines providing quantitative, health-based recommendations for the management of air quality, represented as long- or short-term concentrations for a number of major air contaminants (including PM2.5). Following the WHO guidelines (Coelho *et al.*, 2022) applies the WRF-CAMx modelling framework to assess the health impact of air pollution in Aveiro, Portugal. It anticipates improvements in the concentrations of the principal pollutants, and therefore a decrease in the number of premature deaths caused by them.

1.3.4 Organization of the text

Throughout this work, after a comprehensive review of literature about the topic, that is life insurance overview, climate change risks assessment and mortality consequences and materiality.

In chapter 2 an overall introduction to the life insurance business, relevant actuary notation and the main life insurance products is presented. Followed by chapter 3 where the different climate risks are identified and what repercussion they might have on mortality. Finally, in chapter 4 the impact of the risks chosen is calculated and the Portuguese mortality table is updated in accordance with the results obtained.

2 Life Insurance

Life insurance line of business relies primarily on the risk of death as the main object insured. That means the policyholder pays a premium and in some cases receives a certain amount upon the death of the insured or after a predefined period. This type of insurance can also take the form of a private pension product, in which a person's working life is spent building up retirement savings (Insurance Europe, 2020).

2.1 Life insurance products

The most prevalent types of contracts in Europe and the most traditional are term, endowment, whole life and unit-linked products (Gatzert, 2009). So:

Term contracts: death benefits for a specified term without savings. Insurance beneficiaries get the face value if the insured dies during the policy period. The contract period, time of coverage, coverage alternatives, and coverage amount variations during the policy's term determine the term insurance form. "Level term" insurance has a fixed face amount throughout time, whereas "decreasing" and "growing" term insurance pay down mortgages and increase face values.

Endowment contracts: endowments guarantee death and survivor payouts throughout the term of the contract. Endowment policies, unlike term insurance, save and pay out if the insured survives contract maturity.

Whole life contracts: Pays a lump sum payout upon the policyholder's death, whenever it happens. For regular premium plans, the premium is often due until a certain age cap, such as 80, is reached. This eliminates the possibility that elderly individuals will be less able to pay their premiums (Dickson *et al.*, 2019).

Unit-Linked contracts: unit-linked policies, unlike participating life insurance plans, let policyholders choose how to invest their premiums in several asset types. Unit-linked insurance plans can link funds to mutual fund units or an index like a bond, stock, or other reference index.

A change in mortality due to the variation, positive or negative, in the climate risks will have a distinct impact on the several types of life insurance products. For instance, an increase in the overall mortality on direct account of the different climate risks will likely be damage for term contracts, contrarily to the impact in endowment contracts.

How are the mortality rates and its variations calculated and measured?

2.2 Mortality rates and life tables

2.2.1 Mortality rates

To explain how mortality rates affect the various insurance contract types, it is required to comprehend actuarial notation and their various actuarial formulations.

International Actuarial Notation was designed by actuarial science to represent the probabilities and functions of most interest and use to actuaries. So, the actuarial notation for probabilities of survival and death is (Dickson *et al.*, 2019):

- ${}_tp_x$ represents the probability that an individual aged *x* will survive to at least age $x + t$;
- ${}_tq_x$ represents the probability that an individual aged *x* will die before age $x + t$;
- p_x represents the probability that an individual aged *x* will survive at least 1 year;
- q_x represents the probability that an individual aged *x* will die within 1 year - these probabilities are the mortality rates at all ages *x;*
- ${}_{u|t}q_x$ represents the probability that an individual aged *x* will survive *u* years and will die in the subsequent *t* years (will die between ages$x + u$ and $x + u + t$).

It is easy to deduce the relationships:

$${}_tp_x + {}_tq_x = 1;$$

$${}_{u|t}q_x = {}_up_x - {}_{u+t}p_{x;}$$

$${}_{t+u}p_x = {}_tp_x \times {}_up_{x+t} = {}_up_x \times {}_tp_{x+u.}$$

Each of the listed life insurance plans depends on the insured's demise or survival for payment of benefits. Therefore, the value of the benefit to be paid is dependent on a random variable, the future lifetime of the insured person and, therefore, on the mortality rates.

2.2.2 Life tables

A life table, also denominated as mortality table or actuarial table, is a demographic tool used for analyzing mortality rates and calculating life expectancies at different ages. Commonly generated separately for males and females because of their varied death tendencies (ONS, 2019). According to Dickson *et al.* 2019, a life table is constructed based on a survival, with survival probabilities ${}_tp_x$, with

$${}_tp_x = \frac{l_{x+t}}{l_x}$$

where l_{x+t} is the number of expected survivors aged $x+t$, so the number of survivors is a random variable, dependent on the mortality rate, with expected value for the number of survivors:

$$E[L_t] = l_{x+t}$$

From the number of survivors, the number of deaths of an individual aged x with a year is deduced:

$$d_x = l_x - l_{x+1}$$

Finally, T_x represents a continuous random variable that models the future lifetime of an individual aged (x), that enables the relationship with the complete life expectation $\dot{e}_x = E[T_x]$.

Table 1 illustrates the concept, displaying an extract from the most recent complete (males and females) mortality table for Portugal (Instituto Nacional de Estatística, 2023). The full mortality table is presented in the appendix as *Table 11*.

Age	Mortality Rates	Survivers at age x	Deaths between ages x and x+1	Survivers between the ages x and x+1	Completed years after age x	Life expectation
(x)	**(qx)**	**(lx)**	**(dx)**	**(Lx)**	**(Tx)**	**(ex)**
0	0,002437	100 000	244	99 847	8 095 714	80,96
1	0,000140	99 756	14	99 749	7 995 867	80,15
2	0,000217	99 742	22	99 732	7 896 118	79,17
3	0,000143	99 721	14	99 714	7 796 386	78,18
4	0,000086	99 706	9	99 702	7 696 673	77,19
5	0,000074	99 698	7	99 694	7 596 970	76,20
6	0,000112	99 690	11	99 685	7 497 276	75,21
7	0,000090	99 679	9	99 675	7 397 591	74,21
8	0,000080	99 670	8	99 666	7 297 917	73,22
9	0,000064	99 662	6	99 659	7 198 250	72,23
10	0,000081	99 656	8	99 652	7 098 591	71,23
11	0,000060	99 648	6	99 645	6 998 939	70,24
12	0,000075	99 642	8	99 638	6 899 294	69,24
13	0,000129	99 634	13	99 628	6 799 656	68,25
14	0,000119	99 621	12	99 616	6 700 028	67,25
15	0,000164	99 610	16	99 601	6 600 413	66,26
16	0,000185	99 593	18	99 584	6 500 811	65,27
17	0,000189	99 575	19	99 565	6 401 227	64,29
18	0,000306	99 556	30	99 541	6 301 662	63,30
19	0,000333	99 526	33	99 509	6 202 121	62,32
20	0,000356	99 492	35	99 475	6 102 612	61,34
21	0,000316	99 457	31	99 441	6 003 137	60,36
22	0,000378	99 426	38	99 407	5 903 696	59,38
23	0,000349	99 388	35	99 371	5 804 289	58,40
24	0,000394	99 353	39	99 334	5 704 919	57,42
25	0,000297	99 314	30	99 299	5 605 585	56,44
26	0,000446	99 285	44	99 263	5 506 286	55,46
27	0,000486	99 240	48	99 216	5 407 023	54,48
28	0,000362	99 192	36	99 174	5 307 807	53,51
29	0,000426	99 156	42	99 135	5 208 633	52,53
30	0,000433	99 114	43	99 093	5 109 497	51,55
31	0,000660	99 071	65	99 038	5 010 405	50,57
32	0,000564	99 006	56	98 978	4 911 367	49,61
33	0,000650	98 950	64	98 918	4 812 389	48,63
34	0,000603	98 886	60	98 856	4 713 471	47,67
35	0,000634	98 826	63	98 795	4 614 615	46,69
36	0,000695	98 763	69	98 729	4 515 821	45,72
37	0,000753	98 695	74	98 658	4 417 092	44,76
38	0,000902	98 620	89	98 576	4 318 434	43,79
39	0,000969	98 532	95	98 484	4 219 858	42,83
40	0,000997	98 436	98	98 387	4 121 374	41,87
41	0,001058	98 338	104	98 286	4 022 987	40,91

42	0,001279	98 234	126	98 171	3 924 701	39,95
43	0,001266	98 108	124	98 046	3 826 530	39,00
44	0,001516	97 984	149	97 910	3 728 484	38,05
45	0,001666	97 835	163	97 754	3 630 574	37,11
46	0,001780	97 672	174	97 585	3 532 820	36,17
47	0,002075	97 499	202	97 397	3 435 235	35,23
48	0,002299	97 296	224	97 184	3 337 838	34,31
49	0,002793	97 073	271	96 937	3 240 653	33,38
...	...	...	...	...	...	...

Table 1: Mortality table for Portugal, 2020-2022 (Instituto Nacional de Estatística, 2023)

In our work will try to quantify the effects of the risks associated to climate changes on this particular mortality table, as it is the most recent.

3 Climate Change and Mortality

Global climate change refers to the average, long-term changes that occur over the whole planet. These include rising temperatures and changes in precipitation, in addition to the consequences of global warming, such as:

- Rising sea level;
- Mountain glaciers that recede;
- Greenland, Antarctica, and the Arctic are experiencing faster-than-usual ice loss;
- Alterations in floral and plant blooming cycles.

Like these events, climate change resulting from unchecked Greenhouse Gas (GHG) emissions is anticipated to increase the frequency and severity of existing extreme weather events, which will have a negative impact on ecosystems, living conditions, and economies. These impacts may pose a significant risk to the population, on different levels. That might mean financial, property or life loss. Loss of life is considered one of the most important types of loss in the public perception of disasters; consequently, identifying and measuring the impact of disasters on mortality is essential for determining the future significance of the risk (Clarke *et al.*, 2022).

3.1 Assessment of the climate change risk

A risk may be defined as the chance (or probability) of a future event occurrence multiplied by the severity of its repercussions. The combination of probability and severity indicates the severity of a risk. For example, a highly probable occurrence with little repercussions would represent a moderate risk, whereas a low probability event with possibly catastrophic repercussions would represent a substantial risk. In general, these low-probability, high-impact hazards are known as "tail risks." Often, the capacity to recognize, evaluate, and manage risk is indicative of an organization's responsiveness and adaptability to change. Risk assessment enables firms to swiftly identify possible bad occurrences, be more proactive and forward-looking, and build appropriate risk responses, therefore decreasing surprises and the related costs or losses. The true value of risk assessment rests in preventing or limiting unfavorable shocks and identifying new opportunities (Gordon *et al.*, 2015).

3.1.1 Different types of risks

Extreme weather events, such as heatwaves, droughts, and heavy rains, are becoming increasingly intense every year as a result of climate change. This results in repercussions on people, property, and nature that would not have occurred in the absence of these increases in the frequency and severity of events, that are defined as disasters (Clarke *et al.*, 2022). Acknowledging the uncertainty of the climate events, the wide categories of these climate phenomena fall in under two main categories, present in the following Table 2:

Physical Risk	Transition Risk
• This risk might be event-driven (acute) or longer-term (chronic) variations in climate patterns. • The location, frequency, and severity of these events are unknown.	• Heavily depending on local and industry-specific circumstances. • Ensuing from governmental, legal, technological, and commercial developments to address climate change mitigation and adaptation needs.

Table 2: Climate risks categories (University of Cambridge Institute for Sustainability Leadership (CISL), 2022)

Going into more detail about transition risks, they arise from the transitioning to a lower-carbon economy, and may need considerable policy, legal, technological, and market adjustments to satisfy climate change mitigation and adaptation needs (TCFD, 2017).

- **Policy and legal risks**: In general, the aims of policy measures fall into two categories: those that seek to restrict behaviors contributing to the negative consequences of climate change and those that strive to encourage adaptation to climate change. Another significant risk is litigation or legal risk.
- **Technology risk**: Technological advancements or inventions that facilitate the transition to a low-carbon, energy-efficient economic system can have a substantial influence on companies.
- **Market Risk**: Climate change impacts markets in several ways, including shifting supply and demand for commodities, products, and services due to climate-related risks and opportunities.

- **Reputation Risk**: Climate change may pose reputational risks for organizations due to shifting customer perceptions of their role in the transition to a lower-carbon economy.

Climatic change affects physical risks through acute or chronic climate pattern alterations:

- **Acute Risks**: Acute physical threats include the intensification of extreme weather events such as cyclones, storms and floods.
- **Chronic Risks**: Chronic physical hazards are longer-term changes in climatic patterns (e.g., prolonged higher temperatures) that may lead to sea level rise or chronic heat waves.

Moreover, the exposure of each region, country or continent varies and while some countries are more vulnerable to heatwaves, other are more likely to see tropical storms increase. It is important to account this when studying the potential future impacts of climate change.

3.2 Climate change and extreme weather events

Extreme weather events, such as heatwaves, droughts, and heavy rains, are more and more intense every year as a result of climate change. In contrast to some other consequences of climate change, extreme weather events appear on short timeframes, and changes in extremes are inadequately captured by the climatological methods investigated for many forecasts (Clarke *et al*., 2022).

As highlighted, climate change influences society on different levels, mortality and health being a fundamental factor when evaluating its impact. Global atmospheric warming results in climate change that triggers a cascade of events, heightens environmental exposures, and exacerbates health and social vulnerabilities that impact human mortality. In the past 50 years, climate change has led to an increase in global temperatures and an increase in the frequency of extreme weather occurrences (McDermott-Levy *et al*., 2021). So, what are the environmental changes from climate change that pose a risk to mortality change patterns?

Heat: The increase in chronic temperatures as well as the increase in intensity and duration of acute abnormal temperatures, the heatwaves. It is generally recognized that excessive heat and other climate change consequences can worsen preexisting conditions and contribute to early mortality. The elderly and those with chronic conditions are more susceptible to heat-related death, so factors like population aging will increase the vulnerability of the regions to this risk (McDermott-Levy *et al*., 2021).

Urban heat Island is defined as an urban region that is much warmer than its rural surrounds due to man-made infrastructure and activity. While metropolitan regions have a greater share of paved surfaces, rural areas are covered with grass, crops, or woodland. This flora serves to chill the air, whereas asphalt and concrete cause temperatures to rise by absorbing heat. For example, typical night-time temperatures in London and Paris, for example, are around 4°C higher than in rural areas (Copernicus, s.d.).

According to the "G20 Climate Risk Atlas: Impacts, Policy, Economics" for the European Union (Spano *et al*., 2021), heatwave frequency will increase by 83,7% by 2100 in the highest emission scenario, while the heatwave duration will increase 1247% of its current time.

Cold: Although there is fewer research evaluating the effects of cold weather on mortality, climate change has increased the intensity of winter storms and the adverse health effects of extreme cold weather. In addition, to older people and those with cardiovascular and cerebrovascular illness, there is evidence of cold-related mortality in younger age groups (Conlon *et al*. 2011). It is important to note that the chronic rise of temperature will increase the minimum temperatures, resulting in warmer winters, and consequently decrease the overall mortality due to this underlying effect. For example, in the European Union the minimum temperature of the coldest month alone is expected to increase by 2.8ºC in the highest emission climate scenario by 2050, with respect to the reference period 1985-2014 (Spano, et al., 2021).

Air Quality: In recent decades, the air quality in Europe has deteriorated as a result of rising human emissions, particularly from the power production sector. The consequences of air pollution (and especially fine particulate matter with a diameter lower that 2.5 microns, PM2.5) on human health are now indisputable; it is mostly linked to cardiovascular and respiratory disorders, as well as morbidity and even mortality (McDermott-Levy *et al*., 2021). Additionally, it is estimated that PM2.5 exposure causes 301 000 premature deaths in Europe per year.

Drought: In most cases, drought is an indirect cause that results in long-term secondary exposures that contribute to early mortality. These long-term secondary exposures might include increased airborne dust, smoke from wildfires, food shortages, and hunger (McDermott-Levy *et al*., 2021).

Wildfires: Wildfire smoke is a complicated combination of PM and gaseous contaminants. The phenomena releases (PM2.5), which may enter the lungs and circulate via the alveoli, becoming a major concern among air pollutants. Wildfire-related PM2.5 is more dangerous than urban PM2.5 owing to its chemical makeup, smaller particle size, and co-exposure to damaging environmental variables, such as high temperatures. Even after fire seasons, PM2.5 from wildfires continues to contribute to poor air quality through long-distance travel (Chen *et al*., 2021).

Tropical Storms and Natural Disasters: Extreme occurrences may cause mortality owing to both the direct and indirect consequences of environmental degradation and climate change. Both the frequency and severity of natural catastrophes are anticipated to grow significantly. Tornadoes, tropical cyclones, wildfires, and storms are examples of unexpected occurrences. (International Actuarial Association, 2017).

Precipitation, Flooding and Rising Sea Levels: There are two primary causes of water-related fatalities: rapid calamities, such as coastal floods, and slow-onset circumstances, such as increasing sea levels. Assuming adequate warning, although immediate deaths may be minimal, the secondary effects of crowded emigration areas (e.g., waterborne and infectious diseases and violence) can have a significant impact on mortality, with those with lower incomes more likely to be affected by temporary living conditions that are substandard. (International Actuarial Association, 2017)

Vector-Bone diseases: Vector-borne diseases (VBDs) are infectious illnesses caused by parasites, bacteria, or viruses, such as malaria, dengue, Chagas disease, leishmaniasis, and yellow fever, which annually afflict millions of people. Vectors spread infectious agents from infected animals to humans and other animals. Mosquitoes, ticks, flies, fleas, and lice are common vectors (European Food Safety Authority, s.d.).

Particularly as an outcome of climate change, numerous disease-carrying vectors have expanded their territory northwards and to higher elevations throughout Europe. In southern and south-eastern Europe, locally transmitted epidemics of dengue, chikungunya, West Nile fever, and even malaria have occurred in recent years (mostly since 2010). Increased climatic conditions favorable to disease vectors have contributed to these outbreaks (Vector-borne diseases, s.d.).

After this comprehensive understanding of the different risks, it is important to know which of them are material. Although climate change increases and intensifies risks' patterns, most of them will possibly have only residual impacts on future mortality variations.

3.3 Materiality of climate risks

Although there is a general increase and change in the frequency or intensity of extreme climate events or propagation of diseases, not all the risks will be material for the enterprises to project the impact.

EIOPA (European Insurance Occupational Pensions Authority), established since 2010, ensures there is robust, consistent, and fair regulation and oversight, taking into mind the interests of all member states and the various types of financial institutions (European Union, s.d.). In the “Application Guidance on Running Climate Change Materiality Assessment and Using Climate Change Scenarios in the ORSA”, (EIOPA, 2022), there is an assessment on materiality of the different climate risks through the construction of "dummy" life and non-life companies, in order to generate tangible instances and make the exercise more relevant for enterprises analyzing their exposure to climate change risk under the ORSA. An ORSA, “Own Risk Solvency Assessment”, is an insurer's or insurance group's internal assessment of the appropriateness of its risk management and existing and projected solvency situations under normal and extreme stress scenarios. It will compel insurers to assess all relevant and reasonably foreseeable substantial risks that might affect their ability to satisfy policyholder commitments (NAIC, 2023).

In accordance with the Solvency II risk profile, the life insurance business is subject to market and mortality risk. It was shown in the report (EIOPA, 2022) that climate change may alter the (long-term) pattern underpinning the future development of death rates. This risk applies to insurance policies that pay out based on the insured person's survival (e.g., "annuities") or death (e.g., "term life insurance products"). Therefore, when assessing climate risks, life insurers should consider the following facts:

- Regarding the impact of physical risks, the (EIOPA, 2022) report concluded that only in non-profit participating products, in long-term analyses, would these types of risks be material, with particular focus on the temperature risk.
- Regarding the impact of transition risks, if we assume that the dummy company comprehends the with-profit participation plans and term life insurance products, then these risks are not material, for the three-time horizons (short-term 1-5 years, medium-term 5-10 years and long-term 10+ years). However, the report highlights the contribution to mortality risk from long-term exposure to air pollution and the need to implement a quick decrease in fossil-fuel power plants and increased usage of renewable energy, to

reduce pollution-related illnesses and death rates in the long run. Detailed information on the methodology used for this assessment, both for physical and transitional risks, can be found in (EIOPA, 2022) for.

With the support of this analysis, we can determine the material risks needed to model the effect of climate change on mortality rates. Ignoring catastrophic-type hazards, vector-borne diseases, physical risks, such as drought and floods, results from the immaterial nature of these threats with respect to the mortality risk.

3.4 Scenarios for climate change emissions

Climate change scenarios are essential to project and being able to estimate the repercussions of climate change on different levels. In response to this need, the Intergovernmental Panel on Climate Change Fifth Assessment Report established a global RCP–SSP–SPA (Representative Concentration Pathways – Shared Socioeconomic Pathways – Shared climate Policy Assumptions) scenario architecture (RCP–SSP–SPA), see IPCC (2014).

3.4.1 Representative concentration pathways climate scenarios

The Representative Concentration Pathways (RCPs) outline four distinct greenhouse gas emissions and atmospheric concentrations, air pollutant emissions, and land use scenarios for the 21st century.

The scenarios are designed to evaluate the costs associated with emission reductions that comply to certain concentration pathways. The scenarios include one with rigorous mitigation (RCP2.6), two with moderate mitigation (RCP4.5 and RCP6.0), and one with very high greenhouse gas emissions (RCP8.5). Baseline scenarios (scenarios without extra measures to restrict emissions) result in trajectories between RCP6.0 and RCP8.5 (IPCC, 2014). In addition, the rise in global mean surface temperatures for 2081–2100 compared to 1986–2005 is anticipated to fall between the ranges derived from concentration-driven, according to model simulations: 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), and 2.6°C to 4.8°C (RCP8.5). Figure 1 illustrates.

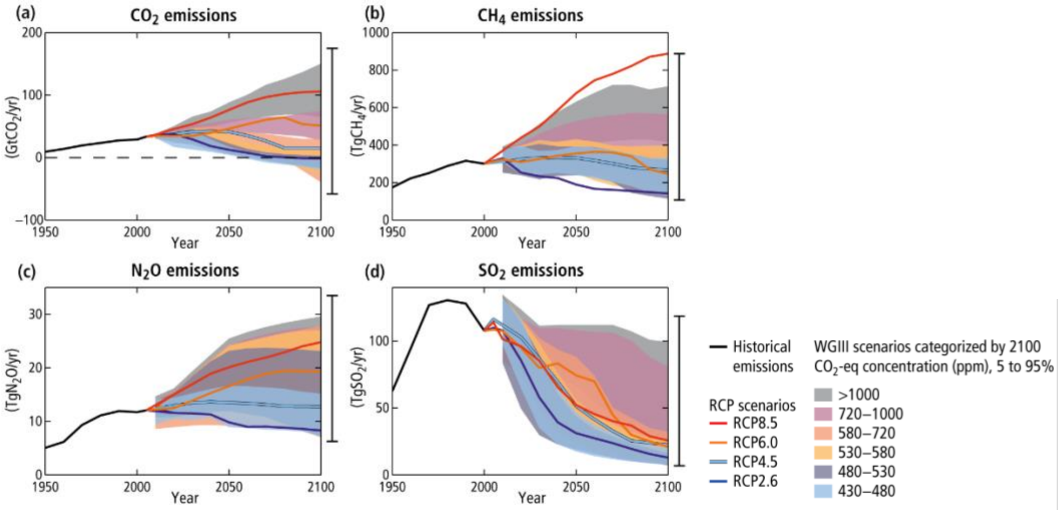

Figure 1: Projection of emissions according to each one the RCP scenarios,

source: https://ar5-syr.ipcc.ch/topic_futurechanges.php

RCP 4.5 is described by the IPCC (2014) as an halfway scenario and the most probable baseline scenario. Additionally, (Banque the France, 2023) chose RCP4.5 as the underlying climate scenario for their climate exercise, and stated: "More adverse effects can be considered within the framework of a single emission trajectory". Consequently, choosing an unique consensual pathway was important to our study and we have opted for RCP 4.5.

3.4.2 Shared socioeconomic pathways climate scenarios

The Shared Socioeconomic Pathways (SSPs) are a component of a new scenario framework developed by the climate change research community to allow the integrated study of future climate effects, vulnerability, adaptation, and mitigation. The paths were established over the last several years because of a collaborative community effort, and they depict likely key global trends that might lead to varied difficulties for climate change mitigation and adaptation in the future. The SSPs are based on five different socioeconomic development narratives, including sustainable development, regional competition, inequality, fossil-fueled growth, and middle-of-the-road development (Riahi *et al.*, 2017). Consideration of appropriate mitigation and adaptation policies is required for scenario paths planned to attain a given radiative forcing level to accomplish the stated emission levels and deal with the resultant climate change (Kebede *et al.*, 2018).

The SSP scenarios are based on five narratives explaining distinct social development pathways:

1. SSP 1: Sustainability – Taking the Green Road

The world gradually but pervasively changes toward more sustainable, inclusive development that respects perceived environmental constraints. Slowly improving global commons management, educational and health investments drive the demographic transition, and economic growth moves to human well-being. Increasing commitment to development goals reduces inequality across and within countries. Consumption emphasizes minimal material growth and resource/energy intensity.

2. SSP 2: Middle of the Road

The world's social, economic, and technical tendencies follow historical patterns. Some countries excel while others fail in development and income growth. Global and national institutions operate slowly to achieve sustainable development goals. Despite advancements, environmental systems will be degraded as resource and energy use decreases. Global population growth will be moderated in the second half of the century. In regard to the income disparity, it will persist or improve slowly and minimizing vulnerability to social and environmental changes will be difficult.

3. SSP 3: Regional Rivalry – A Rocky Road

Resurgent nationalism, competitiveness and security concerns, and regional conflicts compel countries to prioritize internal or regional matters. Policies gradually focus on national and regional security. Countries prioritize regional energy and food security over global development. Education and technology investments fall. Economic growth is modest, consumption is material-intensive, and inequality worsens. Industrialized nations have modest population growth while undeveloped nations have high. Some regions suffer from environmental degradation due to low international environmental priority.

4. SSP 4: Inequality – A Road Divided

Highly uneven human capital investments, combined with rising economic and political inequality, increase inequalities and stratification between and within countries. An internationally connected society that contributes to knowledge- and capital-intensive sectors of the global economy grows apart from a fragmented collection of lower-income, poorly educated cultures that work in a labor-intensive, low-tech economy. Social cohesion declines and conflict and instability rise. The high-tech economy and sectors create technology rapidly. The internationally connected energy sector invests in coal, unconventional oil, and low-carbon energy sources. Local environmental policies focus on middle- and high-income communities.

5. SSP 5: Fossil-fueled Development – Taking the Highway

This world relies on competitive markets, innovation, and participatory societies to accelerate technological progress and human capital development for sustainable development. More global markets are integrated. Health, education, and institutions get significant investments to boost human and social capital. Economic and social progress is accompanied by the exploitation of rich fossil fuel resources and the adoption of resource- and energy-intensive lifestyles worldwide. All these variables drive strong global economic expansion while population peaks and falls in the 21st century. Air pollution in local areas is controlled. People believe social and ecological systems can be managed, especially by geo-engineering.

Overall, the SSP3 and SSP5 baselines' increase fossil fuel dependence, CO2 emissions and mitigation challenges. Low fossil fuel dependence and greater deployment of non-fossil energy sources (SSP1 and SSP4) reduce CO2 emissions and mitigation issues (Fig. 5). SSP2 shows a century-long CO2 emission doubling, which is midway among the baselines.

In the existing literature, namely in Carleton *et al*., 2022, the SSP3 scenario is chosen to assess the mortality shocks associated to temperature change and therefore this will be also our choice.

3.4.3 Shared climate Policy Assumptions

The SPAs (Shared climate Policy Assumptions) reflect fundamental policy characteristics, such as the objectives, tools, and roadblocks of mitigation and adaptation efforts (Kebede *et al.*, 2018). They serve a crucial role in connecting the RCPs and SSPs and offer a platform for developing common assumptions across a variety of studies to evaluate the impacts of certain adaptation and/or mitigation policy measures (Kebede *et al.*, 2018). However, the full definition, narratives, and quantifications of the SPAs at the global level are still underdeveloped.

This study will not consider these scenarios, one of the reasons being the less progress that has been made on the SPAs global level narratives and quantitative specifications (Kebede *et al.*, 2018). In addition, the exhaustive literature review did not reveal any articles or reports that applied these scenarios to their methodologies.

4 Impact of climate change on mortality in Portugal

Considering the materiality assessment developed by EIOPA (EIOPA, 2022), temperature in the long term is the only material mortality risk that is considered relevant in the estimation of this risk. However, the mortality impact of air pollution might also be relevant to assess, since its future impact on mortality depends on the climate change mitigation transition, as has been discussed before. In the following analysis, where data is processed using the R software, all the effects are assessed in the long-term spectrum, that is, 2030 and 2050. But what will be the impact of the chronic rise of temperature in the mortality rates? How can the shocks be calculated? There are several studies that model the present and future impact of temperature on mortality at different geographic granularities and age stratification.

4.1 Impact of rising temperatures

Examining the different studies published that model the mortality shock effect from climate change, both from heat and cold, there are three more relevant to our project:

- "Projections of temperature-related excess mortality under climate change scenarios", (Gasparrini *et al.*, 2017) – **Model 1**;
- "Estimates of country level temperature-related mortality damage functions", (Bressler *et al.*, 2021) – **Model 2**;
- "Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits", (Carleton *et al.*, 2022) – **Model 3**.

Model 1:

The (Gasparrini *et al.*, 2017) assessment allows consistent comparison across hundreds of areas in varied regions of the world with different temperatures, socioeconomic and demographic conditions, infrastructure, and public health service development. The strategy compensates for heat- and cold-related excess mortality, local climates, and temperature–mortality relationships using advanced analytic methods.

To assess the overall impact of temperature on mortality, the estimation of exposure-response function was obtained in the first stage, to then project the whole effect on mortality. Two-stage time series analysis generated location-specific estimates of temperature–mortality relationships.

So, firstly, performed a quasi-Poisson regression (Gasparrini, et al., 2017) independently in each site while adjusting for season, long-term trends, and day of the week.

Secondly, using multivariable meta-regression (Gasparrini, Armstrong, and Kenward, 2012), pooled the reduced estimates of the entire cumulative exposure–response curves. The best linear objective forecast of the aggregate cumulative exposure–response connection in each site, given as relative risk, was produced next.

Then, to project the impact on mortality, the authors calculated the increased mortality owing to temperature by projecting the effect using the modelled daily series of temperature and mortality, under the assumption that neither adaptation nor population changes would occur. For each day of the series at each site, the number of fatalities, D_{attr}, attributable to suboptimal temperature was calculated as follows:

$$D_{attr} = D^*_{mod} \cdot \left(1 - e^{-\left(s^*\left(T^*_{mod};\theta^*_b\right) - s^*\left(T_{mm};\theta^*_b\right)\right)}\right), \tag{1}$$

where:

- D^*_{mod}, projected series of mortality counts;
- T^*_{mod}, series recalibrated using the monthly mean and daily variation around the monthly mean of T_{obs};
- θ^*_b, best linear unbiased prediction of the coefficients in each location;
- T_{obs}, nonlinear and lagged exposure-response between outside temperature and;
- s^*, transformed bi-dimensional spline function from the first stage;
- T_{mm}, temperature corresponding to minimum mortality risk.

This daily attributable mortality was then aggregated across periods and geographic locations, and the corresponding attributable fraction was calculated as the ratio between the corresponding total number of deaths and the corresponding attributable mortality rate.

Model 2:

The study (Bressler *et al.*, 2021) considers prior forecasts for the impacts of climate change on heat- and cold-related mortality for 23 countries, which were reported in (Gasparrini *et al.*, 2017), and extrapolates these results to the global scale. As a consequence, this study gives a more in-depth overview of the procedures that were used and extends the conclusions previously obtained. Under climate change scenarios, (Gasparrini *et al.*, 2017) expect an increase in heat-related excess mortality and a reduction in cold-related excess mortality for all 23 countries, with the majority of nations suffering a net mortality increase. The extrapolation to additional nations is based on 368 estimates (23 countries, heat and cold-related mortality, two time periods, and 4 RCPs).

The paper assessed heat deaths separately from cold deaths testing temperature, hottest month average temperature, coldest month average temperature and GDP as the explanatory variables to estimate the percentages increase/decrease on mortality due to the changing temperature patterns. Heat deaths were accounted through a regression, where multiple model specifications incorporating these variables were evaluated (4 different models).

In equation *(2)* below the dependent variable is $\mathbf{Y_{Hot_{s,c,t}}}$, the percentage increase in the mortality rate due to heat estimated by Gasparrini et al., where the subscript s represents the scenario (whether the projection is for RCP 2.6, 4.5, 6.0, or 8.5), the subscript c represents the country, and the subscript t represents whether the projection is for mid-century or end of century. When there is no scenario or time subscript, this implies that the variable is an observed variable for the present period (the 2001–2020 average).

$$\begin{aligned} \mathrm{Y\_Hot}_{s,c,t} = \beta_1 \mathrm{T}_{s,c,t} + \beta_2 \mathrm{T}_{s,c,t})^{\,2} + \beta_3 (\mathrm{T}_{s,c,t})^{\,3} \times \mathrm{HottestMonthAvgTemp}_c \\ + \beta_4 \mathrm{T}_{s,c,t} \times \mathrm{HottestMonthAvgTemp}_c \times \log(\mathrm{GDPPC}_c) + \varepsilon_{s,c,t} \end{aligned} \tag{2}$$

Further:

- $\mathbf{T_{s,c,t}}$ is the increase in the yearly average temperatures with relation to the current time (2001–2020 average);
- $\mathbf{HottestMonthAvgTemp_c}$ is the current population-weighted average temperature in the country's warmest month;
- $\mathbf{GDPPC_c}$ is the gross domestic product per capita at country level;
- $\boldsymbol{\varepsilon_{s,c,t}}$ is the standard error clustered at the country level.

So, the estimates of the coefficients modelled by this interaction are presented in Table 3, and can be used to project the future mortality impact of climate change:

β_1	β_2	β_3	β_4
- 0.532	- 0.0629	0.525	- 0.0409

Table 3 Estimated coefficients of heat, for Model 2

Source: (Bressler et al., 2021)

This model has an adjusted R^2 of 0.6, which determines the proportion of variation in the target field that may be attributed to the inputs.

In the same manner, to model the mortality attributable to cold temperatures, as a function of the rise in annual average temperatures at the national level:

$$\mathrm{Y\_Cold}_{s,c,t} = \beta_1 T_{s,c,t} + \beta_2 (T_{s,c,t})^{2} + \beta_3 (T_{s,c,t})^{3} \times \mathrm{ColdestMonthAvgTemp}_c + \varepsilon_{s,c,t} \tag{3}$$

- $\mathbf{ColdestMonthAvgTemp_c}$ is the current population-weighted average temperature in the country's coldest month.

The estimates of the coefficients are presented in Table 4, with an adjusted R^2 of 0.911:

β_1	β_2	β_3
- 0.532	- 0.0629	0.525

Table 4 Coefficients of the model

Source: (Bressler et al., 2021)

The performance of the cold-related mortality model is better according to the R^2, which may be explained by the fact that there is less variance in cold-related mortality across nations. However, further details can be found in the original paper (Bressler *et al.*, 2021).

Model 3:

Moving to (Carleton *et al.*, 2022), these authors use subnational data from 40 countries, to estimate age-specific mortality-temperature connections and to extend them to nations lacking data and into a climate-changed future. They modelled a U-shaped link between severe cold and heat and death rates, uncovering that the impact is particularly heightened among the elderly.

To better describe the mortality shocks, population is divided in 3 age groups according to vulnerability, where mortality data was aggregated based on age-specific annual mortality rates:

- < 5 years;
- Between 5 and 64 years;
- > 64 years.

Carleton *et al.* (2022) assume that the shocks are equal to all ages in the same risk group. The model is fitted defining the age-specific all-cause mortality ***M*** at region level. In equation

(4) ***a*** denotes the age category, ***i*** refers to the 2nd administrative level (ADM2, that can be denoted as county), ***t*** is the year, ***s*** refers to the 1st administrative level (ADM1, state or province), ***pc*** stands for 'per capita' and ***c*** represents the country.

$$M_{ait} = g_a(T_{it}\ ,TMEAN_s, log(GDP_{pc})_s) \ + \ q_{ca}(R_{it}) \ + \ \alpha_{ai} \ + \ \delta_{act} \ + \ \varepsilon_{ait} \tag{4}$$

Further:

- $g_a(\dots)$ defines the temperature effect of mortality through a fourth-degree polynomial of the daily temperatures T_{it}, the sample-period average yearly temperature $TMEAN_s$, and the sample-period average yearly gross domestic product per capita GDP_{pc};
- $q_{ca}(\dots)$ defines a second-order polynomial of daily precipitation R_{it};
- α_{ai}, and δ_{act} are expressed as fixed effects.

To capture the full mortality effects of climate change with benefits of income growth and adaptation, the function $g_a(\dots)$ estimated in equation *(4)* was used to calculate the mortality effects of temperature. M_{ait} was used to estimate the interaction model, taking into account factors like precipitation and the multiple fixed parameters, but $g_a(\dots)$ was used to obtain the results through the relation, where *t* is the year in the future being studied and t_0 the baseline year:

$$g(T_t\ ,TMEAN_t, log\big(GDP_{pc})_t\big) - \ g(T_{t_0}\ ,TMEAN_{t_0}, log(GDP_{pc})_t) \tag{5}$$

Figure 2 depicts the projected impacts of climate change on mortality across all age groups, as shown by the mean estimate of a collection of Monte Carlo simulations that account for both climate model and statistical uncertainty. Additionally, the model allows for income growth and climate adaptation to be taken (or not) into consideration over the results. However, in our work we want these measures to be accounted for, since they have a toll in the results, that can be seen in Figure 2. These full mortality effects are captured through equation *(5)*.

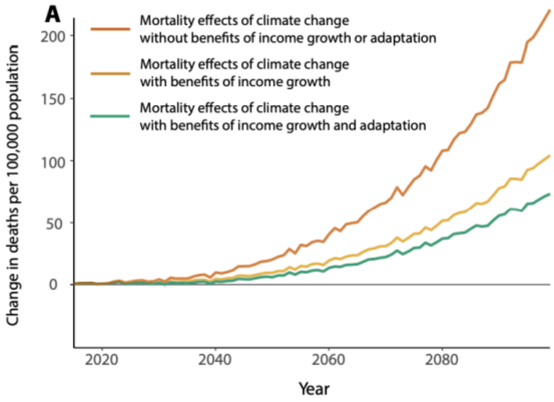

Figure 2: Projected mortality rate impacts of climate change

Source: (Carleton, et al., 2022)

After gaining a thorough grasp of the various methodologies, Model 2 captures the influence of temperature only at the nation level, but Model 3 is able to surpass this degree of granularity in order to deliver research with the finest possible resolution. This argument applies equally to Model 1, which considers the temperature impacts only at country level and discloses results for a selected number of countries and at continent level.

It is believed that it is feasible or to construct a model from scratch, selecting the factors that influence temperature-triggered death, or to use modeled data. (Carleton *et al.*, 2022) comprehensive work was cited by EIOPA, and since part of the results are publicly available, the preferred methodology was to employ the paper's working results.

4.1.1 Measuring the impact of rising temperatures

A public repository containing the relevant code for reproducing the findings is provided in the publication[1]. In addition to this code repository, a file containing public data used in the development of the framework is available for download. Despite the fact that recreating the model is not manageable since it takes 1000 Monte Carlo runs and a large amount of computer storage and processing capacity, this repository contains results for various climatic scenarios at the regional level, until 2099.

Going in more detail on the climate scenarios publicly available, there is a combination of RCP-SSP, which means that the paper projected the results using the SSPs socioeconomic

[1] https://github.com/ClimateImpactLab/carleton_mortality_2022/tree/main/1_estimation

scenarios under the RCPs emissions scenarios. Since the present work focus on a middle scenario, the RCP 4.5-SSP 3 combination was selected.

The repository contains ADM2 region-level findings for each of the climatic scenarios. When selecting results for Portugal, ADM2 region-level results in 20 areas (districts) with yearly results for each age group, until 2099. This indicates that there is a separate yearly mortality shock for each area and each of the three age groups outlined in the research. The results are represented in units of deaths per 100,000 population, for the climate scenario RCP 4.5-SSP 3:

District	Year	Young	Older	Oldest
Açores	2030	-0,60152	-0,22462	-12,26983
Açores	2050	-0,52463	0,53844	-4,24071
Aveiro	2030	-1,70059	3,40063	-31,23174
Aveiro	2050	-2,10672	7,71794	23,01123
Beja	2030	-0,36755	0,64112	-7,25341
Beja	2050	-0,54874	1,76292	1,98370
Braga	2030	-1,89239	3,80517	-47,09455
Braga	2050	-2,30920	9,28968	-2,99400
Bragança	2030	-0,34915	0,57489	-10,19382
Bragança	2050	-0,42579	2,23222	-16,12055
Castelo Branco	2030	-0,54374	1,15391	-10,84368
Castelo Branco	2050	-0,67919	3,04782	-0,65870
Coimbra	2030	-1,11132	1,85191	-21,94580
Coimbra	2050	-1,43454	4,65883	6,89034
Évora	2030	-0,41630	0,89786	-7,43818
Évora	2050	-0,59105	2,18749	4,03836
Faro	2030	-0,78001	1,05853	-15,77382
Faro	2050	-1,18267	3,65930	4,90824
Guarda	2030	-0,46708	0,73747	-12,50706
Guarda	2050	-0,53733	2,60573	-14,18187
Leiria	2030	-1,00733	1,75499	-19,77947
Leiria	2050	-1,34632	4,59557	9,14877
Lisboa	2030	-3,90265	7,21343	-54,55235
Lisboa	2050	-5,63779	20,17447	42,06529
Madeira	2030	-0,29413	0,65203	-8,62718
Madeira	2050	-0,49007	2,12691	-1,77074
Portalegre	2030	-0,32211	0,85403	-4,84435
Portalegre	2050	-0,44525	1,90066	5,03152
Porto	2030	-3,87878	9,07715	-70,79311
Porto	2050	-4,73811	19,55958	84,03235
Setúbal	2030	-1,60514	1,27200	-34,11767
Setúbal	2050	-2,46677	5,51919	-1,14488
Viana do Castelo	2030	-0,57833	0,79753	-15,07226
Viana do Castelo	2050	-0,76227	2,60498	-8,69696
Vila Real	2030	-0,56794	0,59506	-20,87514
Vila Real	2050	-0,64364	3,32727	-35,21490
Viseu	2030	-1,00049	1,75102	-23,62958
Viseu	2050	-1,22612	4,96262	-10,03699

Table 5: Mortality results for Portugal, for the years 2030 and 2050

In Table 5 are stated the results for each of the age groups where:

- Younger represents the age group where the population is below 5 years old.
- Older represents the age group where the population is aged between 5 and 64 years old.
- Oldest represents the age group of the remaining population, above 64 years old.

For example, in the district of Lisboa, in the year 2030, there will be approximately less 3.9 deaths in the younger age group per 100,000 people within the age group (0-4 years old). But how does this impact the country's mortality table? It is required to reach a national level shock for each age group.

The approach chosen to obtain the mortality shock at the whole country level was to calculate a population weighted shock, using Eurostat most recent data on demographics, that is, using their 5-year age groups data at NUTS III level, from January 1st of 2022 (Eurostat, 2023). The NUTS (Nomenclature of territorial units for statistics) are a three-tiered hierarchical classification system, where NUTS III is a more granular level divided in small regions. In fact, more granular that the district level presented in Table 5 with the temperature climate results.

Figure 3: Portugal map divided into districts,

Source: https://www.nacionalidadeportuguesa.com.br/mapa-de-portugal/

Figure 4: Portugal map divided into NUTS III,

Source: (PORDATA, s.d.)

There are areas in the NUTS III nomenclature that overlap the districts, Figure 3, hence the NUTS III division does not correspond to the district division, Figure 4. This indicates that certain NUTS areas are separated by districts and belong to two distinct districts. Because demographic data is in accordance with the NUTS III partition it was necessary to use a **proxy variable** to match the NUTS III – District divisions.

For the proxy variable, it was assumed that a NUTS III region, whose municipalities belong to more than one district, belonged to the district with the greatest number of municipalities. As a result of this proximate method, two NUTS III areas were absorbed by other in the national rate computation (Lezíria do Tejo and Médio Tejo), so the demographic data with the association of the different districts with NUTS III is presented in Table 6.

NUTS.III	District	Dem_younger	Dem_older	Dem_oldest
Alentejo Central	Évora	5675	105241	41447
Alentejo Litoral	Setúbal	3542	68057	25305
Algarve	Faro	19687	334157	111857
Alto Alentejo	Portalegre	3719	69507	31236
Alto Minho	Viana do Castelo	7556	157790	65596
Alto Tâmega	Vila Real	2247	52138	29698
Área Metropolitana de Lisboa	Lisboa	129108	2114092	626427
Área Metropolitana do Porto	Porto	66355	1285972	387790

Ave	Braga	15965	313236	88555
Baixo Alentejo	Beja	4605	78877	31464
Beira Baixa	Castelo Branco	2430	51224	27077
Beiras e Serra da Estrela	Guarda	6099	134677	69541
Cávado	Braga	16757	316962	82881
Douro	Viseu	5515	124908	53245
Oeste	Lisboa	14427	262787	88995
Região Autónoma da Madeira (PT)	Madeira	9374	191039	50769
Região Autónoma dos Açores (PT)	Açores	10376	186272	39840
Região de Aveiro	Aveiro	14532	268011	87250
Região de Coimbra	Coimbra	14998	300898	122316
Região de Leiria	Leiria	10933	204222	72814
Tâmega e Sousa	Porto	15159	313170	79371
Terras de Trás-os-Montes	Bragança	3100	67546	36370
Viseu Dão Lafões	Viseu	8601	172507	72155

Table 6: Demographic data by age group and NUTS III-District association

After this association it was possible to calculate a country level shocks for the years 2030 and 2050, for the 3 age groups:

Year	Younger Shock	Older Shock	Oldest Shock
2030	-2,68956	5,22612	-41,93424
2050	-3,62936	13,21830	29,51652

Table 7: Country level mortality shock for temperature, for Portugal

The shocks presented in Table 7, for each age-group, can be translated into the number of additional deaths per 100.000 population. Although Table 7 results might look really despair between 2030 and 2050, when compared with the national level aggregated results from UNDP (United Nations Development Programme)[2], which sustained their calculations on (Carleton *et al.*, 2022) methodology they make are not dispar.

It was necessary to translate each rate into a mortality shock that can be applicable onto the life table. Based on the susceptibility of each year of age when exposed to changing temperature patterns, each age group was defined in (Carleton *et al.*, 2022), so the assumption of the shocks, within an age group, was made for this study assessment

[2]https://horizons.hdr.undp.org/?_gl=1*idnz7w*_ga*MTQzMTU5MTYxLjE2OTUxMTgwMDY.*_ga_3W7LPK0WP1*MTY5NTExODAwNS4xLjEuMTY5NTExODMwMy42MC4wLjA.#/country/PRT/mortality/4.5

This deduction allows the mortality rates calculated through (Carleton *et al.*, 2022) to be incorporated later in the life table. It is important to highlight that with this association we are assuming that q_x is equal for all ages within a age group.

4.2 Impact of air pollution

Despite considerable progress, Europe's air quality remains severe, even in high-income nations. According to the European Environmental Agency (EEA), air pollution killed over 500,000 persons in Europe in 2015 (EEA, 2018). The data collected by the EEA account for fatalities due to PM2.5, NO2, and ozone. The first has been identified as the most significant risk factor related to air pollution. About 83 percent of all deaths attributable to air pollution in Europe in 2015 were ascribed to PM2.5, 14 percent to NO2 and the unallocated deaths were attributed to ozone (Carvalho, 2019). Accounting for particle matter mortality is the most critical aspect of the evaluation, since it accounts for about 83 percent of all fatalities caused by air pollution.

According to the "Pollution Action Note", from the UN environment program (Programme, 2023), each person in Portugal has an annual mean exposure of 1.7 times the World Health Organization (WHO) guideline and in 2019 alone 2086 deaths were attributable to fine particle pollution. But how can the impact of air pollution (more specifically, of particle matter) on mortality be estimated and projected?

The (WHO, 2021) defined an annual air quality guideline (AQG) concentration level for PM2.5 that is based on all non-accidental mortality and cause-specific mortality, below which there are no significant impacts on mortality, the baseline concentration. That baseline concentration was established at 5 μg/ m^3 (micrograms per cubic meter). To measure the direct impact of this pollutant on mortality a concentration-response function (CRF) was used, in other words, a statistical function or model based on the results of epidemiological studies that estimates the relative risk from air pollution for a disease or health outcome (such as premature death, heart attack, asthma attack, etc.) in a population per unit concentration of PM2.5.

To determine the impact of air pollution on mortality, our work follows the WHO recommendations that relay on the baseline concentration and the CRF to determine a relative risk (*RR*) (Coelho, 2022). The *RR* is determinant to establish a direct relation between the pollutant's concentration level and mortality that results from the long-term exposure to this air constituent:

$$RR = e^{-\beta(C_i - C_0)},$$

(6)

where β can be estimated based on the CRF, C_i designates the concentration level the population is exposed to in a certain region and C_0 denotes the baseline concentration. According to (Chen and Hoek, 2020) there is positive association between PM2.5 and natural cause (non-accidental) mortality and summarizes the relationship at a RR of 1.08. This means, in line with (WHO, 2021) methodology, that an increase in 10 µg/ m^3 of PM2.5 is associated with an 8% increase in the total mortality, assuming the relationship is linear.

For the calculation of the climate change mortality, it is necessary to retrieve information about future estimates of the concentration of this pollutant, in order to determine the difference between the future and current region level concentrations (which must be multiplied by *RR* to determine the impact on mortality).

4.2.1 Measuring the impact of air pollution

The PM2.5 concentration is dependent of numerous climatic factors and variables. According to (Cheng *et al*., 2021) this pollutant's concentration is significantly altered by the interplay of seasonal and atmospheric conditions and it comes from directly released primary particles and secondary particles created by chemical processes involving PM forming (precursor) gases: SO2, NOx, NH3 and volatile organic molecules other than methane (Guerreiro, Foltescu, and Leeuw, 2014).

In (Zhai *et al*., 2017) there are references of data collection of ground-level PM2.5 data, satellite-retrieved aerosol optical depth (AOD) data, meteorological data (e.g., temperature, wind speed, humidity, pressure, and precipitation), topography and land use data, and PM2.5 emissions related data (e.g., industrial and traffic emissions, and surface dust) for the estimation of the model. The concentration of this pollutant is correlated to several different variables. The model estimated in the referred paper had a fitting adjusted R^2 of 0.905, which explains almost all the concentration behavior in the locations investigated. Modelling the concentration levels of particle matter requires extensive climate and geographic data, both historical and projections for the future. The trade-off regarding execution time and necessary data gathering does not outweigh the available projection data for this work's calculation.

So, the approach chosen to proceed in this paper relies on the projections modelled through the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model, provided by IIASA (IIASA, 2023). GAINS assesses, for each nation or region, the possible emission reductions given by around 2000 distinct emission control methods and their associated costs. For the air quality analysis, they give two public models, ECLIPSE and Clean Air Outlook, with estimates and predictions for ambient PM2.5 concentrations and expected reduction.

In both this models, ECLIPSE and Clean Air Outlook, the climate scenarios used for the projections are defined and named differently than the IPCC AR5 pathways defined in Chapter 3. However, ECLIPSE sectorial emissions projections are consistent with RCPs, as well as the spatial distribution of PM2.5 that was prepared from RCP-consistent proxies (Klimont *et al.*, 2017). For further details on the construction of the emissions scenarios underlying this model may be found in (Klimont *et al.*, 2017).

The ECLIPSE model has two emission scenarios, Current legislation (CLE) and Maximum feasible reduction (MFR): CLE assumes that appropriate country- and sector-specific policies and initiatives have already been implemented, or have been declared as future policies; MFR assumes the greatest possible application rates for the most effective abatement technology and policy actions to minimize pollutant emissions and considers the lowest feasible application rates (Rafaj *et al*., 2021). For this reason, CLE was selected for the calculation of the impact of future PM2.5 concentrations on mortality in our work.

The coordinate (longitude and latitude) granularity of the modeled projections is 0.5ºx0.5º, therefore it is important to obtain a proxy to approximate the closest NUTS III coordinates cell to the predicted data of GAINS. The closest GAINS cell was identified, and in each case forecasts of the concentration level of the PM2.5 pollutant were connected to NUTS III regions for 2030 and 2050, as presented in the following Table 8:

NUTS Name	Long Proxy	Lat Proxy	Long Original	Lat Original	2030	2050
Região de Aveiro	-8,75	40,625	-8,5128	40,6376	6,21014861	6,62596232
Beira Baixa	-7,75	39,875	-7,5191	39,8617	4,34132777	4,43200445
Médio Tejo	-8,25	39,625	-8,2401	39,5844	4,69639184	4,89734843
Beiras e Serra da Estrela	-7,25	40,625	-7,2846	40,5254	4,3008094	4,34377692
Oeste	-9,25	39,375	-9,1199	39,2885	5,0131012	5,67759449
Baixo Alentejo	-7,75	37,875	-7,8202	37,8602	5,14888554	5,59231164
Alentejo Litoral	-8,75	37,875	-8,5526	37,9819	5,3022833	5,93780211
Douro	-7,25	41,125	-7,4329	41,1566	4,30218992	4,325884
Terras de Trás-os-Montes	-6,75	41,625	-6,826	41,5841	3,91221409	3,91954045
Área Metropolitana de Lisboa	-8,75	38,625	-8,8878	38,6221	6,03999579	6,37294896
Lezíria do Tejo	-8,75	39,125	-8,6158	39,1152	5,17101238	5,57711506
Viseu Dão Lafões	-7,75	40,625	-7,9368	40,7086	4,70003461	4,73999261
Região de Coimbra	-8,25	40,125	-8,3354	40,2176	5,01749805	5,1937485

Cávado	-8,25	41,625	-8,4633	41,619	5,32738245	5,43147666
Ave	-8,25	41,625	-8,2057	41,5262	5,32738245	5,43147666
Alentejo Central	-7,75	38,625	-7,8568	38,5987	4,90439281	5,14922726
Região de Leiria	-8,75	39,625	-8,8099	39,7488	5,2474375	5,66441975
Alto Minho	-8,75	41,875	-8,5052	41,8705	5,86981451	6,17429512
Algarve	-8,25	37,125	-8,1299	37,2026	5,20244063	5,82331476
Tâmega e Sousa	-8,25	41,125	-8,1152	41,1956	5,74665209	5,83926429
Área Metropolitana do Porto	-8,25	41,125	-8,4882	41,1062	5,74665209	5,83926429
Alto Alentejo	-7,75	39,375	-7,6244	39,2868	4,58893095	4,73453614
Alto Tâmega	-7,75	41,625	-7,6302	41,6642	4,19013965	4,25087799
Região Autónoma da Madeira	-16,75	32,625	-16,9503	32,7326	3,36419751	3,72199577
Região Autónoma dos Açores	-17,25	32,875	-25,3659	37,7846	3,31372816	3,64891198

Table 8: Matching of the NUTS cells to the projections cells and coordinates

Since *RR* links the change in PM2.5 concentration to mortality, it is required to acquire the most recent values for this pollutant at NUTS III level. The European Environment Agency (EEA) has estimates for 20 different stations within Portugal (European Environment Agency, 2018), but stations geographic distribution is not well spread throughout the country; for this reason, OECD NUTS III concentration levels for 2020 were used (OECD, s.d.). The national mortality table used is for the years 2020-2022, so it is assumed that it captures the mortality effects of 2020.

After retrieving all the information needed, that is proxied concentrations for 2030 and 2050, the differences of the changes in concentration were calculated, see Table 9 below.

NUTS.III	2020	2030	2050	Dif 2030	Dif 2050
Alentejo Central	7,35	4,90	5,15	-2,45	-2,20
Alentejo Litoral	7,07	5,30	5,94	-1,77	-1,13
Algarve	8,59	5,20	5,82	-3,39	-2,77
Alto Alentejo	6,88	4,59	4,73	-2,29	-2,15
Alto Minho	7,42	5,87	6,17	-1,55	-1,25
Alto Tâmega	5,91	4,19	4,25	-1,72	-1,66
Área Metropolitana de Lisboa	9,19	6,04	6,37	-3,15	-2,82
Área Metropolitana do Porto	8,76	5,75	5,84	-3,01	-2,92
Ave	8,45	5,33	5,43	-3,12	-3,02
Baixo Alentejo	6,82	5,15	5,59	-1,67	-1,23
Beira Baixa	6,51	4,34	4,43	-2,17	-2,08
Beiras e Serra da Estrela	6,26	4,30	4,34	-1,96	-1,92
Cávado	7,91	5,33	5,43	-2,58	-2,48
Douro	6,02	4,30	4,33	-1,72	-1,69
Lezíria do Tejo	7,95	5,17	5,58	-2,78	-2,37
Médio Tejo	7,81	4,70	4,90	-3,11	-2,91
Oeste	8,03	5,01	5,68	-3,02	-2,35
Região Autónoma da Madeira (PT)	4,85	3,36	3,72	-1,49	-1,13
Região Autónoma dos Açores (PT)	5,59	3,31	3,65	-2,28	-1,94
Região de Aveiro	10,03	6,21	6,63	-3,82	-3,40
Região de Coimbra	9	5,02	5,19	-3,98	-3,81
Região de Leiria	8,08	5,25	5,66	-2,83	-2,42
Tâmega e Sousa	8,96	5,75	5,84	-3,21	-3,12
Rerras de Trás-os-Montes	5,9	3,91	3,92	-1,99	-1,98
Viseu Dão Lafões	6,98	4,70	4,74	-2,28	-2,24

Table 9: Regional concentrations for 2020, 2030 and 2050, with the correspondent change

To calculate a population-weighted national estimate for 2030 and 2050, the process used in the temperature shock section was reproduced in order to determine the national difference estimate, getting a difference of -2.906 μg/ m^3 for 2030 and -2.6444 μg/ m^3 for 2050.
The final step is to apply the results to the mortality table.

In the latter section, differences in the national concentration of PM2.5 were estimated, through a population weighted average of regional level estimates. Because the RR was established at 1.08 μg/ m^3 for an increase of 10 μg/ m^3 in the concentration of PM2.5 it is necessary to translate a final relationship, APS_t, to get to a final shock that applies directly to the life table:

$$APS_t = q_x \times \frac{(RR-1)}{10} \times \Delta PM_{2.5},$$

(7)

where:

APS_t, air pollution mortality shock at time *t*;

q_x, the life table mortality rate;

RR, the relative risk established;

$\Delta PM_{2.5}$, national level PM2.5 concentration difference.

4.3 Adjustment of the Portuguese life table

After the two mortality shocks have been calculated, we can now display in Table 10 the updated mortality table for Portugal in years 2030 and 2050, where the green resembles a decrease in mortality and the red an increase:

		Mortality rate updated with temperature shock		Air Pollution Shock		Final Mortality rate	
(x)	qx	2030	2050	2030	2050	2030	2050
65	0,010049	0,010034	0,010054	-0,000234	-0,000213	0,009801	0,009842
66	0,010994	0,010978	0,010998	-0,000256	-0,000233	0,010722	0,010766
67	0,011745	0,011732	0,011753	-0,000273	-0,000248	0,011459	0,011505
68	0,012736	0,012721	0,012743	-0,000296	-0,000269	0,012425	0,012473
69	0,013570	0,013557	0,013579	-0,000315	-0,000287	0,013242	0,013292
70	0,014344	0,014329	0,014352	-0,000333	-0,000303	0,013996	0,014049
71	0,015537	0,015520	0,015543	-0,000361	-0,000329	0,015159	0,015215
72	0,018111	0,018092	0,018117	-0,000421	-0,000383	0,017671	0,017734
73	0,018752	0,018739	0,018765	-0,000436	-0,000397	0,018303	0,018368
74	0,021176	0,021155	0,021182	-0,000492	-0,000448	0,020663	0,020734
75	0,023978	0,023963	0,023991	-0,000557	-0,000507	0,023405	0,023484
76	0,026350	0,026331	0,026361	-0,000613	-0,000557	0,025718	0,025804
77	0,030882	0,030863	0,030896	-0,000718	-0,000653	0,030145	0,030243

78	0,035471	0,035447	0,035484	-0,000825	-0,000750	0,034623	0,034733
79	0,037858	0,037838	0,037877	-0,000880	-0,000801	0,036958	0,037077
80	0,043778	0,043756	0,043801	-0,001018	-0,000926	0,042739	0,042875
81	0,049679	0,049641	0,049692	-0,001155	-0,001051	0,048486	0,048641
82	0,056681	0,056639	0,056697	-0,001318	-0,001199	0,055321	0,055498
83	0,065968	0,065921	0,065989	-0,001534	-0,001396	0,064387	0,064594
84	0,077768	0,077708	0,077792	-0,001808	-0,001645	0,075900	0,076146
85	0,092759	0,092696	0,092800	-0,002156	-0,001962	0,090540	0,090837
86	0,108612	0,108528	0,108659	-0,002525	-0,002298	0,106003	0,106361
87	0,126603	0,126497	0,126667	-0,002943	-0,002678	0,123554	0,123989
88	0,146437	0,146309	0,146534	-0,003404	-0,003098	0,142904	0,143436
89	0,168433	0,168228	0,168532	-0,003916	-0,003563	0,164313	0,164969
90	0,194434	0,194171	0,194596	-0,004520	-0,004113	0,189651	0,190483
91	0,221071	0,220695	0,221302	-0,005139	-0,004677	0,215555	0,216625
92	0,250044	0,249510	0,250405	-0,005813	-0,005290	0,243697	0,245116
93	0,281336	0,280493	0,281860	-0,006540	-0,005952	0,273953	0,275909
94	0,314889	0,313599	0,315769	-0,007321	-0,006662	0,306278	0,309108
95	0,350601	0,348455	0,352056	-0,008151	-0,007417	0,340304	0,344639
96	0,388324	0,384453	0,390722	-0,009028	-0,008215	0,375425	0,382507
97	0,427857	0,420939	0,432468	-0,009947	-0,009051	0,410992	0,423417
98	0,468951	0,455370	0,477876	-0,010902	-0,009921	0,444468	0,467956
99	0,511306	0,483153	0,530036	-0,011887	-0,010817	0,471267	0,519219
100	0,554572	0,495800	0,600885	-0,012893	-0,011732	0,482907	0,589153

Table 10:Final mortality table results, age-group >65

The full mortality table is Table 12 of the Appendix, also containing the variation from the original mortality rates results.

Both mortality shocks, for each risk, are added to the original q_x values of the Portuguese table using equation *(7)*, where APS_t is defined, for the calculation of the air pollution shock, and the temperature updated mortality rates determined following the assumption of equal shocks within each one of the age groups.

The overall mortality shock is negative based on the results in Table 12. This happens because the temperature shock due to the rising temperature determined in our work only produces a very moderate excess mortality in 2050 (in 2030 there was no significative excess mortality) and the air pollution shock is expected to have a quite positive evolution in the future (again, according to the outcome of the applied model). Consequently, it ends up outweighing the temperature rises, throughout almost all ages ages for 2050. This leads to a minor decline in mortality over the majority of the life table.

Analyzing the results further, through the variation from the initial q_x, see Figure 5, it is noticeable that the shocks have a more favorable impact (decrease of the mortality rates) from ages 0 to 5. Additionally, in the oldest age group a divergent behavior is noticeable between the two years in our study (2030 and 2050).

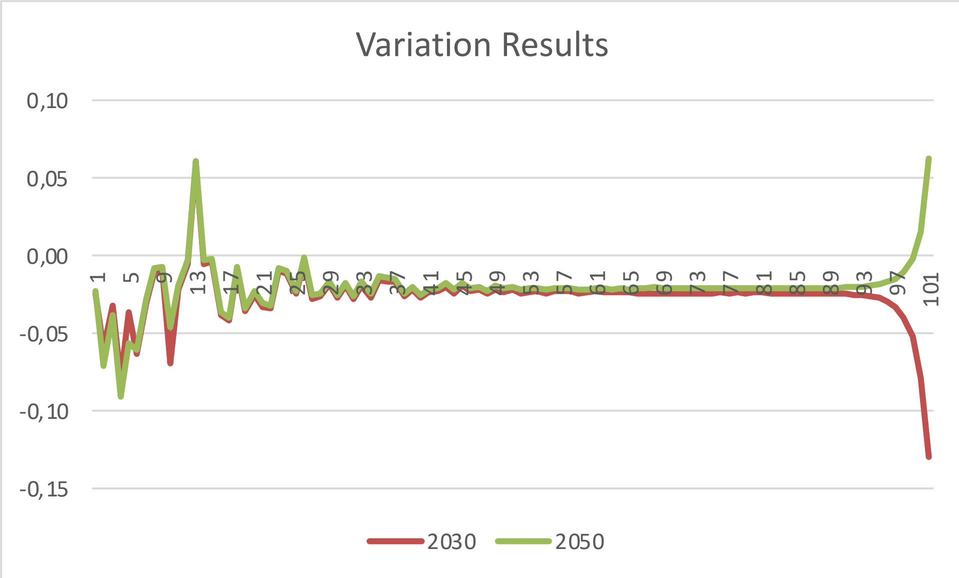

Figure 5: Variation of mortality rates for 2030 and 2050

Insofar, as the adjustments were accomplished, it may be necessary to take into consideration certain restrictions. When retrieving (Carleton *et al.*, 2022) findings, additional scenario assumptions cannot be made, i.e., when integrating the temperature and air pollution results, the assumption was made that the climatic scenario was applicable to both measurements. This may lead to deviations in the projections.

Additionally, when assessing these risks there was no separation between genders, it was considered the risks are universally the same, gender wise.

Finally, air pollution concentrations and temperature might be correlated, even if sightly, and that was not taken into the model.

5 Conclusions

The selection of the risks to be assessed was a thorough process, which attempted to be in line with EIOPA, insurance business applicability and risks materiality.

This thesis followed closely the work of (Carleton *et al.*, 2022) for the temperature shock, as well as the (WHO, 2021) recommendations for the air pollution shock to project the impact of climate change in the mortality tables. The combination of these methodologies resulted in an adjusted mortality table for the years of 2030 and 2050, which impacts ultimately contributed to a decrease on the mortality rates.

These findings could not have been foreseen, since it was anticipated that climate change would have a detrimental impact on the rates of the life table, particularly among the elderly. Because increasing temperatures also imply the generalized increase of minimum temperatures, the effect of overall temperature is amortized by the decrease of cold related mortality. Adding these effects to the decrease in air pollution mortality, the global impact of climate change may not be that substantial.

However, it does not mean that the impact in a life insurance company is encouraging, nor that its impact can be diminished. Remembering the life insurance survival products mentioned above, the long-term climate change effects will result in a not profitable outcome for the insurer, since the mortality will decrease, and the insured will end up living longer. This implies more payable obligations for the company.

Contrarily to this, for contracts paying benefits on death, the insurance company might benefit from the decrease in mortality, since the benefits might not be paid out, for instance, in term insurance. It is worth noting that this analysis cannot be entirely conclusive, since there is no public access to an insurance portfolio, but the methodology can be easily applied to the mortality tables used by life insurers to access the vulnerability to the risks.

Another point to highlight is the fact that even if an insurance company applies the methodology, the geographic exposure will not be accounted in the same effective way. It would be ideal applying the shocks according to the policyholder's locations, since their exposure to the risks, being temperature or air pollution, varies as close as near districts. The application of climate change shocks to a national life table may result in exposure loss, and the insurance company may not fully estimate the risks.

This work is easily transmutable to other national life tables. Both for temperature and air pollution the information used is available for other European countries. However, it is crucial to note that global and national climate change regulations and agreements are always being evaluated and revised, which will impact climate projections. Consequently, there is a need for continual adjustments to climate forecasts.

Even though (EIOPA, 2022) was developed in the scope of Solvency II, and this work acknowledged the analysis of the application guidance, a closer look on how the climate mortality risks can be introduced in the scope of this regime might be relevant, as the topic of climate change is increasingly gaining interest among insurance companies. For example, it could be useful to perform a series of stress tests for risk management purposes, including different climate scenarios, or even other emerging risks that can in some way be associated to the climate changes.

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Appendix

Idade	Mortality Rates	Survivers at age x	Deaths between ages x and x+1	Survivers between the ages x and x+1	Completed years after age x	Life expectation
(x)	(qx)	(lx)	(dx)	(Lx)	(Tx)	(ex)
0	0,002437	100 000	244	99 847	8 095 714	80,96
1	0,000140	99 756	14	99 749	7 995 867	80,15
2	0,000217	99 742	22	99 732	7 896 118	79,17
3	0,000143	99 721	14	99 714	7 796 386	78,18
4	0,000086	99 706	9	99 702	7 696 673	77,19
5	0,000074	99 698	7	99 694	7 596 970	76,20
6	0,000112	99 690	11	99 685	7 497 276	75,21
7	0,000090	99 679	9	99 675	7 397 591	74,21
8	0,000080	99 670	8	99 666	7 297 917	73,22
9	0,000064	99 662	6	99 659	7 198 250	72,23
10	0,000081	99 656	8	99 652	7 098 591	71,23
11	0,000060	99 648	6	99 645	6 998 939	70,24
12	0,000075	99 642	8	99 638	6 899 294	69,24
13	0,000129	99 634	13	99 628	6 799 656	68,25
14	0,000119	99 621	12	99 616	6 700 028	67,25
15	0,000164	99 610	16	99 601	6 600 413	66,26
16	0,000185	99 593	18	99 584	6 500 811	65,27
17	0,000189	99 575	19	99 565	6 401 227	64,29
18	0,000306	99 556	30	99 541	6 301 662	63,30
19	0,000333	99 526	33	99 509	6 202 121	62,32
20	0,000356	99 492	35	99 475	6 102 612	61,34
21	0,000316	99 457	31	99 441	6 003 137	60,36
22	0,000378	99 426	38	99 407	5 903 696	59,38
23	0,000349	99 388	35	99 371	5 804 289	58,40
24	0,000394	99 353	39	99 334	5 704 919	57,42
25	0,000297	99 314	30	99 299	5 605 585	56,44
26	0,000446	99 285	44	99 263	5 506 286	55,46
27	0,000486	99 240	48	99 216	5 407 023	54,48
28	0,000362	99 192	36	99 174	5 307 807	53,51
29	0,000426	99 156	42	99 135	5 208 633	52,53
30	0,000433	99 114	43	99 093	5 109 497	51,55
31	0,000660	99 071	65	99 038	5 010 405	50,57
32	0,000564	99 006	56	98 978	4 911 367	49,61
33	0,000650	98 950	64	98 918	4 812 389	48,63
34	0,000603	98 886	60	98 856	4 713 471	47,67
35	0,000634	98 826	63	98 795	4 614 615	46,69
36	0,000695	98 763	69	98 729	4 515 821	45,72
37	0,000753	98 695	74	98 658	4 417 092	44,76
38	0,000902	98 620	89	98 576	4 318 434	43,79
39	0,000969	98 532	95	98 484	4 219 858	42,83
40	0,000997	98 436	98	98 387	4 121 374	41,87
41	0,001058	98 338	104	98 286	4 022 987	40,91
42	0,001279	98 234	126	98 171	3 924 701	39,95

43	0,001266	98 108	124	98 046	3 826 530	39,00
44	0,001516	97 984	149	97 910	3 728 484	38,05
45	0,001666	97 835	163	97 754	3 630 574	37,11
46	0,001780	97 672	174	97 585	3 532 820	36,17
47	0,002075	97 499	202	97 397	3 435 235	35,23
48	0,002299	97 296	224	97 184	3 337 838	34,31
49	0,002793	97 073	271	96 937	3 240 653	33,38
50	0,002982	96 801	289	96 657	3 143 716	32,48
51	0,003102	96 513	299	96 363	3 047 059	31,57
52	0,003576	96 213	344	96 041	2 950 696	30,67
53	0,003994	95 869	383	95 678	2 854 655	29,78
54	0,004319	95 486	412	95 280	2 758 977	28,89
55	0,004732	95 074	450	94 849	2 663 697	28,02
56	0,005018	94 624	475	94 387	2 568 848	27,15
57	0,005436	94 149	512	93 893	2 474 461	26,28
58	0,005783	93 638	541	93 367	2 380 567	25,42
59	0,006513	93 096	606	92 793	2 287 201	24,57
60	0,006951	92 490	643	92 168	2 194 408	23,73
61	0,007579	91 847	696	91 499	2 102 239	22,89
62	0,008101	91 151	738	90 782	2 010 741	22,06
63	0,008872	90 412	802	90 011	1 919 959	21,24
64	0,009144	89 610	819	89 200	1 829 948	20,42
65	0,010049	88 791	892	88 345	1 740 747	19,61
66	0,010994	87 899	966	87 415	1 652 403	18,80
67	0,011745	86 932	1 021	86 422	1 564 987	18,00
68	0,012736	85 911	1 094	85 364	1 478 566	17,21
69	0,013570	84 817	1 151	84 242	1 393 202	16,43
70	0,014344	83 666	1 200	83 066	1 308 960	15,65
71	0,015537	82 466	1 281	81 825	1 225 894	14,87
72	0,018111	81 185	1 470	80 449	1 144 069	14,09
73	0,018752	79 714	1 495	78 967	1 063 619	13,34
74	0,021176	78 220	1 656	77 391	984 652	12,59
75	0,023978	76 563	1 836	75 645	907 261	11,85
76	0,026350	74 727	1 969	73 743	831 616	11,13
77	0,030882	72 758	2 247	71 635	757 873	10,42
78	0,035471	70 511	2 501	69 261	686 238	9,73
79	0,037858	68 010	2 575	66 723	616 977	9,07
80	0,043778	65 435	2 865	64 003	550 255	8,41
81	0,049679	62 571	3 108	61 017	486 252	7,77
82	0,056681	59 462	3 370	57 777	425 235	7,15
83	0,065968	56 092	3 700	54 242	367 458	6,55
84	0,077768	52 392	4 074	50 354	313 216	5,98
85	0,092759	48 317	4 482	46 076	262 862	5,44
86	0,108612	43 835	4 761	41 455	216 785	4,95
87	0,126603	39 074	4 947	36 601	175 330	4,49
88	0,146437	34 127	4 998	31 629	138 729	4,07
89	0,168433	29 130	4 906	26 677	107 101	3,68
90	0,194434	24 223	4 710	21 869	80 424	3,32
91	0,221071	19 514	4 314	17 357	58 555	3,00
92	0,250044	15 200	3 801	13 299	41 199	2,71

93	0,281336	11 399	3 207	9 796	27 899	2,45
94	0,314889	8 192	2 580	6 902	18 104	2,21
95	0,350601	5 613	1 968	4 629	11 201	2,00
96	0,388324	3 645	1 415	2 937	6 573	1,80
97	0,427857	2 229	954	1 752	3 636	1,63
98	0,468951	1 276	598	976	1 883	1,48
99	0,511306	677	346	504	907	1,34
100	0,554572	331	184	239	402	1,22

Table 11: Complete Portugal mortality table

		Mortality rate updated with temperature shock		Air Pollution Shock		Final Mortality rate		Variation Mortality rate	
(x)	**qx**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
0	0,002437	0,002435	0,002433	-0,000057	-0,000052	0,002378	0,002381	-0,024224	-0,022903
1	0,000140	0,000135	0,000133	-0,000003	-0,000003	0,000132	0,000130	-0,059323	-0,070691
2	0,000217	0,000215	0,000213	-0,000005	-0,000005	0,000210	0,000209	-0,031664	-0,038259
3	0,000143	0,000135	0,000133	-0,000003	-0,000003	0,000132	0,000130	-0,079215	-0,090308
4	0,000086	0,000085	0,000083	-0,000002	-0,000002	0,000083	0,000081	-0,036404	-0,056238
5	0,000074	0,000071	0,000071	-0,000002	-0,000002	0,000069	0,000070	-0,062681	-0,060597
6	0,000112	0,000111	0,000111	-0,000003	-0,000002	0,000109	0,000109	-0,030299	-0,028215
7	0,000090	0,000091	0,000091	-0,000002	-0,000002	0,000089	0,000089	-0,010372	-0,008289
8	0,000080	0,000081	0,000081	-0,000002	-0,000002	0,000079	0,000079	-0,009070	-0,006987
9	0,000064	0,000061	0,000062	-0,000001	-0,000001	0,000060	0,000061	-0,068975	-0,046069
10	0,000081	0,000081	0,000081	-0,000002	-0,000002	0,000079	0,000079	-0,021448	-0,019363
11	0,000060	0,000061	0,000061	-0,000001	-0,000001	0,000060	0,000060	-0,005212	-0,003127
12	0,000075	0,000081	0,000081	-0,000002	-0,000002	0,000079	0,000080	0,058850	0,060934
13	0,000129	0,000131	0,000131	-0,000003	-0,000003	0,000128	0,000129	-0,005057	-0,002973
14	0,000119	0,000121	0,000121	-0,000003	-0,000003	0,000119	0,000119	-0,003702	-0,001617
15	0,000164	0,000161	0,000161	-0,000004	-0,000003	0,000158	0,000158	-0,038510	-0,036425
16	0,000185	0,000182	0,000182	-0,000004	-0,000004	0,000177	0,000178	-0,041602	-0,039517
17	0,000189	0,000192	0,000192	-0,000004	-0,000004	0,000187	0,000188	-0,009068	-0,006984
18	0,000306	0,000302	0,000302	-0,000007	-0,000006	0,000295	0,000296	-0,035648	-0,033563
19	0,000333	0,000332	0,000332	-0,000008	-0,000007	0,000325	0,000325	-0,024932	-0,022847
20	0,000356	0,000353	0,000353	-0,000008	-0,000008	0,000344	0,000345	-0,032654	-0,030569
21	0,000316	0,000313	0,000313	-0,000007	-0,000007	0,000305	0,000306	-0,034139	-0,032054
22	0,000378	0,000383	0,000383	-0,000009	-0,000008	0,000374	0,000375	-0,009865	-0,007780
23	0,000349	0,000353	0,000353	-0,000008	-0,000007	0,000345	0,000346	-0,011725	-0,009641
24	0,000394	0,000393	0,000393	-0,000009	-0,000008	0,000384	0,000385	-0,024756	-0,022671
25	0,000297	0,000303	0,000303	-0,000007	-0,000006	0,000296	0,000297	-0,003246	-0,001161
26	0,000446	0,000444	0,000444	-0,000010	-0,000009	0,000434	0,000435	-0,027644	-0,025559
27	0,000486	0,000485	0,000485	-0,000011	-0,000010	0,000473	0,000474	-0,026247	-0,024163
28	0,000362	0,000364	0,000364	-0,000008	-0,000008	0,000355	0,000356	-0,018271	-0,016186
29	0,000426	0,000424	0,000424	-0,000010	-0,000009	0,000415	0,000415	-0,026901	-0,024816
30	0,000433	0,000435	0,000435	-0,000010	-0,000009	0,000425	0,000426	-0,019291	-0,017206
31	0,000660	0,000657	0,000657	-0,000015	-0,000014	0,000642	0,000643	-0,027851	-0,025766
32	0,000564	0,000566	0,000566	-0,000013	-0,000012	0,000553	0,000555	-0,018830	-0,016745
33	0,000650	0,000648	0,000648	-0,000015	-0,000014	0,000633	0,000634	-0,026847	-0,024762
34	0,000603	0,000608	0,000608	-0,000014	-0,000013	0,000594	0,000595	-0,015569	-0,013485

35	0,000634	0,000638	0,000638	-0,000015	-0,000013	0,000624	0,000625	-0,016378	-0,014293
36	0,000695	0,000700	0,000700	-0,000016	-0,000015	0,000683	0,000685	-0,016752	-0,014668
37	0,000753	0,000751	0,000751	-0,000018	-0,000016	0,000733	0,000735	-0,026348	-0,024264
38	0,000902	0,000903	0,000903	-0,000021	-0,000019	0,000882	0,000884	-0,021777	-0,019692
39	0,000969	0,000965	0,000965	-0,000023	-0,000020	0,000943	0,000945	-0,027337	-0,025252
40	0,000997	0,000996	0,000996	-0,000023	-0,000021	0,000973	0,000975	-0,023803	-0,021719
41	0,001058	0,001058	0,001058	-0,000025	-0,000022	0,001034	0,001036	-0,022819	-0,020734
42	0,001279	0,001284	0,001284	-0,000030	-0,000027	0,001254	0,001256	-0,019707	-0,017622
43	0,001266	0,001265	0,001265	-0,000029	-0,000027	0,001235	0,001238	-0,024201	-0,022116
44	0,001516	0,001522	0,001522	-0,000035	-0,000032	0,001486	0,001489	-0,019595	-0,017510
45	0,001666	0,001667	0,001667	-0,000039	-0,000035	0,001628	0,001632	-0,022675	-0,020591
46	0,001780	0,001782	0,001782	-0,000041	-0,000038	0,001741	0,001745	-0,021922	-0,019838
47	0,002075	0,002073	0,002073	-0,000048	-0,000044	0,002024	0,002029	-0,024343	-0,022259
48	0,002299	0,002303	0,002303	-0,000053	-0,000049	0,002250	0,002254	-0,021444	-0,019360
49	0,002793	0,002793	0,002793	-0,000065	-0,000059	0,002728	0,002734	-0,023377	-0,021292
50	0,002982	0,002986	0,002986	-0,000069	-0,000063	0,002917	0,002923	-0,021769	-0,019685
51	0,003102	0,003099	0,003099	-0,000072	-0,000066	0,003027	0,003033	-0,024225	-0,022140
52	0,003576	0,003576	0,003576	-0,000083	-0,000076	0,003493	0,003501	-0,023159	-0,021075
53	0,003994	0,003996	0,003996	-0,000093	-0,000084	0,003903	0,003911	-0,022757	-0,020673
54	0,004319	0,004316	0,004316	-0,000100	-0,000091	0,004215	0,004224	-0,024011	-0,021927
55	0,004732	0,004734	0,004734	-0,000110	-0,000100	0,004624	0,004634	-0,022804	-0,020720
56	0,005018	0,005021	0,005021	-0,000117	-0,000106	0,004904	0,004915	-0,022685	-0,020601
57	0,005436	0,005439	0,005439	-0,000126	-0,000115	0,005313	0,005324	-0,022667	-0,020583
58	0,005783	0,005779	0,005779	-0,000134	-0,000122	0,005644	0,005656	-0,024006	-0,021922
59	0,006513	0,006510	0,006510	-0,000151	-0,000138	0,006359	0,006373	-0,023645	-0,021561
60	0,006951	0,006953	0,006953	-0,000162	-0,000147	0,006792	0,006806	-0,022942	-0,020858
61	0,007579	0,007579	0,007579	-0,000176	-0,000160	0,007403	0,007418	-0,023266	-0,021182
62	0,008101	0,008098	0,008097	-0,000188	-0,000171	0,007909	0,007926	-0,023678	-0,021594
63	0,008872	0,008871	0,008871	-0,000206	-0,000188	0,008665	0,008684	-0,023305	-0,021221
64	0,009144	0,009141	0,009142	-0,000213	-0,000193	0,008928	0,008949	-0,023618	-0,021372
65	0,010049	0,010034	0,010054	-0,000234	-0,000213	0,009801	0,009842	-0,024704	-0,020626
66	0,010994	0,010978	0,010998	-0,000256	-0,000233	0,010722	0,010766	-0,024708	-0,020762
67	0,011745	0,011732	0,011753	-0,000273	-0,000248	0,011459	0,011505	-0,024316	-0,020448
68	0,012736	0,012721	0,012743	-0,000296	-0,000269	0,012425	0,012473	-0,024392	-0,020620
69	0,013570	0,013557	0,013579	-0,000315	-0,000287	0,013242	0,013292	-0,024181	-0,020467
70	0,014344	0,014329	0,014352	-0,000333	-0,000303	0,013996	0,014049	-0,024273	-0,020600
71	0,015537	0,015520	0,015543	-0,000361	-0,000329	0,015159	0,015215	-0,024358	-0,020756
72	0,018111	0,018092	0,018117	-0,000421	-0,000383	0,017671	0,017734	-0,024286	-0,020839
73	0,018752	0,018739	0,018765	-0,000436	-0,000397	0,018303	0,018368	-0,023934	-0,020481
74	0,021176	0,021155	0,021182	-0,000492	-0,000448	0,020663	0,020734	-0,024238	-0,020875
75	0,023978	0,023963	0,023991	-0,000557	-0,000507	0,023405	0,023484	-0,023878	-0,020593
76	0,026350	0,026331	0,026361	-0,000613	-0,000557	0,025718	0,025804	-0,023980	-0,020731
77	0,030882	0,030863	0,030896	-0,000718	-0,000653	0,030145	0,030243	-0,023866	-0,020698
78	0,035471	0,035447	0,035484	-0,000825	-0,000750	0,034623	0,034733	-0,023917	-0,020795
79	0,037858	0,037838	0,037877	-0,000880	-0,000801	0,036958	0,037077	-0,023782	-0,020642
80	0,043778	0,043756	0,043801	-0,001018	-0,000926	0,042739	0,042875	-0,023739	-0,020628
81	0,049679	0,049641	0,049692	-0,001155	-0,001051	0,048486	0,048641	-0,024008	-0,020899
82	0,056681	0,056639	0,056697	-0,001318	-0,001199	0,055321	0,055498	-0,023989	-0,020872
83	0,065968	0,065921	0,065989	-0,001534	-0,001396	0,064387	0,064594	-0,023966	-0,020834

84	0,077768	0,077708	0,077792	-0,001808	-0,001645	0,075900	0,076146	-0,024014	-0,020853
85	0,092759	0,092696	0,092800	-0,002156	-0,001962	0,090540	0,090837	-0,023927	-0,020716
86	0,108612	0,108528	0,108659	-0,002525	-0,002298	0,106003	0,106361	-0,024025	-0,020722
87	0,126603	0,126497	0,126667	-0,002943	-0,002678	0,123554	0,123989	-0,024086	-0,020650
88	0,146437	0,146309	0,146534	-0,003404	-0,003098	0,142904	0,143436	-0,024123	-0,020496
89	0,168433	0,168228	0,168532	-0,003916	-0,003563	0,164313	0,164969	-0,024463	-0,020566
90	0,194434	0,194171	0,194596	-0,004520	-0,004113	0,189651	0,190483	-0,024600	-0,020323
91	0,221071	0,220695	0,221302	-0,005139	-0,004677	0,215555	0,216625	-0,024949	-0,020111
92	0,250044	0,249510	0,250405	-0,005813	-0,005290	0,243697	0,245116	-0,025383	-0,019710
93	0,281336	0,280493	0,281860	-0,006540	-0,005952	0,273953	0,275909	-0,026243	-0,019291
94	0,314889	0,313599	0,315769	-0,007321	-0,006662	0,306278	0,309108	-0,027346	-0,018359
95	0,350601	0,348455	0,352056	-0,008151	-0,007417	0,340304	0,344639	-0,029369	-0,017006
96	0,388324	0,384453	0,390722	-0,009028	-0,008215	0,375425	0,382507	-0,033216	-0,014979
97	0,427857	0,420939	0,432468	-0,009947	-0,009051	0,410992	0,423417	-0,039416	-0,010378
98	0,468951	0,455370	0,477876	-0,010902	-0,009921	0,444468	0,467956	-0,052207	-0,002123
99	0,511306	0,483153	0,530036	-0,011887	-0,010817	0,471267	0,519219	-0,078308	0,015476
100	0,554572	0,495800	0,600885	-0,012893	-0,011732	0,482907	0,589153	-0,129225	0,062356

Table 12: Mortality rates results, separated by risk