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Actuarial Perspectives on *World Population Prospects 2019*

Population Issues Working Group

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Actuarial Perspectives on *World Population Prospects 2019*

by the IAA Population Issues Working Group

Acknowledgements

"Actuarial Perspectives on *World Population Prospects 2019*" was prepared by the Population Issues Working Group (PIWG) of the International Actuarial Association (IAA).

The IAA is the worldwide association of professional actuarial associations, with several special interest sections and working groups for individual actuaries. The IAA exists to encourage the development of a global profession, acknowledged as technically competent and professionally reliable, which will contribute to the public interest being served.

The role of the PIWG is to identify and discuss population issues that are of interest to share with actuaries worldwide and to which the actuarial profession, at an individual, national, or supranational level, can make useful contributions in the public interest.

The paper was primarily an effort of a subgroup of the PIWG led by Chris Daykin, with Dermot Grenham and Sam Gutterman. Comments were incorporated from other members of the PIWG. It was approved by the PIWG and the Scientific Committee of the IAA for publication and reviewed for presentational aspects by the IAA Communications Subcommittee.

The views expressed in this paper do not represent those of the IAA, nor those of the entire PIWG. They do not constitute an actuarial standard of practice.

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All results of WPP2019 and all graphs in this paper, with the exception of Figures 5 and 17, are drawn by the authors from the data published online in WPP2019, for which the citation is:

United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019, Online Edition. Rev. 1*.

The citation is not repeated under each graph.

Executive Summary

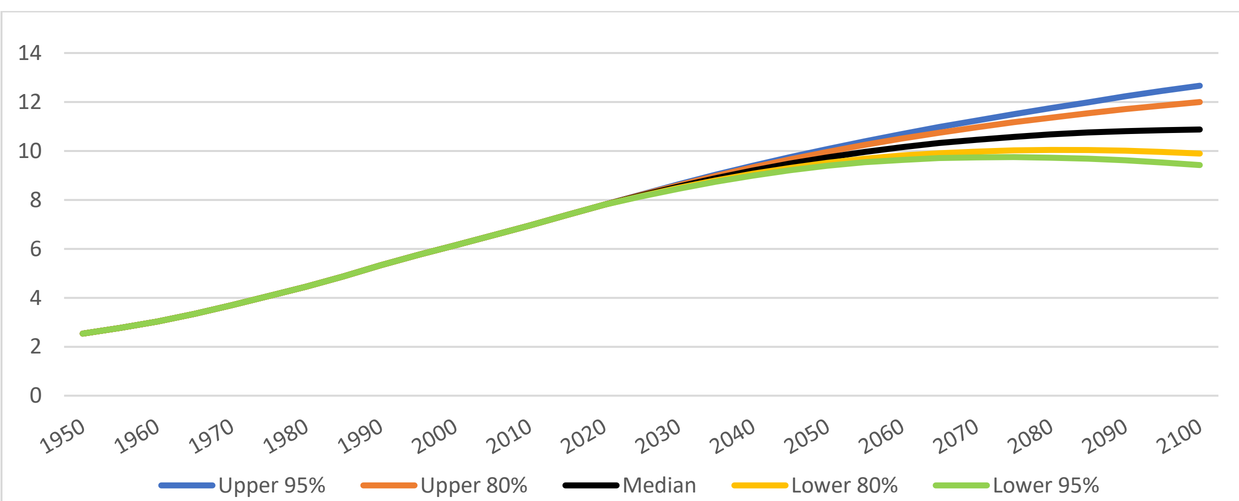
This paper provides an overall actuarial perspective on the future evolution of the world's population, in particular, the United Nations' (UN) *World Population Prospects 2019* (WPP2019). WPP2019 presents the latest revision of population projections for the world and for individual countries, groups of countries and regions, summarizing estimates for 1950 to 2019 and projections from 2020 to 2100.

The aims of the paper are to:

1. inform actuaries around the world about the possible evolution of the world's population and its implications for the future demographic landscape in terms of overall population size, births, deaths and international migration, as well as the age structure of the population;
2. draw attention to the wider implications of population growth if the assumptions made by the UN Population Division in WPP2019 are borne out in practice, and to present observations regarding the uncertainty in making projections for so many years into the future;
3. offer informed commentary on the assumptions underlying the projections, and identify some areas of particularly great uncertainty; and
4. summarize some of the key features of the results of WPP2019 in a way which will interest and inform actuaries, as well as a wider audience of organizations with which the IAA interacts.

At a global level the median total population is projected by the UN Population Division to grow from 7.8 billion in 2020 to 10.9 billion in 2100, with a 95% confidence interval of 9.4 billion to 12.7 billion. Whilst the median projection represents 39.5% growth over 80 years from 2020 to 2100, the growth in the world population over the 70 years since 1950 up to the present has seen a three-fold increase, so the pace of growth is projected to be greatly reduced for the future.

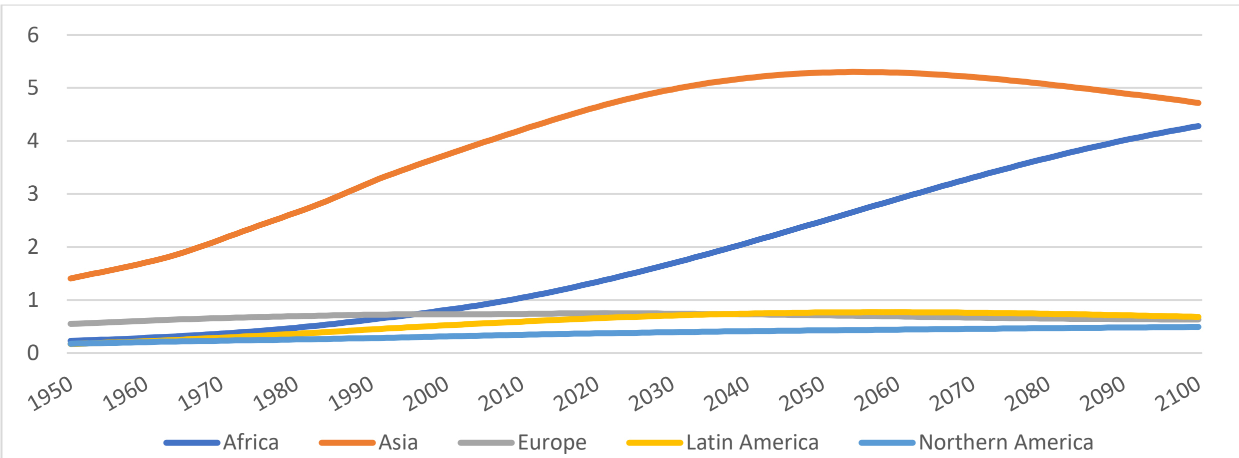
Figure A. World population in billions from 1950 to 2100 with probabilistic variants for future growth



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

The median population projection implies significant changes in the balance of the world's population between regions. The population of Africa has grown from 9.0% to 17.2% of world population between 1950 and 2020 and is projected to grow to 39.4% in 2100. The population of Asia, which at 59.5% is by far the largest continent in population size in 2020 (having grown from 55.4% in 1950), is projected to rise only modestly in numbers from 4.6 billion in 2020 to a peak of around 5.3 billion in 2055 before falling back to 4.7 billion in 2100, which would by then only be 43.4% of world population.

Figure B. World population by region in billions from 1950 to 2100. Median projection



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

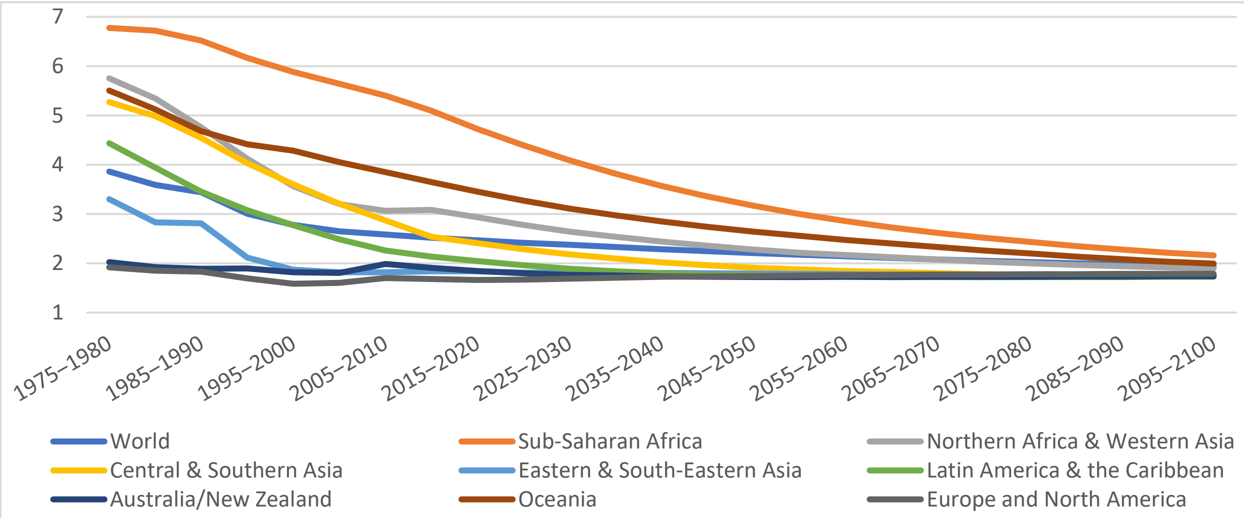
Fertility

Projecting future overall fertility has often been considered to be the area of greatest uncertainty in long-range population projections, but now it is generally accepted that fertility will converge to low levels over the projection period.[1] Even countries with a total fertility rate (TFR, the average number of children born to females across all age groups in a given calendar year) currently in excess of four children for each woman are projected to experience steady declines, with the highest TFRs in 2100 being around 2.5 and the majority of countries having TFRs of between 1.7 and 1.9. This is a major contributing factor in the reduction in growth of total projected population worldwide. However, Africa appears to be an exception. The UN Population Division projects that the total number of births in Africa will continue to grow throughout the projection period, from 11.5 million a year in 1950–55 to 45.0 million a year in 2020–25 and 62.9 million a year in 2095–2100.

Figure C shows the TFRs since 1975–80 and the projected rates to 2095–2100 by UN Sustainable Development Goal (SDG) region, as well as for the world as a whole. This points to substantial falls in fertility, especially for those regions which 40 years ago had very high fertility. The projections of total numbers in the population are critically dependent on these fertility assumptions, since without sustained falls in fertility population would grow considerably more than is projected.

[1] See, for example, European Commission Joint Research Centre (2018) and Vollset, Goren, Yuan et al. (2020).

Figure C. TFRs by SDG region from 1975–80 to 2095–2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

Mortality

There is some consensus that mortality is likely to continue to improve in all countries, with the main question relating to the rate of improvement. As a consequence, expectation of life at birth is increasing, accelerated by the impact of rapidly falling infant and child mortality in regions which have still been experiencing high mortality at these ages. At the global level, expectation of life at birth for males grew from 45.5 years to 69.9 years from 1950–55 to 2015–20 and is projected to grow by a further ten years to 79.8 in 2095–2100. Expectation of life at birth for females grew from 48.5 in 1950–55 to 74.7 in 2015–20 and is projected to grow to 83.7 in 2095–2100.

More directly relevant to public policy and pension and health care financing issues is the expectation of life at retirement age. At the global level, expectation of life at age 70 for females increased from 9.5 in 1950–55 to 14.7 in 2015–20 and is projected to grow to 18.5 in 2095–2100. Expectation of life at age 70 for males increased from 8.2 in 1950–55 to 12.4 in 2015–20 and is projected to grow to 16.7 in 2095–2100. This means an increase of a year roughly every 20 years.

Migration

Projecting international migration is highly speculative, as future migration trends are uncertain and will depend on politics, conflicts, social and economic conditions and human behaviour. The world has seen some fairly large movements of migrants in recent years, fleeing from wars, persecution, famine or economic problems. It is impossible to foretell what the corresponding events of the next 80 years might be. The WPP2019 projections assume some reversal of the international migration of recent years, while in many other cases the projections assume continuation of past trends for the whole period of the projections. Chapter 4 considers the issues around assuming continuing trends in international migration.

Population structure

The projections imply that there will be significant changes in population structure over the next 80 years. A key issue of interest to actuaries is the expected development of the old-age dependency ratio (OADR) or its inverse, the support ratio. The OADR, which is defined as the ratio of the population over retirement age to the population of those of working age, is expected to increase steadily in all countries and regions. Substantial increases in the elderly population are projected, particularly at ages over 80 and even over 90. By 2100 five countries are projected to have more than 20% of their population aged 80 and over, and many others will be close to this. The number of centenarians worldwide is projected to grow from 573,000 in 2020 to 19.1 million in 2100, having been only 34,000 in 1950.

Wider implications

The WPP2019 projections should be viewed in the context of some major issues facing the world in the coming years. Actions taken to meet the UN's SDGs should consider the expected changes in the population of those countries which require significant efforts to achieve these goals. Capitalizing effectively on the anticipated 'demographic dividend', resulting from growth of the population of working age, could help, but the benefits of this will not be automatic – they require countries to be politically, socially and financially ready to take advantage of the dividend and to ensure that resulting additional economic growth is widely shared across the population. Other global challenges which may be exacerbated by population growth include resource exhaustion, climate change and structural inequality.

Other projections

An alternative set of projections for the global population and that of constituent countries has been published by the European Commission Joint Research Centre (in collaboration with the International Institute for Applied Systems Analysis – Wittgenstein Centre) (European Commission JRC 2018). Also, a recent paper in *The Lancet* online by authors from the Institute for Health Metrics and Evaluation (IHME) in Washington, USA (Vollset et al. 2020) provides detailed projections for 195 countries and territories from 2017 to 2100. Both of these sets of projections inform future assumptions on the basis of drivers of fertility, migration and mortality. The Wittgenstein Centre global projections have been used extensively by the International Panel on Climate Change.

The conclusions of both of these projections are that fertility may be significantly lower in the future than projected by WPP2019 for countries which already have a low level of fertility, and may fall faster than projected by the UN Population Division for the current high-fertility countries in Africa. They also project a reduction in international migration flows reflecting economic development. As a result, these projections for global population in 2100 are substantially lower than the results of WPP2019. Vollset et al. project the global population to rise to a peak of 9.7 billion in 2064, thereafter falling to 8.8 billion (with a confidence interval 6.8 to 11.8 billion) in 2100. This compares to the WPP projection that global population will continue to grow, reaching 10.9 billion in 2100, with a 95% confidence interval of 9.4 billion to 12.7 billion. The substantial differences between these projections and the WPP2019 projections serve to illustrate the considerable uncertainty which surrounds long-term projections, and offer a warning that actuaries should use the results of any particular set of projections with caution and judgement.

Limitations

This paper provides only a high-level review of projections at a global level and for the main regions. We have not addressed individual countries other than to draw attention to some unusual situations. Actuaries and actuarial associations are encouraged to analyze the WPP2019 projections in more detail in respect of their own countries and regions, and to compare the projections with national population projections and with other sets of global projections such as those mentioned in the previous paragraphs. This will enable actuaries to engage with the results of projections as they affect individual countries, regions and sub-regions.

Recommendations

The availability of a comprehensive set of population projections and underlying assumptions for all countries is of significant value to actuaries, who should however be aware of the uncertainty of such projections and the substantial different results obtained by alternative projections. When developing population projections for applications in individual countries, modification of some of the key assumptions might be considered. These potential modifications include:

- The possibility that fertility of countries currently with below-replacement-level fertility may remain low for the foreseeable future and will not see a reversion towards replacement-level fertility over the long term as projected by WPP2019.
- Alternative scenarios for fertility decline in high-fertility African countries, allowing for a variety of possible faster or slower rates of decline. There would be ways of making the fertility variants more reflective of these possible realistic outcomes, rather than just adding or subtracting 0.5 from the TFR in all years from 2030–35, as was done in the WPP2019 projections.
- Mortality projections should not be based solely on female expectation of life at birth and gender differences in life expectancy. Also, in our view the WPP2019 projections do not give sufficient emphasis to consideration of mortality at older ages.
- Continued mortality improvement for 80 years into the future may not be realistic, and the possibility that recent declines in rates of improvement in a number of countries could be an indicator that the rate of improvement may be levelling off should be considered.
- Migration continuing at current elevated levels for 80 years is a strong assumption. We suggest that migration should be projected to fall off over time, at least as a variant projection.

Glossary

A glossary of some relevant technical terms is provided in Appendix 3.

1. Introduction

1.1 World Population Prospects 2019 (WPP2019) represents the culmination of an enormous amount of work by the Population Division of the Department of Economic and Social Affairs of the UN (UN Population Division). The estimates and projections cover a period of 150 years, from 1950 to 2100, for 235 separate countries. In addition, results are given for 50 groups of countries into areas, regions[2], sub-regions and other groups. A full set of detailed results is provided for 201 countries with 90,000 or more inhabitants. For the remaining 34 smaller countries, only total population and growth rates are published.

1.2 The quality of available information differs by country. For past estimates, regular censuses of the population are important milestones against which population movements can be bench-marked. About 80% of countries had census or registration information dating from 2010 or later. However, for 39 countries the most recent available data were from the period 2000–2009, and nine countries did not have any census information later than 1997, with the most recent census in one country being from 1932. Where full detailed census information is not available, more reliance has to be placed on surveys and other administrative data.

1.3 For fertility, the best source of data is a comprehensive system of registration of births with national coverage. Where this is not available, sample surveys can serve as a basis for estimates. Similarly, comprehensive registration of deaths is best when available, but full information on adult mortality is not available for all countries and is not always recent. Of the 201 countries with more than 90,000 people, 137 had adult mortality data collected in 2015 or later. Where complete information was not available, the UN Population Division made use of a wide range of demographic tools to estimate the missing information from which to prepare a reasonably consistent set of estimates for all countries.

1.4 Statistics on international migration are even more elusive, as many countries do not maintain comprehensive and accurate estimates of international migration flows by age and gender. Reliable emigrant information is especially difficult to obtain. Additional data were provided by the Office of the UN High Commissioner for Refugees (UNHCR) on refugee and asylum-seeker stocks and flows (although illegal migration may not be reflected in these data). The UN Population Division also estimates stocks of foreign-born persons by countries.

1.5 Details of the methodology adopted for producing the estimates and the projections for future years are set out in World Population Prospects 2019: Methodology of the United Nations Population Estimates and Projections[3]. The 2019 revision is based on information from:

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[2] Eight groups of countries classified by the UN as Sustainable Development Goal (SDG) regions: Australia and New Zealand; Central and Southern Asia; Eastern and South-Eastern Asia; Europe and Northern America; Latin America and the Caribbean; Northern Africa and Western Asia; Oceania; and Sub-Saharan Africa.

[3] See https://population.un.org/wpp/Methodology/ and https://population.un.org/wpp/Publications/Files/WPP2019_Methodology.pdf

- 1,690 population and housing censuses for 235 countries or areas, including 236 censuses conducted since 2010;
- vital registration of births and deaths from 163 countries or areas;
- 2,700 surveys, including demographic and health surveys, conducted in 235 countries or areas, among which 540 were administered in 2010 or later;
- official statistics reported to the UN Demographic Yearbook; and
- population registers and other administrative sources of international migration statistics.

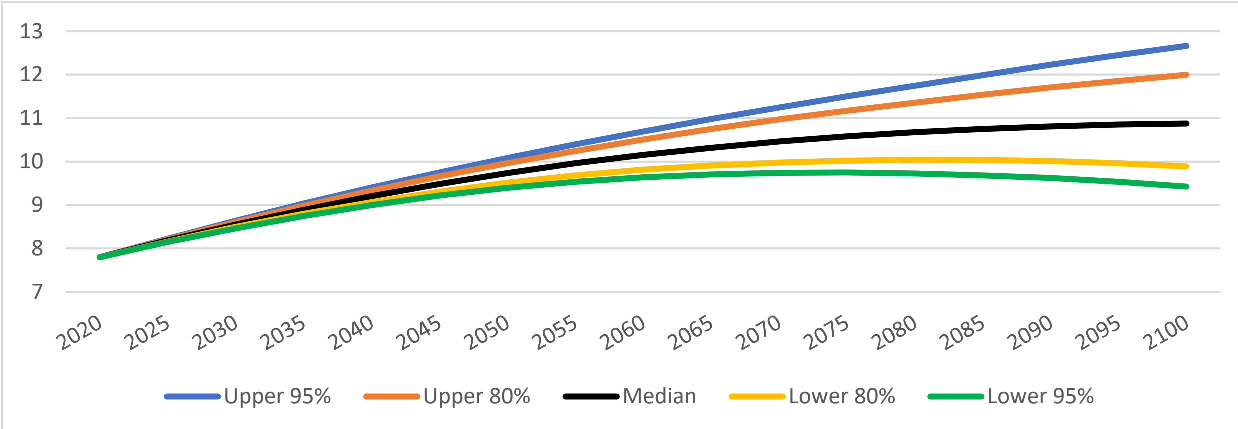
Several other sources of information are also cited.

1.6 In short, the UN Population Division has invested an enormous amount of effort into compiling a set of estimates for past years, going back to 1950, which are consistent within each country and as far as practical between countries. From that perspective alone, WPP2019 provides an invaluable source of information and estimates about the development of population numbers and other population characteristics over 70 years to the present time. For many countries with limited national statistical capabilities, this provides an outstanding resource for planning and resource allocation.

1.7 The main objective of the exercise is to generate projections of the future development of the population, both for individual countries and for areas, regions and groupings of countries. These involve further assumptions and models as to how fertility, mortality and international migration may develop in the future. Population projections are carried out using a standard component methodology, whereby the estimates of population by age and gender at one mid-year point for a country are moved forward twelve months by adding births generated by the fertility model, subtracting deaths generated by the mortality model and adjusting for estimated net international migration into (or out of) the country.

1.8 Projections are prepared using a probabilistic model for both fertility and mortality, based on 100,000 simulations from 2020 to 2100 using a projected trajectory of TFRs and a projected trajectory of life expectancy in the country sampled from the estimated distributions of these quantities. The principal projected statistics are the median of the distribution of probabilistic outcomes and 80% and 95% prediction intervals (confidence levels) on either side of the median. Figure 1 shows the overall projections from 2020 to 2100 for the total world population with these prediction intervals.

Figure 1. World population in billions from 2020 to 2100 with probabilistic variants

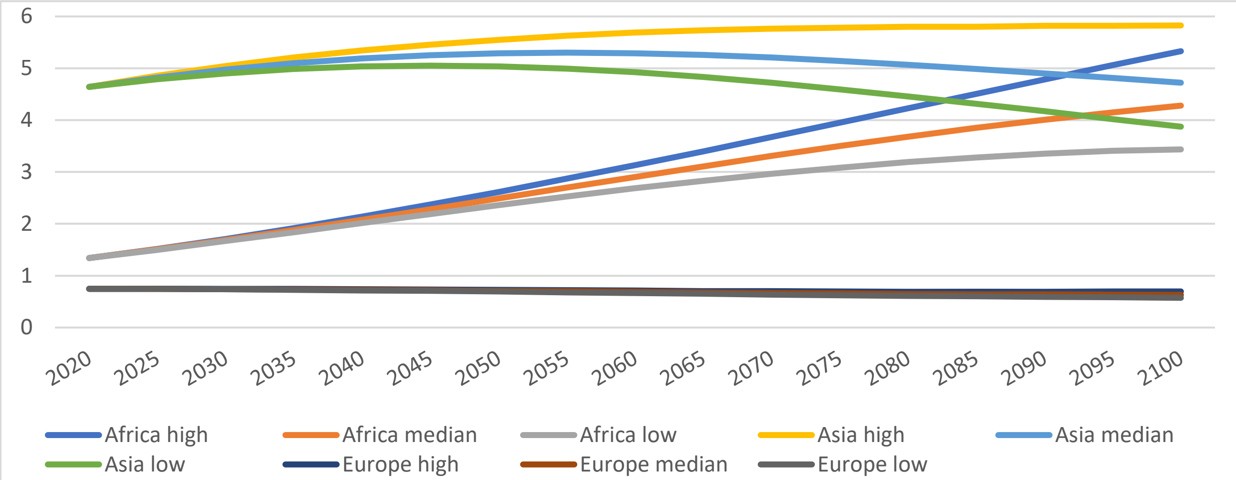


Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

1.9 These are projections of the population based on a set of assumptions, rather than being forecasts or predictions. The projections show what would happen if all the assumptions are fulfilled, covering initial population structure, future fertility, mortality and international migration, with independent assumptions for each.

1.10 Most of the uncertainty in the global projections relates to the projections for Africa and Asia, which also account for most of the population growth. Although each of the UN SDG regions is projected to grow over the period from 2019 to 2050, 52% of the global growth is accounted for by Sub-Saharan Africa, 25% by Central and Southern Asia and 12% by Northern Africa and Western Asia, leaving only 11% for the other five regions. Europe, Northern America (Canada and the United States), Eastern Asia and South-Eastern Asia are only projected to increase by 2.9% over this period. Figure 2 shows the median projections for Africa, Asia and Europe, with what the UN Population Division describes as corresponding 95% prediction intervals. Latin American and the Caribbean and Northern America are almost identical to Europe on this scale. For both Africa and Asia, the 95% and 5% points on the distribution of outcomes are respectively about 1 billion above and below the median projection by 2100. For the other regions the range is only 0.1 billion above and below the median.

Figure 2. Population by continent in billions from 2020 to 2100 with probabilistic variants

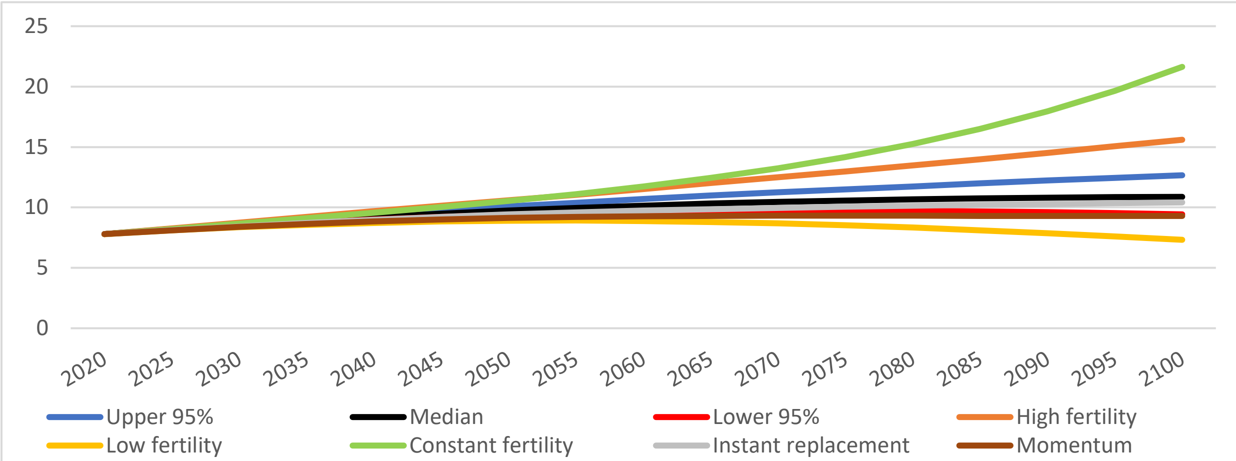


Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

1.11. In addition to the probabilistic variants referred to above, another eight variant projections were prepared for WPP2019. Four of these are fertility variants: (1) low fertility (total fertility 0.5 births per woman below total fertility in the median (also described as medium) projection); (2) high fertility (total fertility 0.5 births per woman above total fertility in the median projection); (3) constant fertility (with total fertility remaining at the 2015–20 level); and (4) instant-replacement fertility (total fertility for each country is set to ensure a net reproduction rate of 1.0 starting in 2020–25). The other four variants are: (5) constant mortality (at the 2015–20 level); (6) zero international migration (from 2020–25); (7) no change in assumptions (with fertility at the 2010–15 level and mortality at the 2015–20 level); and (8) the so-called 'Momentum' variant (with instant switch to replacement fertility, mortality held constant at the 2015–20 level and international migration at zero from 2020–25). In principle this makes it possible to explore separately the impact of the alternative assumptions for fertility, mortality and international migration.

1.12 The alternative fertility projections produce a much wider spread of potential outcomes than the range of probabilistic projections illustrated above. Figure 3 shows the impact on the global projection from 2019 to 2100 of including variants 1, 2, 3, 4 and 8, in addition to the 95% prediction intervals and the median projection. Keeping fertility unchanged at current levels would lead to a total population of 21.6 billion in 2100, almost twice the projected median level. The high-fertility projection would lead to a population of 15.6 billion in 2100, some 3 billion more than the Upper 95% projection from the probabilistic model. At the other extreme, the low-fertility projection would lead to a population of only 7.3 billion in 2100, about two-thirds of the median projection. These variants indicate how sensitive the results towards the end of the projection period are to changes in the assumptions, especially with respect to fertility, with projections so far into the future.

Figure 3. World population in billions with deterministic as well as probabilistic variants



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

1.13 An idea of the relative impact of the alternative assumptions can be obtained from looking at differences in the impact on the projected population of different variants. The difference between the Zero Migration variant and the Medium Fertility projection provides an estimate of the impact of future international migration, since these two projections have the same underlying assumptions for fertility and mortality. The difference is not exactly zero at the world level, since the future international migration also affects subsequent births and deaths, but in Table 1 the rounded figure for the global impact of international migration is zero and the differences balance out between sending regions and receiving regions.

1.14 The difference between the Constant Mortality projection and the Medium Fertility projection provides an estimate of the impact of assumed future mortality improvement, since Constant Mortality holds the mortality assumption at the 2015–20 level, whereas the Medium Fertility projection incorporates the normal mortality assumptions for the future. At the world level, about 18% of the projected population in 2100 on the Medium Fertility projection results from the assumed improvement of mortality over the 80 years from 2020 to 2100. In contrast, this proportion is 22% for Africa and only 12% and 10% for Europe and Northern America, respectively. Table 1 indicates the prominent role in the projections for Africa and Asia that variations in the fertility assumption plays. Without the assumed reduction in fertility, the population of Africa would be projected to grow by 10.4 billion between 2020 and 2100, but 8.4 billion of that growth is eliminated by assumed falling fertility.

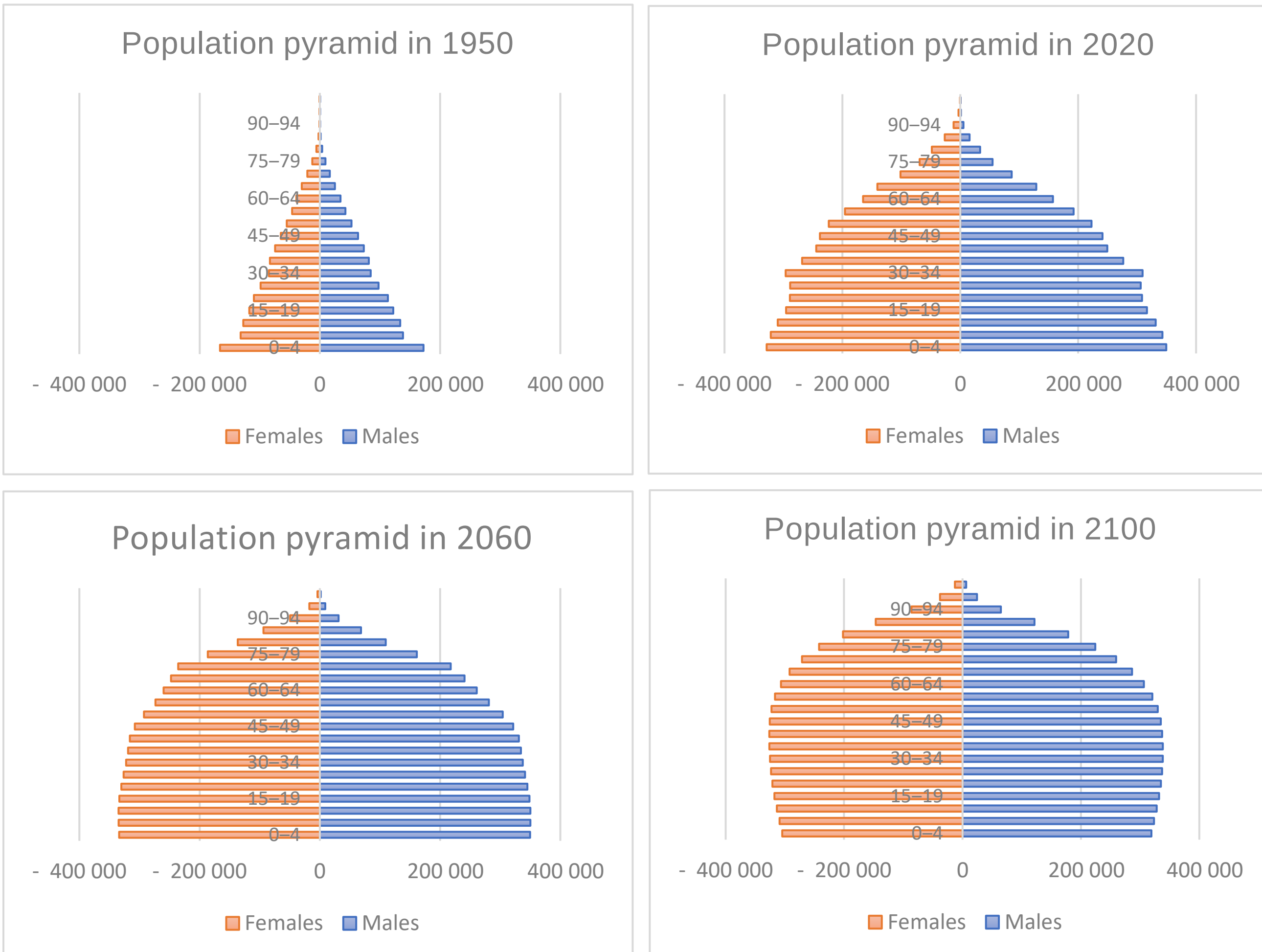
Table 1. Growth in population from 2020 to 2100 (billions)

Increases in population included in Medium Projection					
	Medium projection	**International migration**	**Mortality improvement**	**Fertility reduction**	**Projection without these changes**
World	3.1	0.0	2.0	-10.8	11.9
Africa	2.9	-0.1	1.0	-8.4	10.4
Asia	0.1	-0.2	0.8	-2.1	1.6
Europe	-0.1	0.1	0.1	0.0	-0.3
Latin America	0.0	0.0	0.1	-0.2	0.2
North America	0.1	0.2	0.0	0.0	-0.1

1.15 The difference between the Constant Fertility projection and the Medium Fertility projection provides an estimate of the impact of assumed reduction in fertility from the 2015–20 levels, since the future mortality and international migration assumptions are the same for these two projections. The impact of this is significant, especially for Africa and to a lesser extent for Asia. The world population projected for 2100 is 50% lower with the Medium Fertility projection than with the Constant Fertility projection. For Africa it is 66% lower, for Asia 31% lower and for Latin America and the Caribbean 25% lower. For Europe and Northern America, on the other hand, it is 6% higher and 2% higher, respectively, since the Medium Fertility projection assumes a rise in fertility in the future from recent levels.

1.16 Whilst many will focus on the headline figures of world population growth, we believe the real value of the WPP2019 projections is the insight that they give into projected changes in the population in individual countries and groups of countries, and in particular the implications for changing age structure, which we consider in more detail in Chapter 5. An easy way to appreciate the massive changes that have taken place, and are projected to take place, is to compare the population pyramids at different times. These show the population in each five-year age group, with females to the left of the vertical axis and males to the right. In 1950 the largest age group by far was 0–4, with 13.3% of the total population, and 43.7% of the population was aged less than 20. In 2020 the 0–4 age group accounted for only 8.7% of the total population, and by then 33.3% were aged less than 20. Only 5.1% of the population was aged 65 and over in 1950, whereas by 2020 this was 9.3%. By 2100 there are only projected to be 5.7% in the 0–4 age group, and 23.4% of the population aged less than 20. Further, the population aged 65 and over is projected to have risen to 22.6% of the total, with 8.1% of the total population aged 80 and over.

Figure 4. World population from 1950 to 2100 shown as population pyramids



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

1.17 Over time, the shape of the 'pyramid' changes dramatically, from a fairly regular pyramid on a broad base to an onion-dome with close to 6% of the total population in each five-year age group from 10–14 up to 55–59, and a substantial proportion aged 65 and over.

1.18 In particular, the projections of population size and growth for Africa are noteworthy. In 2020 only four of the 20 largest countries in the world by total population are in Africa, and eleven are in Asia[4]. By 2100 the projections suggest that ten of the largest 20 countries in the world will be in Africa, and six in Asia.

[4] Treating Turkey as Asia and the Russian Federation as Europe.

Table 2. Largest countries in the world by total population in 2020 and 2100 (in millions)

Increases in population included in Medium Projection				
Country	**Population in 2020**	**Country**	**Population in 2100**	**Increase[5] (millions) (%)**
1 China	1,439	1 India	1,447	+67 (+5%)
2 India	1,380	2 China	1,065	-374 (-26%)
3 United States	331	3 Nigeria	733	+527 (+256%)
4 Indonesia	274	4 United States	434	+103 (+31%)
5 Pakistan	221	5 Pakistan	403	+182 (+82%)
6 Brazil	213	6 Dem Rep. of Congo	362	+272 (+304%)
7 Nigeria	206	7 Indonesia	321	+47 (+17%)
8 Bangladesh	165	8 Ethiopia	294	+179 (+156%)
9 Russian Federation	146	9 United Republic of Tanzania	286	+226 (+378%)
10 Mexico	129	10 Egypt	225	+122 (+120%)
11 Japan	126	11 Angola	188	+155 (+473%)
12 Ethiopia	115	12 Brazil	181	-32 (-15%)
13 Philippines	110	13 Niger	165	+141 (+581%)
14 Egypt	102	14 Bangladesh	151	-13 (-8%)
15 Vietnam	97	15 Philippines	146	+37 (+34%)
16 Dem. Rep. of Congo	90	16 Sudan	142	+98 (+225%)
17 Turkey	84	17 Mexico	142	+13 (+10%)
18 Iran	84	18 Uganda	137	+91 (+199%)

[5] Increase in population from 2020 to 2100 for the country listed for 2100.

19 Germany	84	19 Russian Federation	126	-20 (-14%)
20 Thailand	70	20 Kenya	125	+72 (+133%)
21 United Kingdom	68	21 Mozambique	124	+92 (+296%)
22 France	65	22 Iraq	108	+67 (+168%)
23 Italy	60	23 Madagascar	100	+72 (+261%)

1.19 Niger is projected to grow to 6.8 times its current population, averaging 2.4% a year growth over the whole period, and in the first 40 years to 2060 averaging 3.2% a year growth. Angola is projected to grow to 5.7 times its current population, United Republic of Tanzania 4.8 times, Congo 4.0 times and Nigeria, Sudan and Uganda three times or more. This raises issues about the ability of some of these countries to support this growth economically, and in terms of sustainable development. Very modest growth is projected for India, but the population of China is projected to fall to about three-quarters of its current level, so that India will become the largest country by population size. In addition to the four countries in Table 2 which are projected to have population decreases (China, Brazil, the Russian Federation and Bangladesh), some 90 other countries are projected to experience a reduction in size between now and 2100.

1.20 Focusing on the fastest-growing countries, Table 3 sets out the top ten countries for projected percentage growth over 40 years and over 80 years. All of these are in Africa.

Table 3. Countries projected to grow most over the next 80 years on Medium Projection

Fastest-growing from 2020 to 2060		Fastest-growing from 2020 to 2100	
Country	**Percentage Increase**	**Country**	**Percentage Increase**
Niger	250.0	Niger	581.4
Angola	196.2	Angola	472.9
Somalia	171.4	United Republic of Tanzania	378.2
United Republic of Tanzania	166.0	Somalia	376.4
Dem. Rep. of Congo	161.4	Zambia	343.6
Mali	158.9	Burundi	328.1
Zambia	158.3	Dem. Rep. of Congo	304.2
Burundi	158.2	Burkina Faso	298.0
Mozambique	150.7	Mali	296.9
Burkina Faso	149.5	Mozambique	295.6

1.21 Table 4 sets out the ten countries projected to fall in population to the greatest extent over the next 40 years to 2060 and over the next 80 years to 2100, according to the Medium Projection. In some cases, this is affected by projected high levels of international migration, but even under the Nil Migration projection most of these countries would see significant falls in population; for example, 39.4% for Serbia, 38.9% for Bulgaria and 31.6% for Albania through 2100. The falling population in these countries is the result of past population movements and/or low fertility, resulting in a population which has a natural tendency to decline. Improvements in mortality offset this somewhat, but projected falls in fertility and net emigration exacerbate the situation, leading to significant population loss over time.

Table 4. Countries projected to reduce most in population over the next 80 years

Reducing most from 2020 to 2060		Reducing most from 2020 to 2100	
Country	**Percentage Fall**	**Country**	**Percentage Fall**
Bulgaria	-29.1	Albania	-62.2
Lithuania	-27.7	US Virgin Islands	-61.2
Latvia	-26.6	Puerto Rico	-57.5
US Virgin Islands	-25.9	Serbia	-51.7
Ukraine	-25.9	Republic of Moldova	-50.1
Serbia	-25.8	Bosnia and Herzegovina	-50.0
Bosnia and Herzegovina	-25.7	Bulgaria	-48.4
Croatia	-24.6	Croatia	-46.8
Republic of Moldova	-24.2	Ukraine	-44.2
Puerto Rico	-23.9	Lithuania	-44.0

1.22 The population of Europe as a whole is projected to fall by 15.8% between 2020 and 2100 in the Medium Projection. If we strip out international migration to Europe by looking at the Zero Migration projection (often referred to as 'natural increase'), then the population of Europe as a whole is projected to decrease by 28.5%. On the same basis, the population of Northern America is expected to fall by 11.1%. All European countries except the Faroe Islands are expected to lose population by natural increase (deaths exceeding births) between 2020 and 2100, with just 15 countries projected to experience an overall increase in population once international migration is taken into account, seven of these being small countries with populations of under 1 million[6]. Table 5 shows the largest falls due to 'natural increase' in Europe and in the rest of the world.

[6] Belgium, Channel Islands, Denmark, Faroe Islands, France, Iceland, Ireland, Isle of Man, Liechtenstein, Luxembourg, Monaco, Norway, Sweden, Switzerland and the United Kingdom.

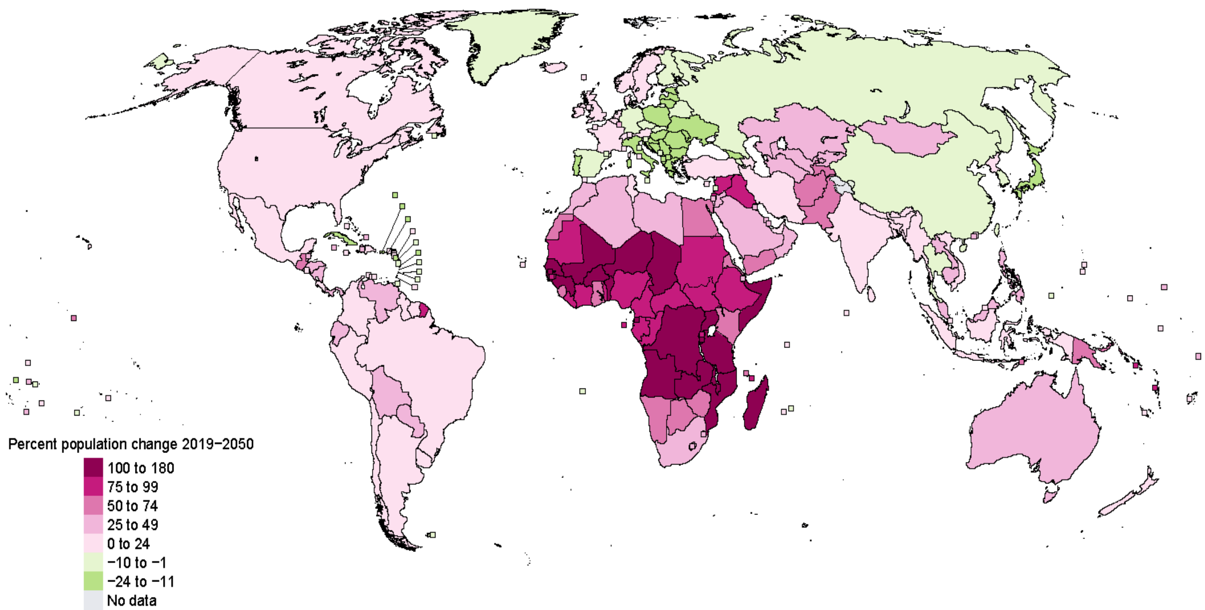
Table 5. Largest falls in population due to natural increase from 2020 to 2100

Europe		Rest of the World	
Country	**Percentage Fall**	**Country**	**Percentage Fall**
Andorra	-49.4	Puerto Rico	-49.4
Bosnia and Herzegovina	-48.4	Singapore	-49.2
Italy	-46.6	Republic of Korea	-48.0
Republic of Moldova	-46.5	Japan	-45.3
Greece	-46.2	Qatar	-44.9
San Marino	-45.4	United Arab Emirates	-42.6
Ukraine	-44.3	Chinese Taipei	-42.3
Portugal	-42.0	Bermuda	-40.7
Croatia	-41.4	Montserrat	-38.3
Serbia	-39.4	Thailand	-36.8

1.23 It is noteworthy that the countries generally with falling population by natural increase are in the High Income (-21.5%) and Upper Middle Income (-8.3%) categories, whereas the highest population growth is in Low Income countries (+227.8%). International migration only reduces the latter figure slightly (to 220.3%) and slightly increases overall projected population (+3.2%) in High Income countries.

1.24 Figure 5, taken from the Data Booklet publication accompanying WPP2019, illustrates graphically the parts of the population in the world expected to grow strongly (shades of pink) and those where the population is expected to decrease (shades of green) between 2019 and 2050.

Figure 5. Changes in total population between 2019 and 2050, Medium Projection



Source: United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Data Booklet (ST/ESA/SER.A/424), page 3.

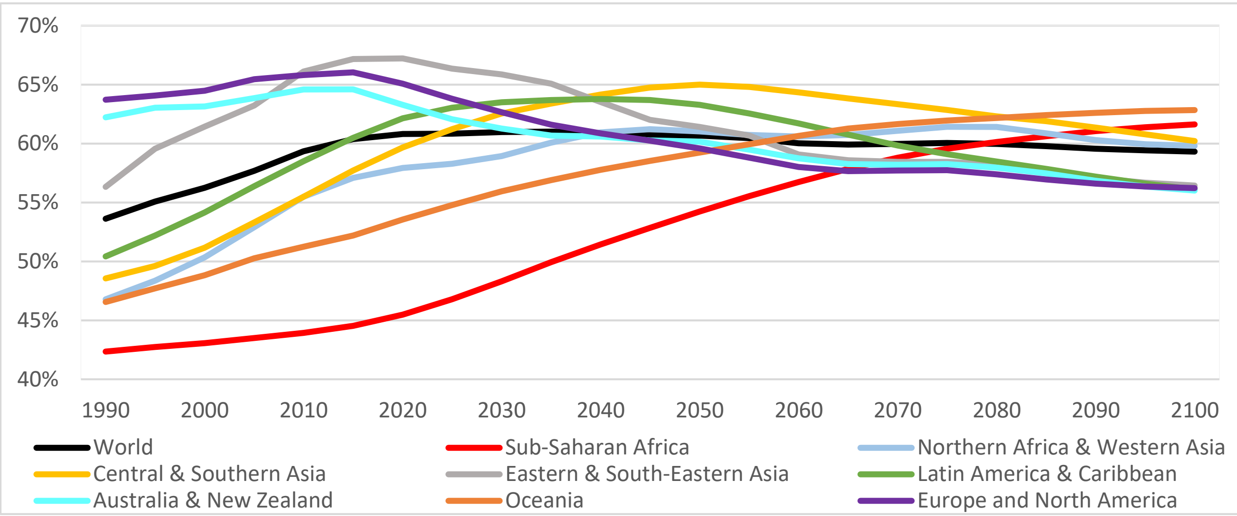
1.25 Projecting the population for any individual country over a period of 80 years is challenging. The future pattern of international migration is particularly uncertain, especially where recent experience has been quite different from longer-term trends, affected by wars, famines, pandemics, changes in economic conditions and religious or other forms of persecution. It is unrealistic to assume that such conditions will stay the same over long periods, but it may not be clear what else might happen, or when a change of fortunes will occur. Countries experiencing high recent immigration might expect migration to moderate because of possible domestic political responses to such movements forcing a change in policy. However, although international migration can lead to falling population, most countries have other demographic or economic factors also contributing to this trend.

1.26 WPP2019 refers to the 'demographic dividend'[7] resulting from an increasing percentage of the population being at working ages in many of the Low Income countries. The countries in the World Bank category of Low Income currently have 52.1% of the population in the under-20 age group and 45.9% between 20 and 70. This compares to 22.2% and 64.7% respectively for High Income countries, 33.2% and 62.0% for Middle Income countries and 38.6% and 57.9% for Lower Middle Income countries. The population of Sub-Saharan Africa aged 20–69 is projected on the Medium Projection to rise from 498 million in 2020 to 2.3 billion in 2100, an increase of 367%. The economic cost of looking after the elderly will remain low, as the population over 70 will only be about 9% of the total in 2100, rising from less than 2% currently. In

[7] 'Demographic dividend' is defined as "the economic growth potential that can result from shifts in a population's age structure, mainly when the share of the working-age population is larger than the non-working-age share of the population".

contrast, the population aged 20–69 in Europe is projected to fall by 28% from 2020 to 2100, while the population aged 70 and over is projected to rise from 13.4% of the total in 2020 to almost 25% in 2100.

Figure 6. Share of the total population at working ages (20–69) from 1990 to 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

1.27 Figure 6 demonstrates the basis for the demographic dividend hypothesis by plotting the population of working ages (taken as 20–69) as a proportion of total population from 1990 to 2100 by region. At the global level, this proportion levels off around 2010. However, for Sub-Saharan Africa and Oceania the proportion continues to grow strongly until near the end of the 21st century. Central and Southern Asia also shows an increase in the short term but levelling off around 2050. Northern Africa and Western Asia and Latin America and the Caribbean show a slower growth for only a few years.

1.28 Consideration of whether or not countries are positioned to take advantage of this demographic dividend is beyond the scope of this paper.

1.29 The assumption of significant decreases in total fertility (for example from 4.4 in 2020–25 to 2.2 in 2095–2100 in Sub-Saharan Africa) will require considerable change in cultures which have a history of high fertility, although total fertility for this region has already fallen from 6.5 in 1950–55 to 4.7 in 2015–20. Further consideration will be given in the next chapter to the projections of fertility.

1.30 It is worth noting that a significant proportion of the population growth for Sub-Saharan Africa up to 2050 is already inherent in the current demographic structure. This can be seen by examining the Momentum Projection, which assumes zero international migration, mortality unchanged at the 2015–20 level and fertility dropping immediately to the replacement rate from 2020–25. For Sub-Saharan Africa, the Medium Projection is for 93.5% growth between 2020 and 2050, while growth under the Momentum Projection only decreases to 39.6%, so almost half of the projected growth over that period is already built into the current population structure.

1.31 The WPP2019 projections are an internally consistent set of projections for all the countries of the world. For those countries which have their own sophisticated demographic analysis of accurate registration of births and deaths and which regularly project their future population, it is inevitable that there will be differences, sometimes quite material, between national projections and the WPP2019 projections. Quantifying these differences systematically would be a major undertaking. However, a high-level comparison can be made with the projections prepared by Eurostat for all the countries in the European Union (EU) (not including the United Kingdom) for the period 2019–80 (ESSPOP2019) as background to the European Commission's forthcoming Ageing Report 2021[8].

Table 6. Comparison of projected population for EU on WPP2019 and ESSPOP2019 (millions)

	2020	2040	2060	2080
WPP2019	445.3	434.5	407.3	379.9
ESSPOP2019	448.7	446.8	432.5	419.2
Difference	-3.4 (-0.8%)	-12.3 (-2.8%)	-25.2 (-5.8%)	-39.3 (-9.4%)

At the individual country level, the WPP2019 projections differ by more than 10% from the ESSPOP2019 projections for 11 out of 27 countries by 2080. In the case of Spain, the WPP2019 projection for 2080 is 23% lower than the ESSPOP2019 projection, with the UN Population Division projections showing a 23.6% reduction from 2020 and the Eurostat projections showing a 0.6% reduction. These differences reflect significant differences in assumptions, in particular with regard to migration.

1.32 The WPP2019 projections have been prepared for 235 separate countries. Inevitably, this will result in some fairly broad-brush assumptions being made, whereas the national statistical offices of individual countries would be expected to be able to take a more nuanced and informed approach to interpreting trends and individual characteristics which may affect the future development of the population. The differences between alternative projection results identified in the previous paragraph emphasize the uncertainty about making projections of the population 80 years into the future, whether at individual country level or for regions or the world.

1.33 It is important, therefore, not to consider any single set of projections as being a forecast. It is not possible to forecast the future level of the population or the details of the age structure with precision, even for a few years ahead and still less for 80 years. It is only possible to model such future outcomes using what appear to be plausible assumptions. Some of these are very uncertain, in particular the future development of fertility and the level of international migration. There is also considerable uncertainty regarding how rapidly mortality will continue to improve and how advances in medicine and control of diseases will be shared across regions and countries. There may also be surprise events, such as the Covid-19 pandemic which is sweeping the world at the time this paper is being written and which, for now at least, has an uncertain outcome in terms of whether it will have a material impact on deaths, international migration and births in particular countries and at the global level, either in this year or for future years. Other pandemics are likely to emerge in future, for which no allowance has been made in the projections. In addition, wars, famine, shortage of resources, climate change and

8 See Meeting the Challenge of Ageing in the EU, published by the Actuarial Association of Europe in March 2019 for an assessment of The Ageing Report 2018.

economic inequality may give rise to unforeseen international migration flows and to considerable perturbation to the trends in fertility and mortality in individual countries.

1.34 The Covid-19 pandemic will have many impacts on population: (1) an increase in deaths, at least in the short term, with, at the time this paper is being written, more than 1 million associated deaths, (2) a probable decrease in births in the next year and possibly several years after the pandemic is over and (3) reduced international migration, as countries put constraints on immigration during the period of the pandemic. However, as indicated, it is difficult to project the effect of such disease events.

1.35 For many countries the WPP2019 projections of the population are the only ones widely available with this level of detail. Actuaries preparing reports on financial assessment of social security plans may therefore be forced to rely on these projections. However, in doing so actuaries should be aware of the particular circumstances of a country and the uncertainties of the projections for long periods into the future. They should also consider the appropriateness of the assumptions made by the UN Population Division in developing these projections and should draw attention to the range of possible future outcomes, which can be illustrated with the variant projections.

1.36 Global population projections have also been published by the International Institute for Applied Systems Analysis – Wittgenstein Centre (European Commission Joint Research Centre 2018) and by the IHME (Vollset et al. 2020). These incorporate much lower fertility assumptions than WPP2019 for those countries which already have sub-replacement-level fertility, as well as a faster fall in fertility for current high-fertility countries. As a result, they project much lower global population than WPP2019. The IHME paper projects a global total of 8.8 billion in 2100 instead of 10.9 billion, and the ten largest countries are slightly different and with generally lower projected populations. A table showing some key assumptions giving rise to differences between the projections for 2100 is provided in Appendix 4. The major differences between these two plausible sets of projections serve to emphasize how uncertain the future is and underline the caution which is needed by actuaries in using any particular set of projections.

Table 7. Comparison of projected population for largest countries in 2100 (millions)

Country	IHME projection for 2100	WPP2019 projection for 2100
India	1,093	1,447 (1st)
Nigeria	791	733 (3rd)
China	732	1,065 (2nd)
United States	336	434 (4th)
Pakistan	248	403 (5th)
Dem. Rep. of Congo	246	362 (6th)
Indonesia	229	321 (7th)
Ethiopia	223	294 (8th)
Egypt	199	225 (10th)
United Republic of Tanzania	186	286 (9th)

1.37 In the next three chapters we will examine in more detail the fertility, mortality and international migration aspects of the WPP2019 projections, before returning to some more general considerations about the forecast changes to the population and the expected impact on considerations such as age groups and dependency ratios.

2. Fertility Projections

2.1 In order to project future births, the WPP2019 requires assumptions for fertility rates, commonly summarized in terms of TFRs[9] and distribution by age, for each country up to 2100. A decreasing trend in TFRs has occurred over the past several decades in almost all countries, sometimes at a breath-taking pace.

2.2 The UN Population Division assumed that there are three phases to fertility in any country:

1. High-fertility/pre-transition period. During this period, the TFR is greater than 5.5 per female. Those in phase 1 often had a high percentage of their population in rural areas. WPP2019 indicated that there are no countries currently in phase 1.
2. Transition period between phase 1 and phase 3.
3. Low-fertility/post-transition period. During this period, the TFR is usually below the long-term replacement rate of about 2.1. The number of countries in phase 3 in WPP2012 was 25, while in WPP2019 it is 40.

2.3 The methodology followed by the UN Population Division was (1) to project the TFR of each country and (2) to distribute that rate by mothers' ages. In general, national TFRs not in phase 3 by 2015–20 were projected ultimately to converge to 2.1.

2.4 For countries already in phase 3 by 2015–20, the long-term projections reflect each country's historical experience (where data is available). In addition, for countries with sub-replacement fertility levels, recovery towards replacement-level fertility is assumed, informed by the experience of a subgroup of countries that have already experienced such recovery. The unweighted mean value for the global distribution based on the 40 countries or areas that have entered phase 3 is 1.78 children per woman in 2095–2100.

2.5 Some countries with fertility below replacement level have experienced recent downward trends in total fertility after a period of sustained increase. To ensure a smooth transition between the last estimation periods and the first projection intervals, the level of fertility projected for 2020–25 and 2025–30 was adjusted by blending the most recent observed trend with the unadjusted model prediction respectively, by weights of two-thirds in 2020–25 and one-third in 2025–30 given to the most recent country trend, and the complement used for the model prediction. Such post-adjustment was applied to five countries: Finland, Italy, Japan, Luxembourg and Ukraine.

2.6 Table 8 shows the UN Population Division's estimates of historical TFRs and forecasts for the future by region and countries aggregated by average income. This table illustrates the rapid decrease in TFR for most regions. It indicates that the Medium variant suggests that natural replacement level will be reached in about 2080. African fertility is expected to remain higher than that of other continents, although it too reaches natural replacement level by the end of the century. These results are shown graphically in Figure C in the Executive Summary. The divergence in projections prepared by various demographers is caused primarily by differences in assumptions regarding the speed at which fertility, especially in Sub-Saharan Africa, decreases over

[9] An alternative measure is the 'cohort fertility rate' or 'completed family size', which is defined as the average number of children born to a woman over her lifetime, for women born in a given year.

the next several decades and whether fertility will rise towards replacement level in countries currently with very low fertility.

Table 8. TFR by SDG region and by average income level. Historical estimates and Medium variant projections

	1975-1980	1995-2000	2015-2020	2035-2040	2055-2060	2075-2080	2095-2100
World	3.86	2.78	2.47	2.29	2.14	2.03	1.94
Sub-Saharan Africa	6.78	5.88	4.72	3.57	2.85	2.43	2.16
Northern Africa and Western Asia	5.75	3.57	2.93	2.44	2.17	2.00	1.89
Central and Southern Asia	5.27	3.60	2.41	2.02	1.85	1.77	1.75
Eastern and Southeastern Asia	3.3	1.87	1.83	1.80	1.78	1.77	1.76
Latin America and the Caribbean	4.44	2.77	2.04	1.80	1.73	1.72	1.73
Australia/New Zealand	2.02	1.82	1.84	1.74	1.72	1.73	1.74
Europe and Northern America	1.92	1.58	1.66	1.69	1.74	1.76	1.77
Low income	6.61	5.93	4.52	3.15	2.69	2.32	2.08
Lower middle income	5.23	3.62	2.71	2.29	2.16	2.04	1.95
Upper middle income	3.41	1.96	1.90	1.81	1.80	1.78	1.78
High income	2.06	1.78	1.67	1.71	1.74	1.76	1.77

2.7 There are a large number of social and demographic changes and trends which will have contributed to this near-universal decrease, consideration of which is beyond the scope of this paper. Many of these appear likely to be irreversible in the absence of a significant change in cultural attitudes. Governmental incentives or mandates are unlikely to alter these trends, other than possibly for short periods.

2.8 A uniform approach is applied by WPP2019 across a wide range of countries. We would suggest that, for those in phase 3, a more nuanced approach would be to take into account the different characteristics of individual countries. One could argue, for example, that some countries with currently very low fertility are quite unlikely to gradually revert towards the replacement rate in the way projected. However, the changes that are projected for phase 3 countries are relatively modest in terms of the overall effect on the projected population, albeit projections made for individual countries might adopt quite different assumptions. More significant for the big picture are the very large reductions in fertility which are projected for many African countries. It is assumed that for these countries fertility will fall well below replacement level towards the end of the projection period. The highest levels of fertility currently are in West Africa, with an assumption that the TFR will fall from 5 or more in 2020–25 to nearly replacement level by 2095–2100. Some might regard this assumption as quite aggressive and it would be instructive to see, for Africa in particular, a more explicit analysis of the impact of a much slower fall in fertility. Clearly the probabilistic projections incorporate a wide range of possibilities, but the high- and low-fertility variants look only at TFR of 0.5 higher or lower for the whole period of the projection from 2030 onwards[10], which is a modest range of variation in the context of some of the assumed falls in fertility that are projected.

2.9 It would be instructive to have a fertility variant reflecting 50%, say, of the changes in fertility projected for the median projection. This would give a significantly less steep trajectory for falling fertility in high-fertility countries and would moderate the assumed increase in fertility in the low-fertility countries, whilst maintaining the overall integrity of the assumptions.

2.10 On the other hand, some might argue that the speed of decline in fertility in the Medium Projection may even be exceeded. As a result, it is possible that decreases in fertility rates in Africa and those in lower-income countries in general may be even more rapid than in the Medium Projection. This could be reflected in a fertility variant with, say, 110% of the changes in fertility projected for the Medium Projection. This would give a smoother transition to a lower-fertility scenario for African and other high-fertility countries than the abrupt drop in fertility in the current Low Fertility projection, combined with a somewhat faster rise in fertility than the Medium Projection for current low-fertility countries.

2.11 The fertility assumptions adopted by Vollset et al. (2020) assume that countries with sub-replacement fertility levels remain at levels of fertility similar to today instead of rising towards replacement level. However, for Africa they assume that fertility will fall even further by 2100 than the WPP2019 projections, to a TFR of 1.73 in 2100 for Sub-Saharan Africa. In their alternative projection, entitled 'The UN Sustainable

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[10] The High Fertility projection assumes a TFR 0.25 higher than the Medium Fertility projection in 2020–25, 0.40 higher in 2025–30 and 0.50 higher from 2030–35 onwards. The Low Fertility projection is the mirror image of this with a TFR 0.25 lower than the Medium Fertility projection in 2020–25, 0.40 lower in 2025–30 and 0.50 lower from 2030–35 onwards.

Development Goals pace alternate scenario', they assume a rate of change which would allow all locations to meet the SDG targets for educational attainment (universal secondary education by 2030) and contraceptive 'met need' (universal coverage by 2030), and the resulting TFR in 2100 for Sub-Saharan Africa is 1.52. These lower-fertility assumptions drive a much lower population-growth outcome than the WPP2019 projections. A comparison of the TFR assumptions for 2100 in the WPP2019 projections and the IHME projections is given in Appendix 4 in respect of a selection of countries.

2.12 We have already noted that population projections undertaken by national statistical institutes may adopt quite different assumptions to those in WPP2019. An example which underlines the different possible approaches to future fertility assumptions is that of Japan. Here the national projections[11] project a TFR of 1.45 in 2065, which compares with 1.60 in WPP2019 (in 2060–65) and 1.38 (in 2050) from Vollset et al. (2020). The national projections do not foresee the rise in fertility rates towards replacement level which underpins the WPP2019 assumptions.

2.13 Beginning from the most recent observation of the age pattern of fertility (2015–20), the projected age patterns were based on past national trends, combined with a trend towards a global model age pattern (seven quinquennial age groups from 15–19 to 45–49) of fertility. The final projection for each age group is a weighted average of two preliminary projections, with assumptions:

1. the rates converge to the global model pattern; and
2. the observed national trend in age rates continues indefinitely.

The method was applied to each of the age pattern trajectories of the TFR of each country, based on the estimated age patterns for 1950–2020. In examining the resultant mean age at childbearing, it was found that the mean values, rather than the median values, of generated age group rates produced a smoother trend line for most countries.

2.14 Whilst this procedure may not be unreasonable, it does reflect an assumption that age patterns of childbearing will tend towards some global norm. In practice, cultural and societal differences between regions and countries are likely to continue to result in different structures of family-building, even with a global trend towards lower overall TFR.

2.15 Table 9 shows the resulting age distribution for three groupings of countries: the world, high-income countries and low-income countries. Although the pattern towards an older average age at birth appears clear from world totals, looking at high- and low-income country patterns indicates different rates of change and different patterns. High-income country patterns are expected to be relatively stable in the future, while experience in low-income countries shows a distinctly younger age distribution over the rest of this century. The mothers' age distribution in low-income countries is projected to be more slowly convergent than TFRs, as shown above in Table 8.

11 See www.ipss.go.jp/pp-zenkoku/e/zenkoku_e2017/pp_zenkoku2017e_gaiyou.html

Table 9. Percentage distribution of births by mothers' age group for the world and high and low-income-level countries. Historical estimates and Medium variant projections

Age Group	15-19	20-24	25-29	30-34	35-39	40-44	45-49
World							
1975-1980	9.2	26.6	27.5	18.9	11.3	5.1	1.4
1995-2000	10.7	29.9	27.7	18.6	9.3	3.7	1.0
2015-2020	8.6	27.3	28.6	20.3	10.8	3.6	0.8
2035-2040	7.5	23.7	29.0	22.7	12.2	4.2	0.7
2055-2060	6.6	21.2	28.7	24.4	13.7	4.6	0.7
2075-2080	5.4	18.8	28.5	26.7	15.6	4.4	0.6
2095-2100	4.2	16.2	27.8	29.2	17.8	4.3	0.5
High Income							
1975-1980	8.9	30.5	34.6	17.3	6.6	1.9	0.3
1995-2000	7.8	21.9	32.3	25.2	10.4	2.1	0.2
2015-2020	4.5	15.5	27.3	30.8	17.5	4.0	0.4
2035-2040	2.7	10.4	24.8	33.8	22.2	5.6	0.5
2055-2060	2.2	9.8	24.2	34.4	22.8	6.1	0.5
2075-2080	2.0	9.6	24.4	34.8	22.8	6.0	0.5
2095-2100	1.7	9.4	24.6	35.1	22.7	5.9	0.5
Low Income							
1975-1980	10.3	21.3	22.5	19.4	14.7	8.5	3.3
1995-2000	10.8	21.8	22.9	19.5	14.3	8.1	2.7
2015-2020	10.7	23.0	24.4	19.8	13.7	6.5	1.9
2035-2040	10.3	23.5	26.5	19.7	13.0	5.5	1.4

2055-2060	9.2	22.8	28.1	20.4	13.3	5.0	1.2
2075-2080	7.6	21.3	29.4	22.2	14.0	4.6	0.9
2095-2100	5.7	19.0	30.2	24.90	15.2	4.3	0.6

2.16 The three major components of population change are inter-related. One important relationship is the effect on fertility in many countries from immigration. Often the fertility of first-generation immigrants is greater than those of native-born women (especially when the immigrants come from a higher-fertility country). In some cases, this difference wears off in the second and later generations. Table 10[12] shows the impact of migration on fertility in several European countries, the United States and Australia.

Table 10. Indicators of the contribution of foreign-born women to fertility in selected European countries, the United States and Australia, 2015 (all values are in %)

	Excess fertility of foreign to native women	Share of foreign women at reproductive ages	Net effect of foreign women on TFR	(Adjusted) share of births to foreign mothers[2]	Percent of births to foreign women which is neutral on TFR
	a	b	c[1]	d	e[3]
Denmark	-5	17	-2	20	-
Australia	-3	31	-1	34	-
Netherlands	2	17	0.3	20	98
Norway	14	21	3	28	91
Finland	17	10	1	12	90
Spain	19	19	3	24	95
United Kingdom	20	20	4	26	85
Sweden	21	22	3	28	88

[12] www.niussp.org/article/the-impact-of-migration-on-the-fertility-of-receiving-countries-limpact-de-la-migration-sur-la-fecondite-des-pays-daccueil/

Greece	24	17	3	20	91
Switzerland	29	36	8	46	86
United States	36	19	6	23	74
Austria	38	24	8	33	77
Italy	41	16	5	23	82
Belgium	42	22	9	31	73
France	73	13	10	22	60

(a) = (TFRf/TFRn) – 1, where f = foreigners and n = natives

(b) = Wf/WT, where W = women of reproductive age, 15-49, f = foreigners and T = Total

(c) = (TFRT – TFRn) / TFRn

(d) = Total effect / TFRT = [Σx ((Wxf / WxT)*ASFRxf)] / [Σx (BxT/WxT)] = [Σx(Bxf/WxT)/Σx(BxT/WxT)]
≈ Σx (Bxf/BxT) ≈ Bf/BT , where ASFR = Age specific fertility rate and B = births

(e) = [Σx(Wxf / Wxn * Bxn)] / Bf

1. Column (c) is not the exact product of column (a) and column (b), because of the combination of excess fertility and population shares of migrants across single ages.
2. It is very close to the share of births to foreign women.
3. As a percentage of the total number of births to foreign-born women.

Source: Bagavos (2019)

2.17 Uncertainty associated with the size of the future population of the world is driven primarily by uncertainty about the projected number of births. This uncertainty is the reason why projections using six variants of fertility were calculated by the UN. They are:

1. Medium;
2. Low – a TFR of 0.5 less than the Medium Projection from 2030–35;
3. High – a TFR of 0.5 greater than the Medium Projection from 2030–35;
4. Constant – the same TFR as the 2015–20 level;
5. Instant Replacement – a TFR that exactly offsets the number of deaths in a country with births; and
6. Momentum – the net reproduction rate of 1.0, with no net migration and mortality at the 2015–20 level.

2.18 One feature of the WPP2019 fertility assumptions which may reasonably be questioned is the focus solely on TFRs for each calendar year. In practice, family-building takes place over the lifetime of cohorts of females and the year-by-year TFRs are the result of a series of snapshots across all ages in particular years. This results in greater volatility because of changes in the timing of children over the childbearing career. Cohort fertility rates (or cumulative family size by cohort leading to completed cohort family size) are much more stable and are usually taken into account in developing fertility projections.

2.19 The IHME projections published in Vollset et al. (2020) are based on modelling CCF50, which is shorthand for ‘completed cohort fertility at age 50’. They argue that this is much less affected by the delay in childbearing which occurs as females become more educated. It also facilitates modelling the progression of CCF50 as a function of changing educational attainment and contraceptive ‘met need’. We also consider that use of cohort fertility measures may be more satisfactory than the methods adopted in WPP2019.

2.20 Open questions posed in the WPP2019 include: (1) how likely is it that past developed-country trends will apply to less developed and developing countries, and (2) will current low fertility rates, particularly in high-income countries, be sustained? These questions would be appropriate topics for future research.

2.21 A typical source of information regarding future fertility patterns is surveys of females regarding desired childbearing preferences. Although theoretically relevant, their results have usually been fairly stable over time, which has been inconsistent with the pattern of emerging experience that has usually been anything but stable. However, this partly reflects differences in timing of births, with more stable results being obtained from using cohort fertility rate measures.

2.22 Although national government policies, including in tax changes and other incentives to have smaller, or in some cases recently, in response to low fertility rates, larger families, may have achieved some results over the short term, there is little evidence to support their long-term sustainability and effectiveness.

3. Mortality Projections

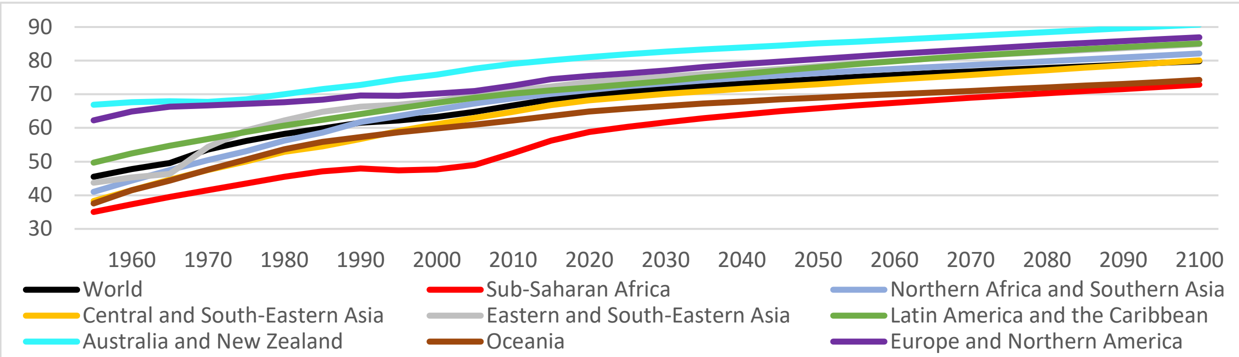
3.1 In order to project future deaths, the WPP2019 requires assumptions for mortality rates (the probability of dying at a particular age over the next year) by age and gender for each country up to 2100. Estimates of mortality rates for past years are used in the process of reconstructing population dynamics up to the present time. Nevertheless, mortality assumptions for WPP2019 are not based directly on mortality rates, but on expectations of life at birth. The following steps have been taken to develop estimates of mortality rates by country, age and gender:

1. estimating and modelling expectations of life of females at birth for future years;
2. modelling the difference (gap) between male and female expectations of life to derive male expectations of life;
3. making adjustments to the resulting expectations of life;
4. developing mortality rates by quinquennial age and quinquennial period;
5. modelling reductions in expectations of life due to HIV/AIDS in countries in which this cause of death is material; and
6. interpolating the quinquennial age/calendar year and mortality rates to derive annual mortality rates for individual years.

The primary set of projections is based on a probabilistic method using 100,000 simulations from 2020 to 2100, as described in 1.8, including probabilistic projections of life expectancy at birth. Further consideration is given later in this chapter and in Appendix 1 to the methodology used in WPP2019 for projecting mortality, which is different from what most actuaries would use.

3.2 A convenient way of summarizing the way in which mortality is projected to develop over the course of the projection is to look at the expectation of life at birth based on mortality rates for each year (the period expectation of life). Figure 7 shows the expectation of life at birth for males from 1950–55 to 2095–2100. At the global level, life expectancy at birth grew from 45.5 years in 1950–55 to 69.9 years in 2015–20, an increase of 24.4 years, representing an average rate of growth of 0.7% a year. From 2015–20 to 2095–2100, global life expectancy at birth is projected to grow from 69.9 years to 79.8 years, an increase of 9.9 years, equivalent to an annual rate of growth averaging 0.2% a year. This pattern is seen for most countries and regions, with continuing increases in expectation of life but at a reduced rate in the future as compared to the past.

Figure 7. Expectation of life at birth for males by SDG region from 1950 to 2100 (years)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

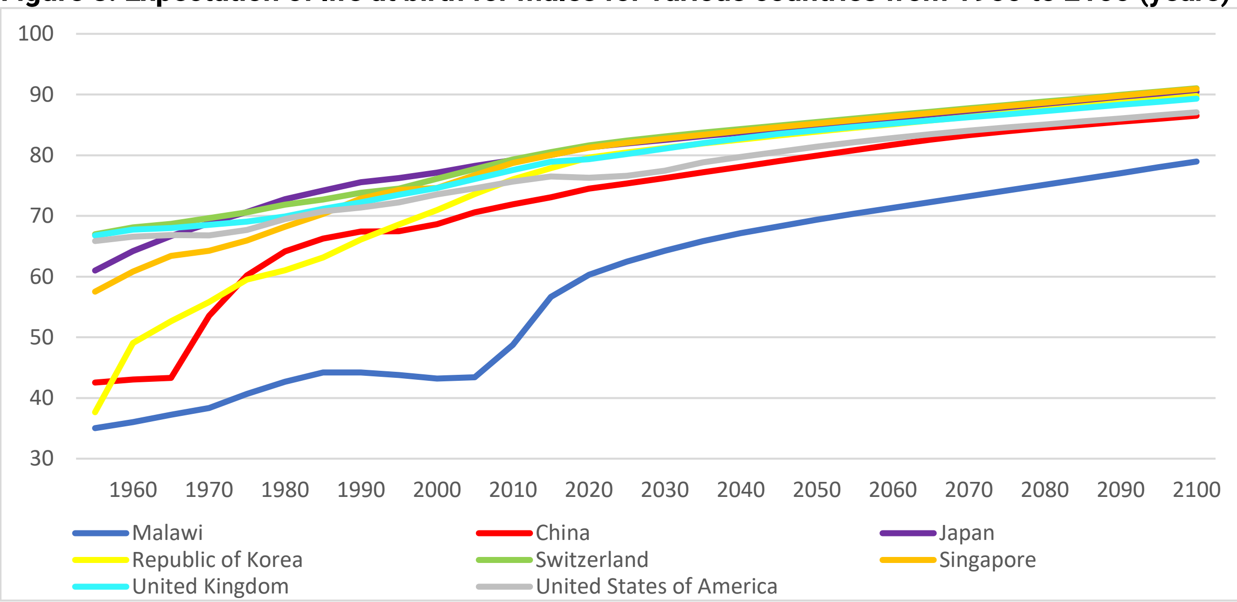
3.3 The table below shows the past and future projected changes in male life expectancy at birth.

Table 11. Changes in life expectancy at birth for males by SDG region from 1950 to 2100

SDG Region	1950-1955 (years)	Increase (annual rate)	2015-2020 (years)	Increase (annual rate)	2095-2100 (years)
World	**45.5**	**24.4 (0.66%)**	**69.9**	**9.9 (0.17%)**	**79.8**
Sub-Saharan Africa	35.0	23.8 (0.80%)	58.8	14.1 (0.27%)	72.9
North Africa and Western Asia	41.0	30.3 (0.85%)	71.3	10.8 (0.18%)	82.1
Central and Southern Asia	38.3	29.9 (0.89%)	68.2	11.9 (0.20%)	80.1
Eastern and Southeastern Asia	43.7	30.0 (0.81%)	73.7	11.2 (0.18%)	84.9
Latin America and Caribbean	49.7	22.3 (0.57%)	72.0	13.1 (0.21%)	85.1
Australia and New Zealand	66.9	14.2 (0.30%)	81.1	9.6 (0.14%)	90.7
Oceania	37.6	27.2 (0.84%)	64.8	9.5 (0.17%)	74.3
Europe and North America	62.3	13.1 (0.30%)	75.4	11.5 (0.18%)	86.9

3.4 Figure 8 shows the estimated past and projected evolution of the male expectation of life at birth for a selection of countries, ranging from Malawi (as an example of an African country and the country with the largest projected increase in expectation of life at birth between 2020–25 and 2095–2100) to countries such as Japan and Switzerland (among countries with the highest life expectancies at birth). Switzerland has male expectation of life at birth of 82.4 years for 2020–25, rising to 91.0 years in 2095–2100, vying with China, Hong Kong Special Administrative Region (SAR) for top position. Meanwhile, although all countries are projected to experience considerable increases by 2095–2100, a dozen countries in Africa are projected to have male expectation of life at birth of less than 70, with Central African Republic as low as 65.5 years. The gap between the country with the highest expectation of life at birth for males and the country with the lowest decreased from 44.7 years in 1950–55 to 30.3 years in 2020–25 and is projected to be 25.6 years in 2095–2100. This remains a large gap.

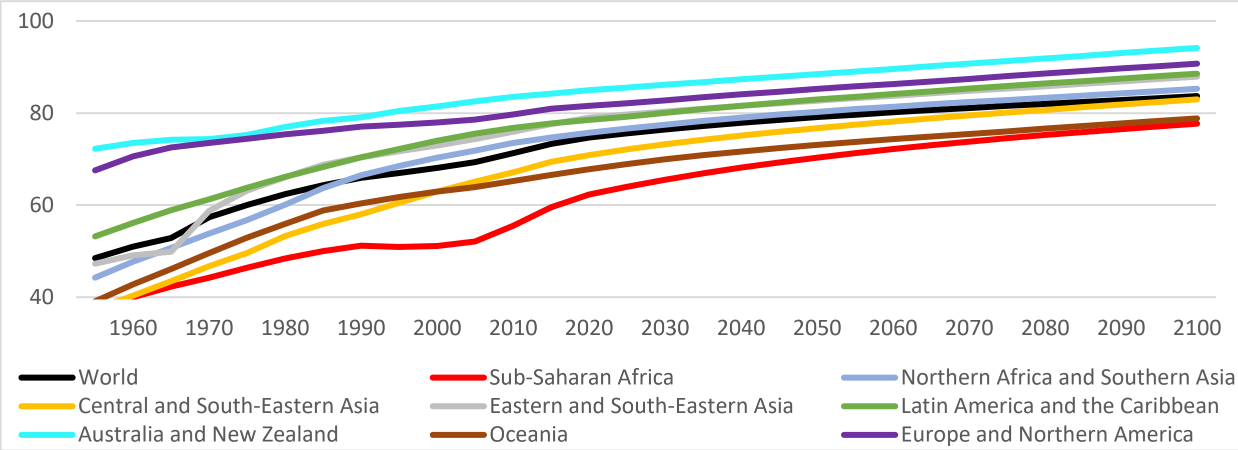
Figure 8. Expectation of life at birth for males for various countries from 1950 to 2100 (years)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

3.5 Figure 9 shows the expectation of life at birth for females from 1950–55 to 2095–2100. At the global level, life expectancy at birth for females grew from 48.5 years in 1950–55 to 74.7 years in 2015–20, an increase of 26.2 years, representing an average growth rate of 0.7% a year. From 2015–20 to 2095–2100 global life expectancy at birth is projected to grow from 74.7 years to 83.7 years, an increase of 9.0 years, equivalent to an annual growth rate averaging 0.1% a year. This general pattern is similar for most countries and regions, with continuing increases in expectation of life, although at a reduced rate in the future as compared to the past. At the global level, female expectation of life at birth was 3.0 years higher than for males in 1950–55, rising to an excess of 4.8 years in 2015–20 and then falling to 3.9 years in 2095–2100. However, the gender difference is not consistent between regions, either in the absolute level or the direction of trend.

Figure 9. Expectation of life at birth for females by SDG region from 1950 to 2100 (years)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

3.6 The table below shows the past and future projected changes in life expectancy at birth for females by SDG region.

Table 12. Changes in life expectancy at birth for females by SDG region from 1950 to 2100

SDG Region	1950-1955 (years)	Increase (annual rate)	2015-2020 (years)	Increase (annual rate)	2095-2100 (years)
World	**48.5**	**26.2 (0.67%)**	**74.7**	**9.0 (0.14%)**	**83.7**
Sub-Saharan Africa	37.7	24.6 (0.77%)	62.3	15.4 (0.28%)	77.7
North Africa and Western Asia	44.2	31.5 (0.83%)	75.7	9.6 (0.15%)	85.3
Central and Southern Asia	37.2	33.7 (0.83%)	70.9	12.1 (0.20%)	83.0
Eastern and Southeastern	47.3	31.7 (0.79%)	79.0	8.9 (0.13%)	87.9
Latin America and Caribbean	53.2	25.3 (0.60%)	78.5	10.1 (0.15%)	88.6
Australia and New Zealand	72.2	12.8 (0.25%)	85.0	9.1 (0.13%)	94.1
Oceania	39.1	28.7 (0.85%)	67.8	11.0 (0.19%)	78.8
Europe and North America	67.6	14.0 (0.29%)	81.6	9.1 (0.13%)	90.7

3.7 Expectation of life at birth is projected to increase by the end of the 21st century to about 91 years for males and about 96 years for females in the countries with the lowest levels of mortality. The figures for the leading countries in 2095–2100 are shown in Table 13.

Table 13. Expectation of life in 2100 for lowest mortality countries (years)

Country	Male expectation of life at birth in 2095–2100	Country	Female expectation of life at birth in 2095–2100
China, Hong Kong SAR	91.1	China, Hong Kong SAR	96.9
Switzerland	91.0	Japan	96.6
Singapore	90.9	China, Macao	96.5
Australia	90.8	Republic of Korea	95.6
Israel	90.8	Spain	95.3
Italy	90.7	Martinique	95.1
Iceland	90.6	Guadeloupe	95.0
China, Macao	90.6	Singapore	94.9
Channel Islands	90.6	Italy	94.6
Japan	90.4	Switzerland	94.5

3.8 In spite of substantial reductions in mortality projected for countries with current high levels of mortality, expectation of life at birth for the highest-mortality countries is projected to remain at very much lower levels than shown in Table 13 for many countries in Africa. Table 14 shows the projected figures for the countries with the highest levels of mortality in 2095–2100.

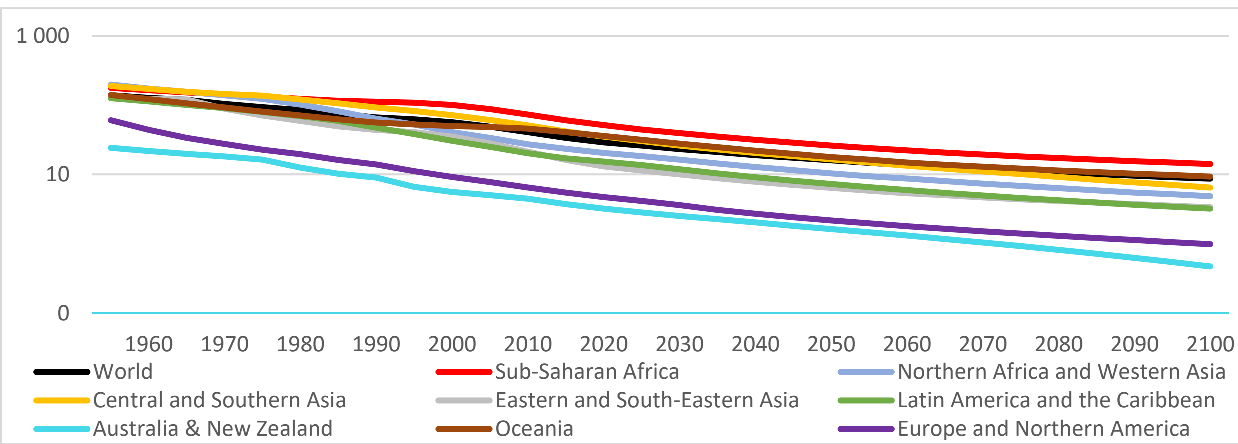
Table 14. Expectation of life in 2100 for highest-mortality countries (years)

Country	Male expectation of life at birth in 2095–2100	Country	Female expectation of life at birth in 2095–2100
Central African Rep.	65.5	Central African Rep.	71.3
Chad	66.9	Chad	72.0
Nigeria	67.7	Nigeria	72.3
Côte d’Ivoire	67.7	Côte d’Ivoire	72.5
South Sudan	68.2	Sierra Leone	73.0
Somalia	68.6	South Sudan	73.3
Sierra Leone	68.6	Somalia	74.1

Lesotho	68.8	Mali	74.2
Guinea-Bissau	69.4	Equatorial Guinea	74.8
Eswatini	69.8	Guinea-Bissau	75.2

3.9 A major contributor to the low expectations of life at birth in much of Africa is higher infant mortality, even though this has fallen considerably and is projected to continue to fall over the projection period. Figure 10 shows the steady reduction in infant mortality rate (deaths before age 1 per 1,000 live births) for both genders combined by SDG region from 1950–55 to 2095–2100, using a logarithmic scale (which shows a straight line when the quantity is changing exponentially; for example, at a constant percentage rate of growth or decline). Although the reduction in infant mortality rates in Sub-Saharan Africa has been considerable, averaging 1.9% a year from 1950–55 to 2015–20, the improvement in other regions has been greater, so the gap has been widening. Infant mortality rates are almost eleven times higher in Sub-Saharan Africa than in Europe and Northern America in 2015–20, compared to three times higher in 1950–55. The figures by SDG region are set out in Table 15.

Figure 10. Infant mortality rate for both genders combined by SDG region from 1950–55 to 2095–2100



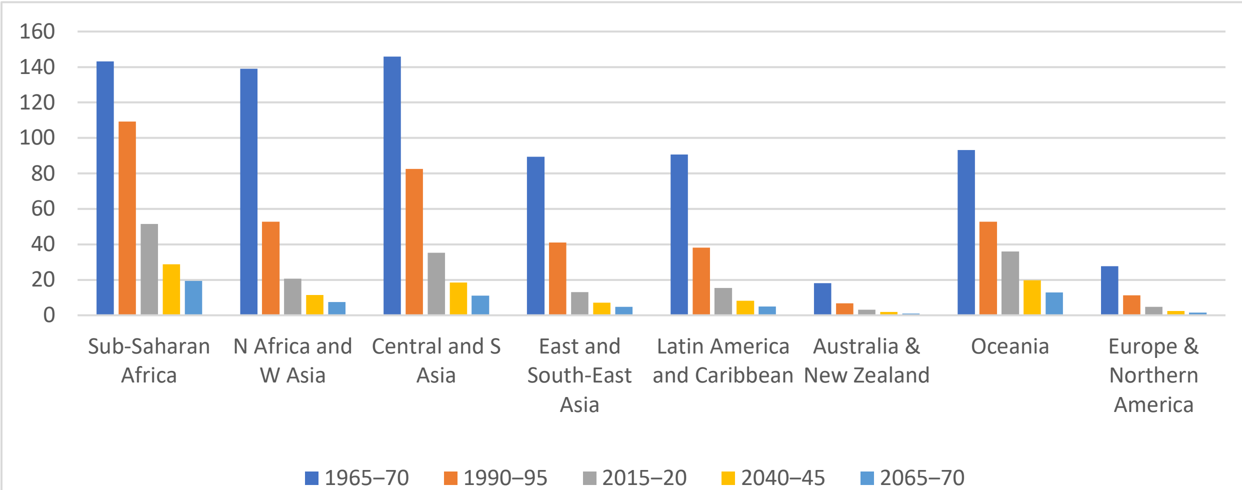
Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

Table 15. Reductions in infant mortality rates by SDG region from 1950–55 to 2095–2100

	Infant mortality rates (both genders combined) per 1,000 live births				
SDG Region	**1950-1955**	**Reduction rate a year**	**2015-2020**	**Reduction rate a year**	**2095-2100**
World	**139.6**	**2.4%**	**29.3**	**1.5%**	**8.7**
Sub-Saharan Africa	177.9	1.9%	51.5	1.6%	14.2
North Africa and Western Asia	198.8	3.4%	20.6	1.8%	4.9
Central and Southern Asia	189.2	2.6%	35.2	2.1%	6.5
Eastern and Southeastern Asia	129.1	3.5%	13.1	1.7%	3.4
Latin America and Caribbean	126.4	3.2%	15.5	1.9%	3.2
Australia and New Zealand	24.3	3.1%	3.2	2.4%	0.5
Oceania	140.5	2.1%	36.0	1.7%	9.3
Europe and North America	60.8	3.9%	4.7	1.9%	1.0

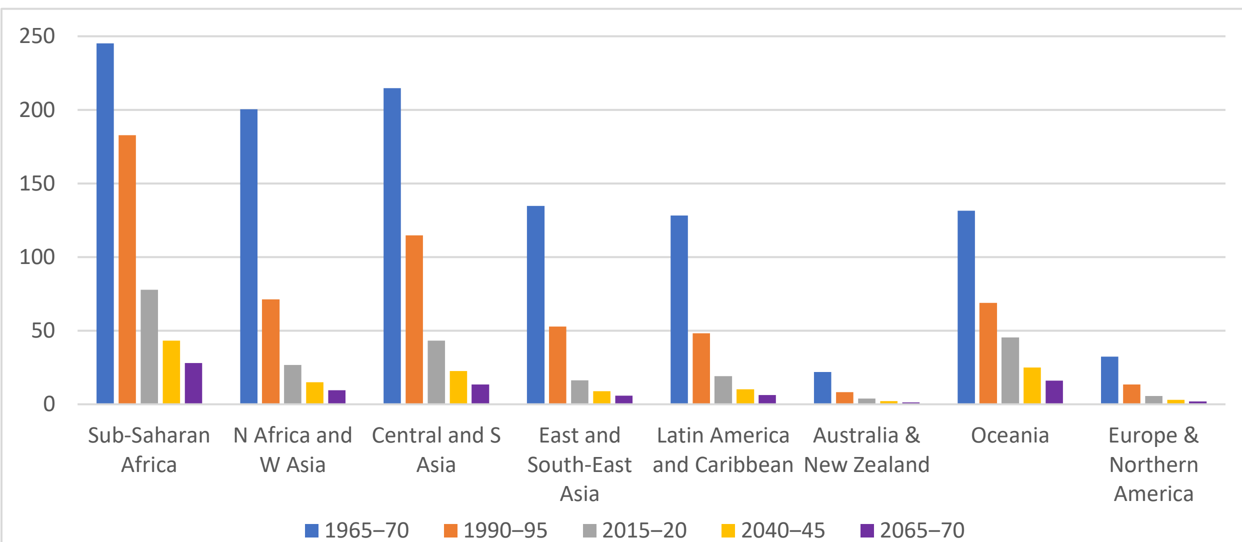
3.10 The mortality rate between ages 1 and 5 is also very high in many developing countries. Figures 11 and 12 show the development of the infant mortality rate (deaths under age 1 per 1,000 live births) and the child mortality rate (deaths between ages 1 and 5 per 1,000 live births) over the past 50 years and projected for the next 50 years. Over the next 50 years both of these infant mortality rates are projected to decrease by a little over 4% a year in all SDG regions, except for the rate for deaths between ages 1 and 5 for Europe and Northern America, where the mortality rate is already very low and is only projected to decrease by 2.6% a year. By 2065–70 the rate for deaths between ages 1 and 5 is projected to have decreased to about 3 per 1,000 live births for all regions except Sub-Saharan Africa, where it is projected to be 8.6 per 1,000 live births.

Figure 11. Deaths under age 1 per 1,000 live births by SDG regions, 1965–70 to 2065–70



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

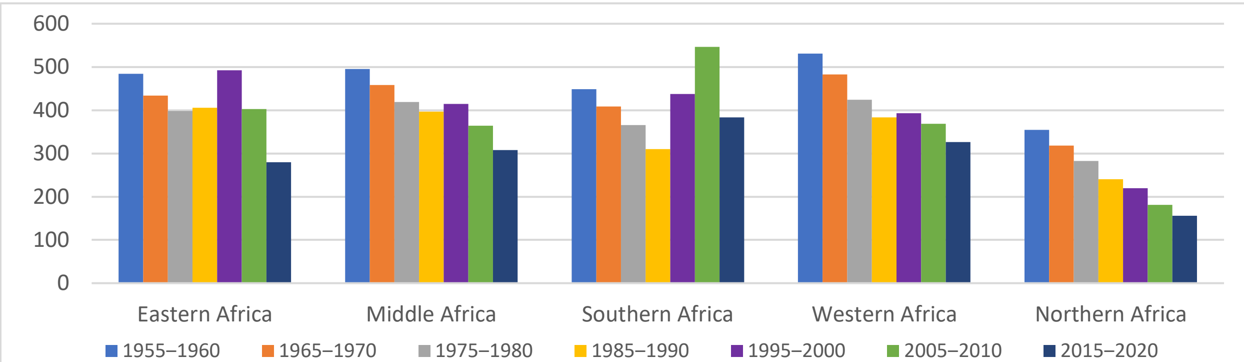
Figure 12. Deaths between ages 1 and 5 per 1000 live births by SDG regions, 1965–70 to 2065–70



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

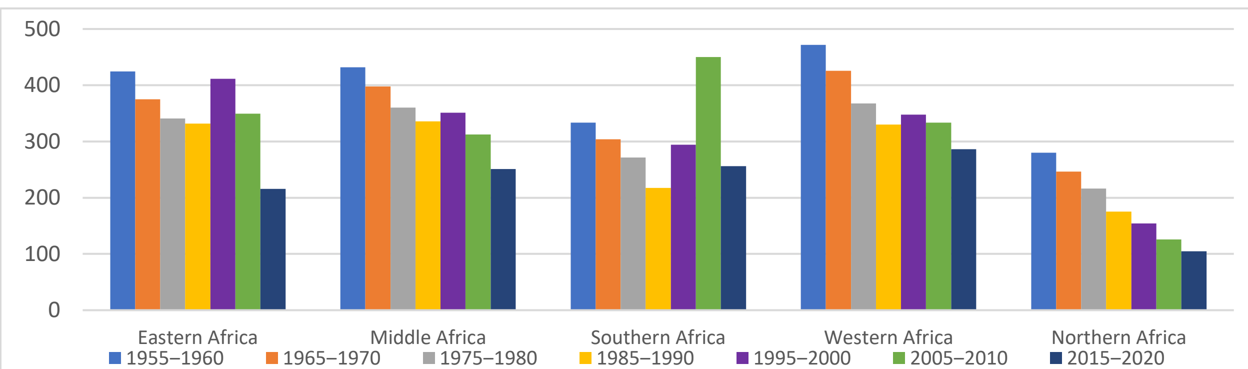
3.11 Mortality between ages 15 and 60 has also declined in all regions, but much less rapidly. One reason for this, particularly for some parts of Africa where the rate of reduction over the last 50 years has been modest, is that mortality rates for males and females of working age actually increased between 1985–90 and 2000–05. This was the result of the spread of HIV infection and AIDS, which was most significant in Eastern Africa and Southern Africa. Figures 13 and 14 show the development of mortality between ages 15 and 60 from 1955–60 to 2015–20 separately for the five sub-regions of the SDG region Sub-Saharan Africa and for males and females. This shows the reversal of the downward trend in 1985–90 and 1995–90, resuming the fall thereafter and getting back on trend by 2015–20. Eastern Africa and Southern Africa show this most strongly. Western and Middle Africa were less affected and Northern Africa was not affected materially by the HIV/AIDS epidemic.

Figure 13. Deaths between ages 15 and 60 for males by African SDG sub-region per 1,000 alive at age 15



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

Figure 14. Deaths between ages 15 and 60 for females by African SDG sub-region per 1,000 alive at age 15

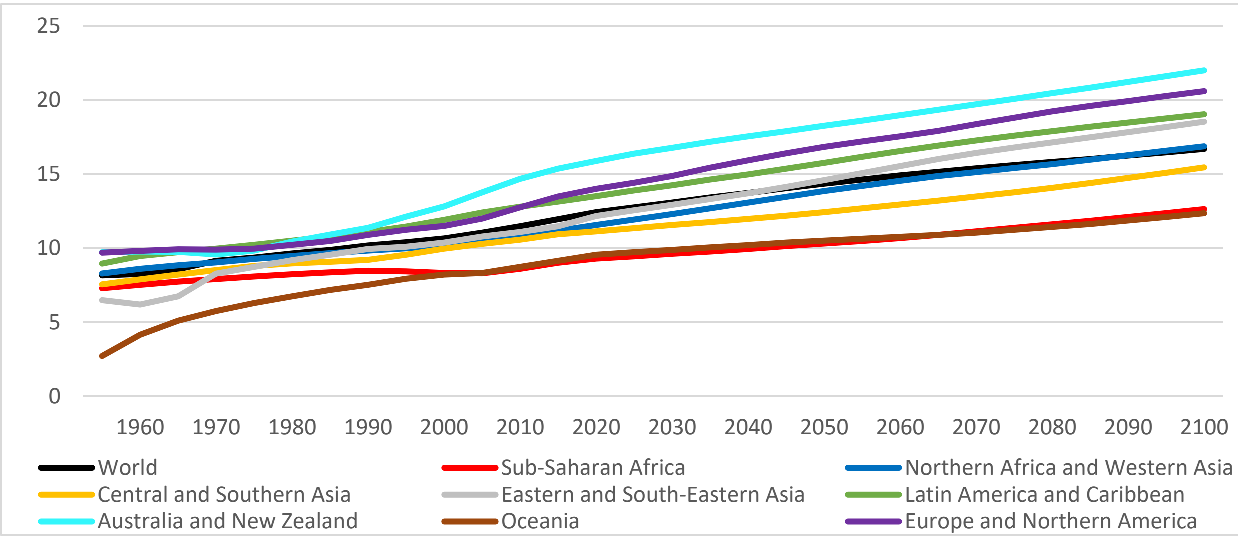


Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

3.12 The evolution of mortality resulting from HIV/AIDS is modelled separately in the WPP2019 projections, although the impact for future years is modest except for certain countries in Southern Africa.

3.13 Mortality at older ages has also declined steadily in all regions. Although detailed WPP2019 outputs focus on expectations of life at ages 60 and 80, expectation of life estimates up to 2015–20 and projections to 2095–2100 are also given for males and females separately (and combined) by five-year age intervals. We show figures here only for expectation of life at age 70, consistent with the projections of elderly population presented in Chapter 5 of this paper. Figure 15 shows the development of expectations of life at age 70 for males from 1950–55 to 2095–2100, and Figure 16 shows the same information for females. At a global level, the expectation of life at age 70 for males increased from 8.16 years in 1950–55 to 12.42 years in 2015–20, an increase of 4.26 years, or on average an increase of 0.66 years per decade (0.65% growth per year on average). The growth projected from 2015–20 to 2095–2100 is from 12.42 years to 16.70 years, which is on average an increase of 0.54 years per decade (or 0.37% average growth per year). In 2015–20 expectation of life at age 70 for males ranged from 9.30 years for Sub-Saharan Africa to 15.88 years for Australia and New Zealand. The ratio of the expectation of life for the highest region to the lowest is projected to increase by 2095–2100, when the Australia and New Zealand region is projected to have a life expectancy at age 70 of 22.01 years and the Europe and Northern America region 20.60 years, with the Sub-Saharan Africa region at 12.64 years.

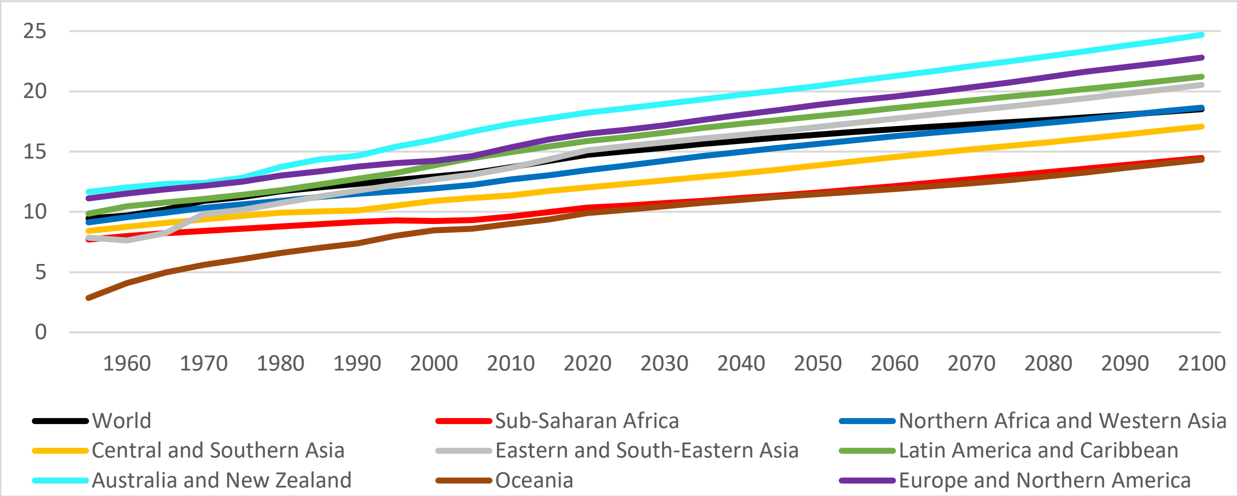
Figure 15. Expectation of life at age 70 for males by SDG region, 1950–2100 (years)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

3.14 The global expectation of life at age 70 for females increased from 9.46 years in 1950–55 to 14.74 years in 2015–20, an increase of 5.28 years, or on average an increase of 0.81 years per decade (or 0.68% growth rate per year on average). The growth projected from 2015–20 to 2095–2100 is from 14.74 years to 18.52 years, on average an increase of 0.47 years per decade (or 0.29% average growth rate per year), a little lower than for males. In 2015–20 the expectation of life at age 70 for females ranged from 10.34 years for Sub-Saharan Africa to 18.23 years for Australia and New Zealand, with the ratio of the expectation of life for the highest region to the lowest projected to decrease to 2095–2100, when the Australia and New Zealand region is projected to have life expectancy at age 70 of 24.69 years, the Europe and Northern America region 22.80 years, and the Sub-Saharan Africa region at 14.47 years.

Figure 16. Expectation of life at age 70 for females by SDG region, 1950–2100 (years)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

3.15 Those countries expected to have the highest expectation of life at age 70 in 2095–2100 are projected to have life expectancy of about 23 years for males and 27 years for females. Some of the leading countries are shown in the table below.

Table 16. Countries with high expectation of life at age 70 projected for 2095–2100 (years)

Country	Expectation of life at age 70 in 2095–2100	Country	Expectation of life at age 70 in 2095–2100
Males		Females	
China, Hong Kong SAR	23.05	China, Hong Kong SAR	27.74
Singapore	22.72	Japan	27.23
Japan	22.28	Republic of Korea	26.21
Switzerland	22.27	Martinique	26.05
Malta	22.25	Guadeloupe	26.05
Israel	22.17	Singapore	25.81
Australia	22.07	Spain	25.64
Italy	21.94	France	25.46
Sweden	21.76	Italy	25.12

France	21.69	Switzerland	25.04
Republic of Korea	21.64	Australia	24.85
Spain	21.61	Channel Islands	24.74
Canada	21.50	Portugal	24.62
Netherlands	21.42	Malta	24.46
Germany	21.31	Finland	24.40
United Kingdom	21.20	United Kingdom	23.01
United States	21.20	United States	22.76

3.16 The expectations of life presented in WPP2019 are period expectations of life. This is an artificial demographic construct, where the expectation of life is built up from the mortality rates at each age for a particular period. They are not the future expectations of life of particular cohorts of individuals for a country or region. A more useful concept for understanding how long people are expected to live is the cohort expectation of life, which allows for the mortality rates appropriate for each future year during which a particular cohort will live. The cohort expectation of life for a 70-year-old in 2020 will be based on the expected mortality at age 70 in 2020, mortality at age 71 in 2021, mortality at age 72 in 2022 and so on. In order to calculate the cohort expectations of life one would need to have mortality rates by single year of age for each future year; making this calculation is not feasible on the basis of the published information in WPP2019. However, the Actuarial Association of Europe has estimated cohort expectations of life at age 65 from the single-age mortality statistics published with the ESSPOP2015 projections.[13] This showed that the cohort expectation of life at age 65 in 2015 was between 1.5 and two years greater than the period expectation of life for males across the countries of the EU and close to two years more for females. Nevertheless, period expectations of life have the advantage of making use of the most recent data available while cohort expectations of life rely on projections, making the results more uncertain.

3.17 A useful check on the reasonableness of the mortality assumptions used in WPP2019 is to compare expectations of life at age 65 between these projections and the ESSPOP2019 projections for EU countries recently published by Eurostat in preparation for the Ageing Report 2021.[14] Making this comparison for projected period expectation of life in 2100 shows that the WPP2019 projections produce roughly similar results to ESSPOP2019 for just over half the countries, while for ten countries the WPP2019

[13] Meeting the Challenge of Ageing in the EU. Actuarial Association of Europe 2019.

[14] The 2021 Ageing Report will be an update of The 2018 Ageing Report: Economic and Budgetary Projections for the 28 EU Member States (2016–2070). European Commission Institutional Paper 079. https://ec.europa.eu/info/publications/economy-finance/2018-ageing-report-economic-and-budgetary-projections-eu-member-states-2016-2070_en

projections for males give expectations more than one year lower (and for seven countries two years or more lower) than ESSPOP2019. The corresponding figures for females are 11 countries where the WPP2019 projections give more than one year lower and five countries where the expectation of life is two or more years lower. Thus, the WPP2019 projections are relatively pessimistic in terms of future mortality improvement, in particular for the countries in central and eastern Europe.

3.18 The assumptions for future mortality improvement are essentially a continuation of past trends of improvement (apart from the specific modelling of HIV/AIDS mortality for African countries most affected by the HIV/AIDS epidemic). In paragraph 3.23 we discuss further how the methodology uses past trends and how this has been modified for some countries.

3.19 No account is taken of the possible disturbance of mortality improvement trends by global pandemics, as we are seeing currently with the Covid-19 pandemic. It is too early to know whether the excess mortality resulting from this pandemic will make a noticeable impact on overall mortality improvement trends, globally or for a particular country or region, although it will likely affect short-term mortality developments in some countries and regions. It is highly likely that during the period of the projections there will be one or more disease events which may impact the overall trend in a material way. It is, however, difficult to incorporate any such disturbance into a formal projection when there is no way of estimating when it might take place or which countries will be most affected. An alternative is to adopt a more cautious approach to the overall mortality improvement assumptions. In any case, it should be made clear whether such projections consider this possible effect.

3.20 As mentioned earlier in this chapter, the initial focus for projecting mortality in WPP2019 is period expectation of life at birth for females. It is assumed that the different levels of mortality in developing countries reflect a mortality transition model, where the first phase of growth in life expectancy is the result of improved hygiene and nutrition, with improvement accelerating as child mortality is reduced by social and economic development, including the adoption of childhood immunization programs to reduce the incidence of infectious diseases. The second phase is characterized by a slower increase in life expectancy, resulting from further progress against most infectious diseases and an emphasis on combating non-communicable diseases which mainly affect older people. With the focus being on life expectancy at birth, the impact of improved mortality at older ages is much less than reductions in child mortality.

3.21 The next step in the modelling process considers the gap between female and male life expectancy, which was modelled using an autoregressive model with female life expectancy serving as a covariate. Further details of the modelling approach are given in Appendix 1.

3.22 Although the methodology summarized in 3.1 was considered to work well for the majority of countries, there were some that have experienced much faster or much slower improvements in recent years for which the methodology did not produce results which the UN Population Division regarded as satisfactory. This resulted in adjustments being made to the projected mortality for 20 countries where the projected mortality was deemed by the UN Population Division to be too high, and for five where it was deemed to be too low.

3.23 There were an additional 20 countries for which recent trends and levels of life expectancy at birth were considered by the UN Population Division to have been negatively affected by crises, including political upheaval, armed conflict, public health issues and environmental disasters. These countries were assumed to experience slower mortality improvement over the next five to ten years, resuming a 'normal' trajectory thereafter. The list of these countries is an unusual mixture, and includes the United States of America, France, the United Kingdom, Canada and Austria, which have not experienced the factors mentioned to any significant extent, but have nevertheless experienced a slowing in the rate of mortality improvement in recent years. The criteria for identifying these countries relate to low increases in life expectancy of birth from 2005–10 to 2010–15 and from 2010–15 to 2015–20, resulting in very low projected increases from 2015–20 to 2020–25. A similar pattern of unusual experience may arise in several additional countries during periods affected by the Covid-19 pandemic, although this effect is generally assumed to be temporary in nature.

3.24 This approach ignores the possibility that these countries have been experiencing a phenomenon which might affect more countries; that is, a reduction in the long-prevailing trend of significant improvement in rates of mortality. It is perhaps too early to tell whether the slow-down in recent years in those countries (and in several others) is a temporary phenomenon or a harbinger of change. The UN Population Division has apparently decided that it is a 'blip' which needs to be adjusted for rather than a genuine change of direction. An alternative projection which treats the slowing down of mortality improvement as a more general phenomenon might be appropriate.

3.25 For many countries and regions the WPP2019 projections are the only reliable source of information about the likely future development of the population – and even of the current structure of the population and levels of mortality. The projections therefore provide an invaluable source of information for understanding the broad sweep of population dynamics for up to 80 years into the future. However, limitations arise as a result of the generic assumptions that have been applied in order to derive a consistent set of mortality rates for countries with sparse statistical information available. For those countries with their own well-developed systems of registration of births and deaths, which prepare national life tables and national population projections on a regular basis, results from national projections should be the primary source of information about the expected future changes in the population.

3.26 The only variant in mortality reported on is the assumption that no change from the 2015–20 period occurs in mortality levels throughout the projection period. A modification to this approach to be considered might include incorporating alternative assumptions which reflect a slowing down or a speeding up of mortality improvement, particularly at older ages.

3.27 The mortality rates underlying the WPP2019 would not in general be suitable for most actuarial applications, except for national social security scheme financial analysis. They may be relevant for considerations of setting retirement ages for national social security schemes, although cohort expectations of life should preferably be used rather than period expectations of life.[15] The longevity of members of occupational and personal pension schemes, as well as annuitants, can be expected to be significantly greater than the expectations projected for the population as a whole. Likewise the

[15] For further discussion of these issues refer to IAA PIWG 2016.

mortality of insured lives will show different characteristics, depending on the extent of selection and the risk characteristics of those insured.

3.28 From an actuarial perspective, it may be argued that the approach of WPP2019 to the projection of mortality is somewhat unusual. It is generally understood that expectations of life at birth are a function of the underlying mortality rates and their behaviour is a consequence of changes in mortality rates and cannot in any sense be seen as the driver. Focusing on life expectation at birth also gives undue weight to infant mortality and insufficient consideration to what has been happening over people's life course and particularly what is likely to happen to mortality at older ages, which is a critical driver of changes in population structure. The approach of making a probabilistic projection of female expectations of life at birth may simplify the projection process for considering a large number of countries with immature mortality curves, but we question whether it is a sound approach to use for countries which already have extremely low infant mortality.

3.29 We would also question the validity of projecting gender differences in expectation of life at birth as a way of deriving male expectations of life at birth. This measure would also appear to be a function of the underlying changes in mortality rates rather than a driver.

3.30 A consequence of the approach to mortality assumptions in WPP2019 is that mortality rates by age and gender are developed as a consequence of the assumptions, rather than driving the underlying mortality assumptions process. Clearly part of the reason for this approach is the absence of robust historical mortality tables for many of the countries for which the projections are being made. In such cases a more simplistic methodology may be justified. However, this is not adequate justification for using the approach based on projecting female expectation of life at birth for the considerable number of countries with reliable mortality data and sophisticated approaches to projecting future mortality developments.

3.31 In particular we suggest that the WPP2019 projections give insufficient focus to analysis of future mortality at older ages and so may not represent well the projected future growth of the population over retirement age and at advanced ages.

3.32 It should also be pointed out that the WPP projections pay no attention to cohort expectations of life and ignore cohort characteristics in mortality developments, which have been quite pronounced for some countries.

3.33 As mentioned in 1.34, for many countries the WPP2019 projections of the population are the only ones widely available with this level of detail. Actuaries preparing reports on financial assessments of social security plans may therefore be forced to rely on these projections. However, in that case actuaries should consider the appropriateness of the assumptions made by the UN Population Division in developing these projections and draw attention to the range of possible future outcomes, which can be illustrated from the variant projections.

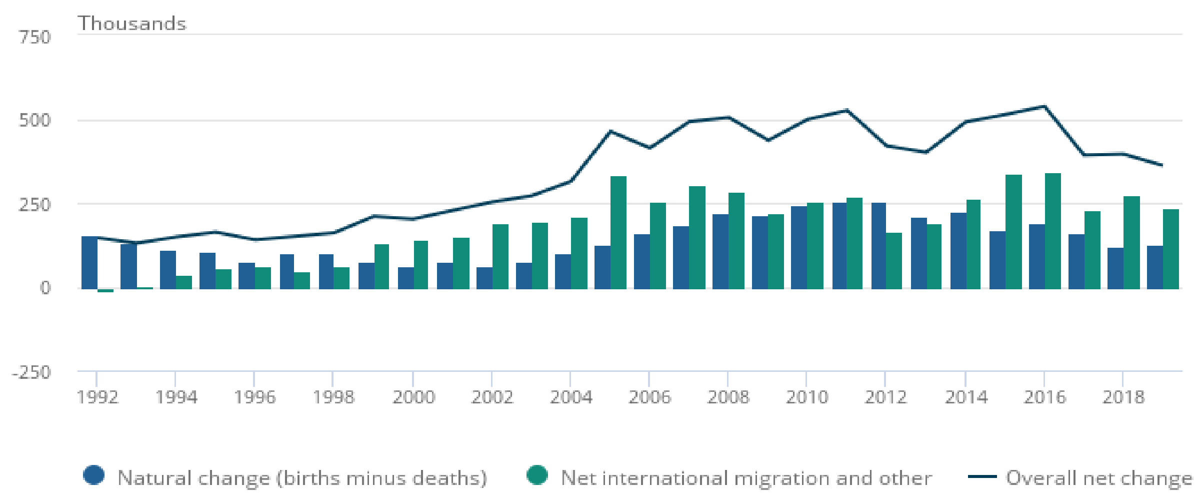
3.34 An alternative set of projections is provided by the IHME, published recently by Vollset et al. In general, for low-mortality, industrialized countries the IHME projections of expectations of life at birth are significantly lower than the WPP2019 projections. However, for many developing countries the IHME assumptions are more optimistic about the development of expectation of life up to 2100. Some examples of assumptions under the two sets of projections for 2100 are given in the comparison of the IHME projections and WPP2019 set out in Appendix 4.

4. Migration Projections

4.1 The only thing we know for certain about international migration is that it must net to zero at a global level. Everything else about projecting migration trends and the impact on future populations at national levels is speculative and difficult to project. Reasons for this difficulty include the fact that the level and type of migration depends upon political action, economic conditions and human behaviour, both in the giving and receiving countries. These are notoriously difficult to predict, especially over a long period. A lack of information regarding both accurate historical information and future related pressures also make this difficult to project on a national and local level. The UN Population Division acknowledges this uncertainty and attempts to do what it can to develop reasonable assumptions. The lack of accurate and complete data on international migration is one of the most significant limitations in producing better-quality population estimates. It is perhaps ironic that, as international migration becomes an almost global phenomena, with very few countries not admitting immigrants or sending out emigrants, the data that would enable a better understanding and projections of such flows suffer from serious inaccuracy and incompleteness (particularly in respect of illegal international migration). International migrants make up about 3.5% of the global population and a much higher proportion in some countries.[16]

4.2 To provide some perspective, the following chart shows the significant contribution to the change in population of the UK since 1992.

Figure 17. Main drivers of population change for the UK from mid-1992 onwards



Source: Office of National Statistics population estimates for the UK, England and Wales, Scotland and Northern Ireland, provisional: mid-2019[17]

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[16] www.un.org/development/desa/en/news/population/international-migrant-stock-2019.html

[17] www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2019. Available for use under Open Government Licence v3.0.

4.3 In this chapter, we look at the methodologies used by the UN Population Division to project migration, including the data sources and the assumptions made. We will also describe how the methodologies and assumptions have changed over time and why migration assumptions play an important role in the demographic trajectory of many countries.

4.4 In the UN Population Division’s 2019 population projections, as in previous versions, only international migration is considered. Although intra-country migration can have demographic consequences, it may be more difficult to model and project than international flows, as well as being outside the scope of national population projections.

4.5 As in previous world population projections, the UN Population Division projects net migration at country level. This is in spite of the fact that some countries can have a high level of both migration into their territory (immigration) and out-migration (emigration). If these are of similar levels then the net migration assumption may be low, even though the component parts may be significant and affecting different age groups. The use of net migration, immigration or emigration depends on the application of this demographic information.

4.6 In preparing the 2019 population projections, the UN Population Division made use of:

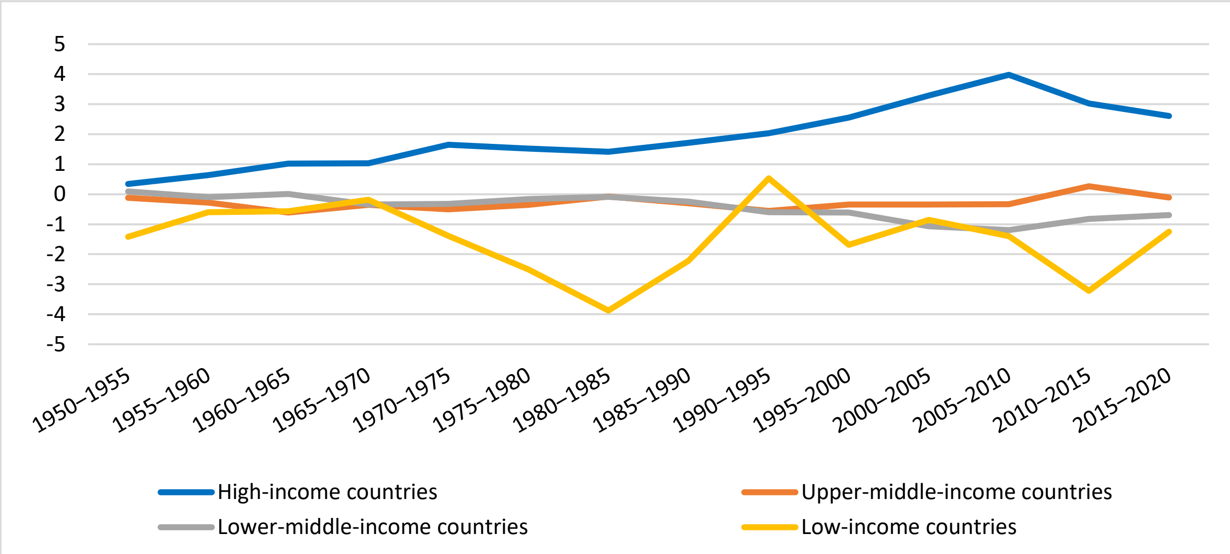
- official country-level estimates of net international migration or its components (immigration and emigration);
- information on labour migration;
- data about undocumented or irregular migrants, refugees and asylum-seekers, as prepared, for example, by the Office of the UNHCR; and
- estimates of stocks of foreign-born persons, prepared by the UN Population Division.

4.7 Data on past trends are often sparse or incomplete. Countries can experience dramatic fluctuations in migration even over relatively short periods of time in response to economic, social, political and environmental factors. Perceptions of relative security and employment opportunities between countries can have dramatic effects on migration levels. Wars, famines and natural disasters of one sort or another can drive people to seek a new life in another country. Countries can swing from experiencing net emigration to experiencing net immigration, or vice versa, in just a few years.

4.8 For example, Uganda had net immigration of 1.2 per 1,000 in the period 1965–70 and emigration of 5.5 per 1,000 in the following five-year period, and South Sudan had net emigration of 2.0 per 1,000 in 2010–15, which increased to 15.9 per 1,000 in 2015–20. Bahrain had net immigration of 51.1, 6.4 and 31.1 per 1,000 in the three periods 2005–10, 2010–15 and 2015–20 respectively.

4.9 The following chart shows the historic net immigration rate per 1,000 population split by World Bank income levels (1950 to 2020).

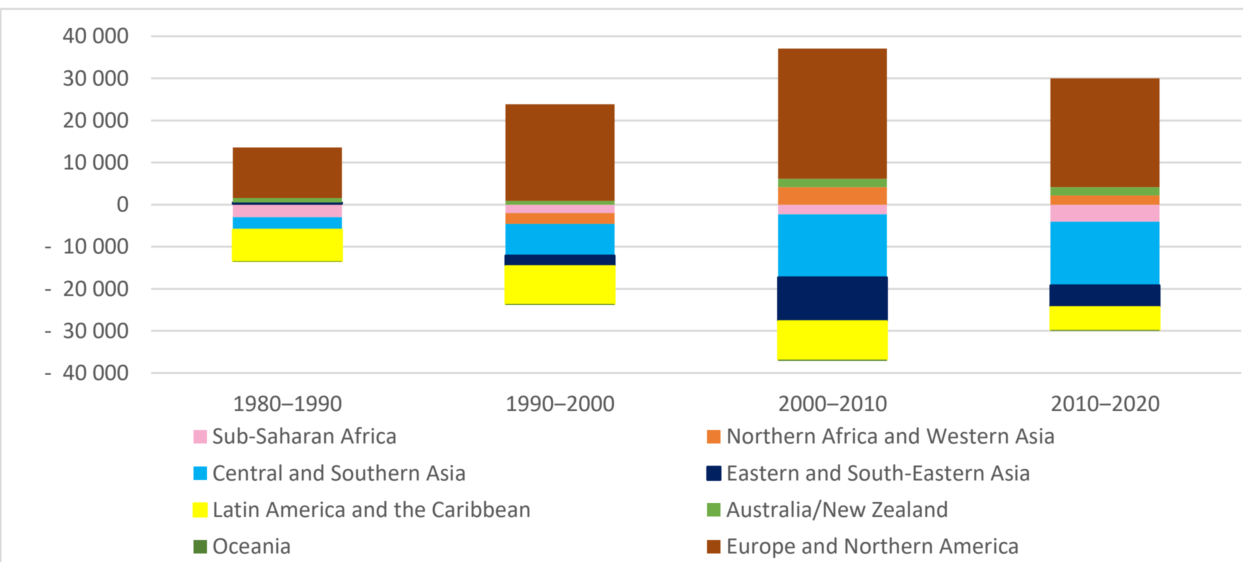
Figure 18. Historic net migration rate per 1,000 population by World Bank income level



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

4.10 It is not surprising that high-income countries are generally recipients of migrants while the lower-income countries are net exporters of people. However, about 40% of international migrants have moved from one developing country to another.[18] This is also shown in the following chart, which splits countries by SDG region.

Figure 19. Net international migration by SDG region, 1980–90 to 2010–2020



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

[18] www.un.org/en/development/desa/population/migration/publications/populationfacts/docs/MigrationStock2019_PopFacts_2019-04.pdf

4.11 Setting assumptions about future trends in international migration is extremely challenging, even over the short term. Faced with this historic variability of migration flows and because, relative to overall population size, migration flows have been relatively small and have had limited impact on the size and composition of most national populations, assuming that net migration will remain constant throughout most of the projection period is a reasonable assumption. However, where migration flows have made or are currently making a significant contribution to a country's demographic structure, or the gross flows in each direction are large compared to the net flow, a different approach is required.

4.12 The UN's basic approach for setting future net international migration assumptions is straightforward for most countries. For international migration, excluding refugees, the UN Population Division assumed that recent levels, if reasonably stable, would continue until 2045–50. For all countries, the projected net migration level in 2045–50 is assumed to remain constant until the end of the projection period. In the previous revision, it was assumed that international migration would fall to half the level projected for 2045–50 by the end of the projection period. The countries' governments' current views on international immigration, as well as estimates of undocumented and irregular migration flows affecting that country, were taken into account. Regarding refugees, the UN Population Division generally assumed that they would return to their country of origin within five to ten years. If a country was expected to experience movements of both refugees and other international migrants, the figures were aggregated to capture total net migration during a given period, except for those countries where refugee movements were already included in international migration data.

4.13 In addition to the overall number of net migrants, the distribution of migrants by age and gender can also play a key role in projecting population. Where it was possible to estimate the age and gender distribution of international migrants, these distributions were used to determine the most suitable model for projecting future migration or, in some cases, used directly as inputs, and the distribution of net migrants by age and gender was generally kept constant over the projection period. In certain cases – for example, where a country was known to be attracting temporary labour migrants – models were used which allowed for the ageing of these migrants and their eventual return to their country of origin. The same method was applied to refugee flows.

4.14 Where distributions by age and gender were not available, the gender distribution was based on what was known about the typical distribution for different types of migration flow. For example, the gender distribution of those migrating for work would differ from those migrating to achieve family reunification. As there is limited information on the age distribution of immigrants, and even less information available regarding emigration, the UN Population Division used models to distribute the overall migration numbers by age group.

4.15 The resulting age and gender profiles of the net migration flows were then used, along with fertility and mortality assumptions, as inputs for a cohort-component projection model.

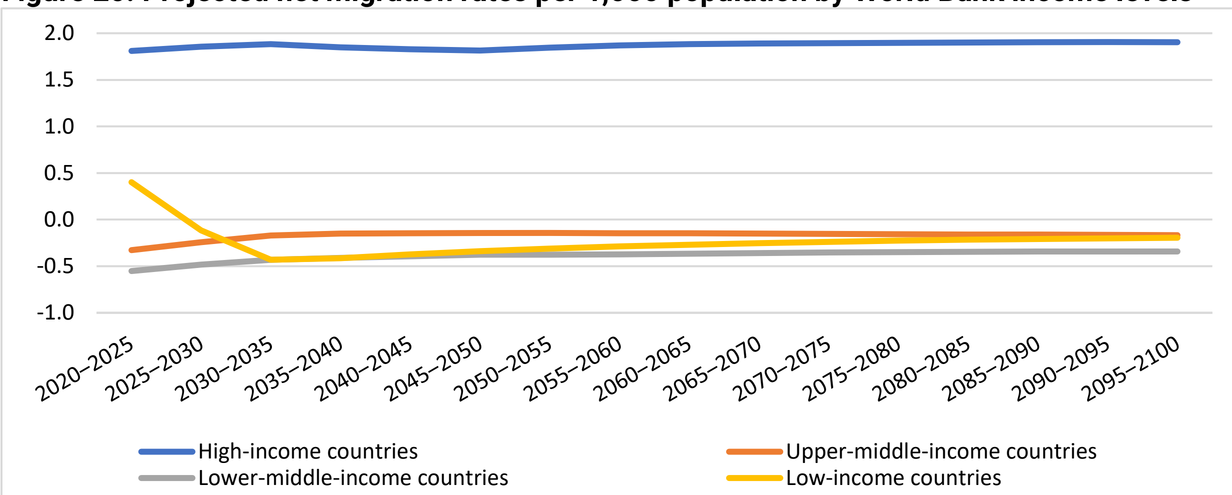
4.16 As mentioned above, the main constraint on setting migration assumptions is that globally net migration must be zero. Therefore, the bottom-up approach of setting migration assumptions at the country level had to be adjusted to ensure consistency at the global level. This was done by applying adjustments to those countries in either the top twelve receiving or top twelve sending countries.

4.17 As with the other demographic variables – i.e., fertility and mortality – where no, or only minimal, demographic information is available, models were used to estimate a country's net migration.

4.18 In addition to the base migration assumptions used in the Median population projection, a variant migration assumption of zero migration from 2020–25 onwards is used in the Momentum variant.

4.19 The following chart shows the projected net inwards migration rates by World Bank income levels from 2020 to 2100.

Figure 20. Projected net migration rates per 1,000 population by World Bank income levels



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

4.20 The chart above highlights the relative stability of the migration rate assumption over the longer-term projection. The decrease in migration rate between 2020–25 and 2030–35 seems to be mainly due to expected reductions in the level of net outwards migration from Syria.

4.21 The table below shows the countries with the highest net immigration and net emigration in 2015–20 according to the WPP2019 population projection.

Table 17. Top ten countries for recent immigration and emigration

Immigration		Emigration	
Country	**Net immigration 2015–20 (000s)**	**Country**	**Net emigration 2015–20 (000s)**
United States	4,774	Venezuela (Bolivarian)	3,266
Germany	2,719	India	2,663
Turkey	1,420	Syrian Arab Republic	2,137
United Kingdom	1,303	Bangladesh	1,848
Canada	1,210	China	1,742
Colombia	1,024	Pakistan	1,167
Russian Federation	912	South Sudan	871
Uganda	843	Myanmar	817
Australia	791	Zimbabwe	584
Italy	745	Indonesia	495

4.22 It is noteworthy that 15 countries are projected to lose more than 10% of their current population as a result of emigration alone over the next 30 years, and another 25 are projected to lose between 5% and 10%. While in a few cases there may be particular reasons for this (for example, the reversal of emigration from Syria to neighbouring countries Lebanon, Jordan and Turkey as a result of the conflict situation of the last few years), others seem to reflect a more persistent haemorrhaging of population, often reflecting political, social or economic differences between countries, which may exacerbate such flows. It should be noted that over time such differences may narrow and extrapolating past trends for the full 80 years of the projections will not reflect this. These countries with high emigration relative to their size are shown in tables 18 and 19.

Table 18. Countries projected to lose more than 10% of current population by migration alone over next 30 years

Country	Population loss by 2050 (000s)	Population in 2020 (millions)	% loss over 30 years
Samoa	-46	198	-23.0%
Tonga	-24	106	-22.7%
Lebanon	-1,537	6,825	-22.5%
Guyana	-123	787	-15.7%
Micronesia (Fed. States of)	-18	115	-15.6%
Jordan	-1,434	10,203	-14.1%
United Arab Emirates	-1,288	9,890	-13.0%
US Virgin Islands	-14	104	-13.0%
São Tomé and Principe	-27	219	-12.3%
El Salvador	-796	6,486	-12.3%
Jamaica	-339	2,961	-11.5%
Timor-Leste	-150	1,318	-11.4%
Sri Lanka	-2,404	21,413	-11.2%
Maldives	-59	540	-11.0%
Kiribati	-12	119	-10.1%

Table 19. Countries projected to lose 5% to 10% of current population by migration alone over next 30 years

Country	Population loss by 2050 (000s)	Population in 2020 (millions)	% loss over 30 years
Albania	-285	2,878	-9.9%
Guam	-15	169	-9.0%
Eritrea	-270	3,546	-7.6%
Georgia	-300	3,989	-7.5%
Dominican Republic	-768	10,848	-7.1%
Solomon Islands	-48	687	-7.0%
Comoros	-60	870	-6.9%
Fiji	-60	896	-6.7%
Lesotho	-140	2,142	-6.5%
Tajikistan	-600	9,538	-6.3%
Haiti	-710	11,402	-6.2%
Seychelles	-6	98	-6.1%
Lao People's Democratic Republic	-441	7,276	-6.1%
Mali	-1,200	20,251	-5.9%
Bangladesh	-9,615	164,689	-5.8%
Guadeloupe	-23	400	-5.7%
Somalia	-900	15,893	-5.7%
Paraguay	-399	7,132	-5.6%
Saint Vincent and the Grenadines	-6	111	-5.4%
Cambodia	-900	16,719	-5.4%

Grenada	-6	112	-5.3%
Lithuania	-145	2,722	-5.3%
Martinique	-19	375	-5.1%
Suriname	-30	587	-5.1%
Armenia	-150	2,963	-5.1%

4.23 For some countries, continuation of emigration at these levels will significantly impact the size and age structure of the population that remains, particularly as emigration is likely to be mainly at working ages. When combined with the automatic ageing of the population which is inherent in their current population structure, this could result in serious population depletion for some countries. Albania, for example, is projected to reduce to just 38% of its current population size by 2100, and the United States Virgin Islands to 39%. It raises the question as to whether projecting the continuation of such a sustained fall in population over 80 years is realistic.

4.24 At the other end of the spectrum there are 15 countries projected to grow by more than 10% over thirty years as the result of immigration. The 32.6% growth projected for Syria, almost all within the next ten years, results from the expected reversal of the mass emigration during the civil war and is the counterpart to the emigration mentioned in 4.22 for Lebanon, Jordan and Turkey.

Table 20. Countries projected to gain more than 10% of current population by migration alone over next 30 years

Country	Population gain by 2050 (000s)	Population in 2020 (millions)	% gain over 30 years
Syrian Arab Republic	5,699	17,501	32.6%
Western Sahara	168	597	28.0%
China, Macao SAR	150	649	23.1%
Luxembourg	125	626	20.0%
Canada	7,446	37,742	19.7%
Qatar	500	2,881	17.4%
Australia	4,296	25,500	16.8%
Norway	840	5,421	15.5%

Equatorial Guinea	210	1,403	15.0%
Channel Islands	25	174	14.4%
Singapore	811	5,850	13.9%
Switzerland	1,178	8,655	13.6%
Bahrain	230	1,702	13.5%
Cyprus	150	1,207	12.4%
French Guinea	36	299	12.1%

4.25 Another 18 countries are projected to grow by between 5% and 10% over 30 years as the result of immigration. This seems a plausible rate of growth, especially for countries which would otherwise see a reduction of population as a result of the ageing process or have plenty of habitable land area that is less populated or under-utilized and which could accommodate substantial numbers of immigrants.

Table 21. Countries projected to gain 5% to 10% of current population over next 30 years by migration alone

Country	Population gain by 2050 (000s)	Population in 2020 (millions)	% gain over 30 years
Curaçao	15	164	9.4%
China, Hong Kong SAR	702	7,497	9.4%
United States	30,846	331,002	9.3%
Sweden	900	10,099	8.9%
Kuwait	360	4,271	8.4%
Denmark	456	5,792	7.9%
New Zealand	372	4,822	7.7%
Bahamas	30	393	7.6%
Finland	420	5,541	7.6%
United Kingdom	4,870	67,886	7.2%
Venezuela (Bolivarian Rep.)	1,943	28,436	6.8%
Austria	600	9,006	6.7%

Belize	26	398	6.4%
Belgium	720	11,590	6.2%
Czechia	660	10,709	6.2%
Ireland	300	4,938	6.1%
Germany	4,582	83,784	5.5%
New Caledonia	15	286	5.3%

4.26 However, although these projected levels of immigration may be a continuation of the experience of recent years, they still imply a level of continued immigration which it could be unwise to assume will continue unchanged for 80 years into the future. There has been an ongoing debate among demographers as to whether future migration patterns will remain similar to those currently being experienced or change as a percentage of the population or be more directly driven by socio-economic developments.

4.27 In our view, the assumption in previous WPP projections that migration flows would tail off in the second half of the projection period would be a more realistic assumption than assuming they remain unchanged throughout. For some countries the overall impact of continued inwards (or outwards) migration at a constant level would have major consequences for the age structure of the population in the longer term. In many cases it seems likely that there will eventually be some re-balancing, either because of resulting pressures or because of changes in the relative economic, political, social or other conditions in the sending and receiving countries.

4.28 It is also unrealistic to assume that the effects of net migration are cumulative, as some element of current net migration may in the future lead to reverse flows of migrants returning to their home country. This might imply that inward and outward flows would become more in balance in future periods, rather than continuing always in the same direction.

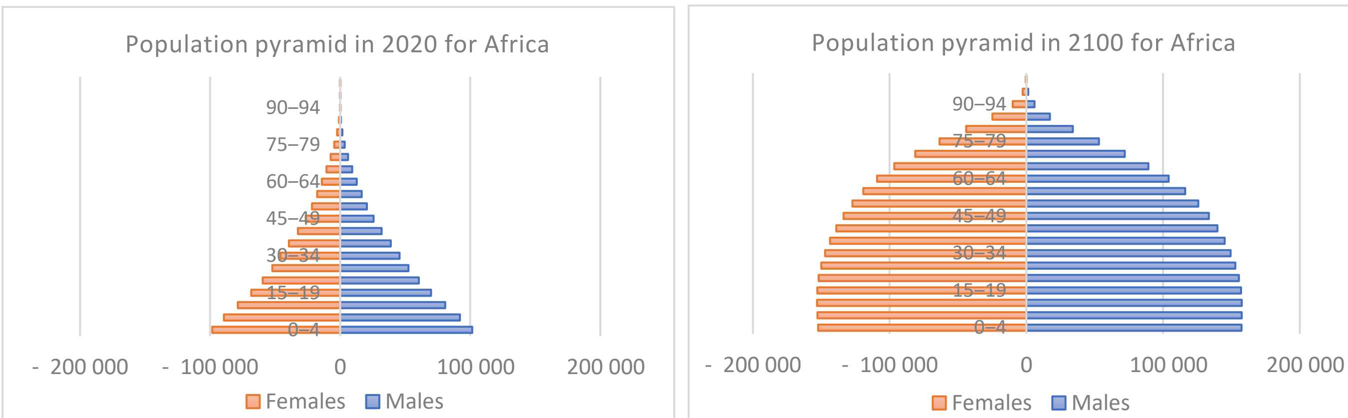
4.29 With regard to refugee flows, or net migration – which is assumed to reflect underlying refugee flows, a rapid reversal over five to ten years may be unrealistic, as it could take significant time for the underlying conditions giving rise to the refugee flows to stabilize to the extent that the refugees will all just return to their country of origin. We would suggest that assuming it would take a longer period for the reversal to take effect would be more appropriate and that it should not be assumed that the reversal is ever fully complete.

4.30 In the IHME projections published in Vollset et al. (2020), international migration is modelled as a function of natural population increase, the socio-demographic index (SDI) and death due to conflict or natural disasters, as well as a random walk with drift. This leads to what might be regarded as more realistic patterns of migration falling gradually over time, particularly in the second half of the 21st century. Some examples of the very different assumptions to which this gives rise, are given in a comparison between key features of the IHME and WPP2019 projections in Appendix 4.

5. Population Size and Structure

5.1 In Chapter 1 we reviewed several aspects of the projections from WPP2019. In Figure 4 we illustrated a series of population pyramids for the world population in 1950, 2020, 2060 and 2100. These showed the sharp pyramid of 1950 opening out into an onion-dome shape by 2100. Comparing the population pyramids by region illustrates how different they are in terms of demographic development. Figure 21 shows the pyramid development for Africa.

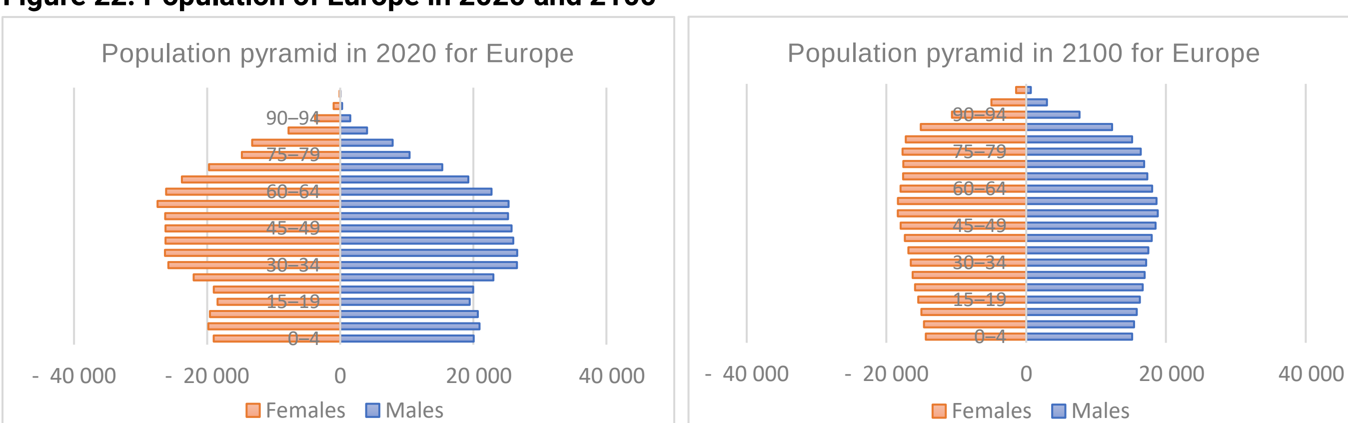
Figure 21. Population of Africa in 2020 and 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

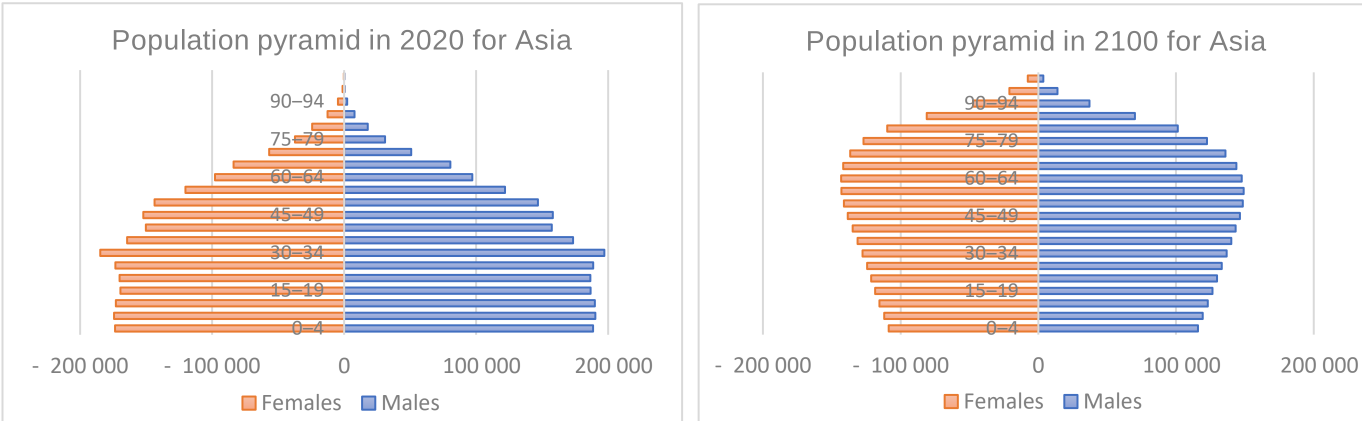
5.2 Africa is still a very young continent in 2020, so the population pyramid for 2020 in Figure 21 is very similar to the world population pyramid for 1950, while in 2100 Africa's mirrors that of the world. Europe shows a very different picture, as it already has a much older age structure in 2020, as can be seen in Figure 22. Asia shows a less dramatic impact from recent low fertility in the 2020 pyramid than Europe, although the picture in 2100 is not too dissimilar, as shown in Figure 23.

Figure 22. Population of Europe in 2020 and 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

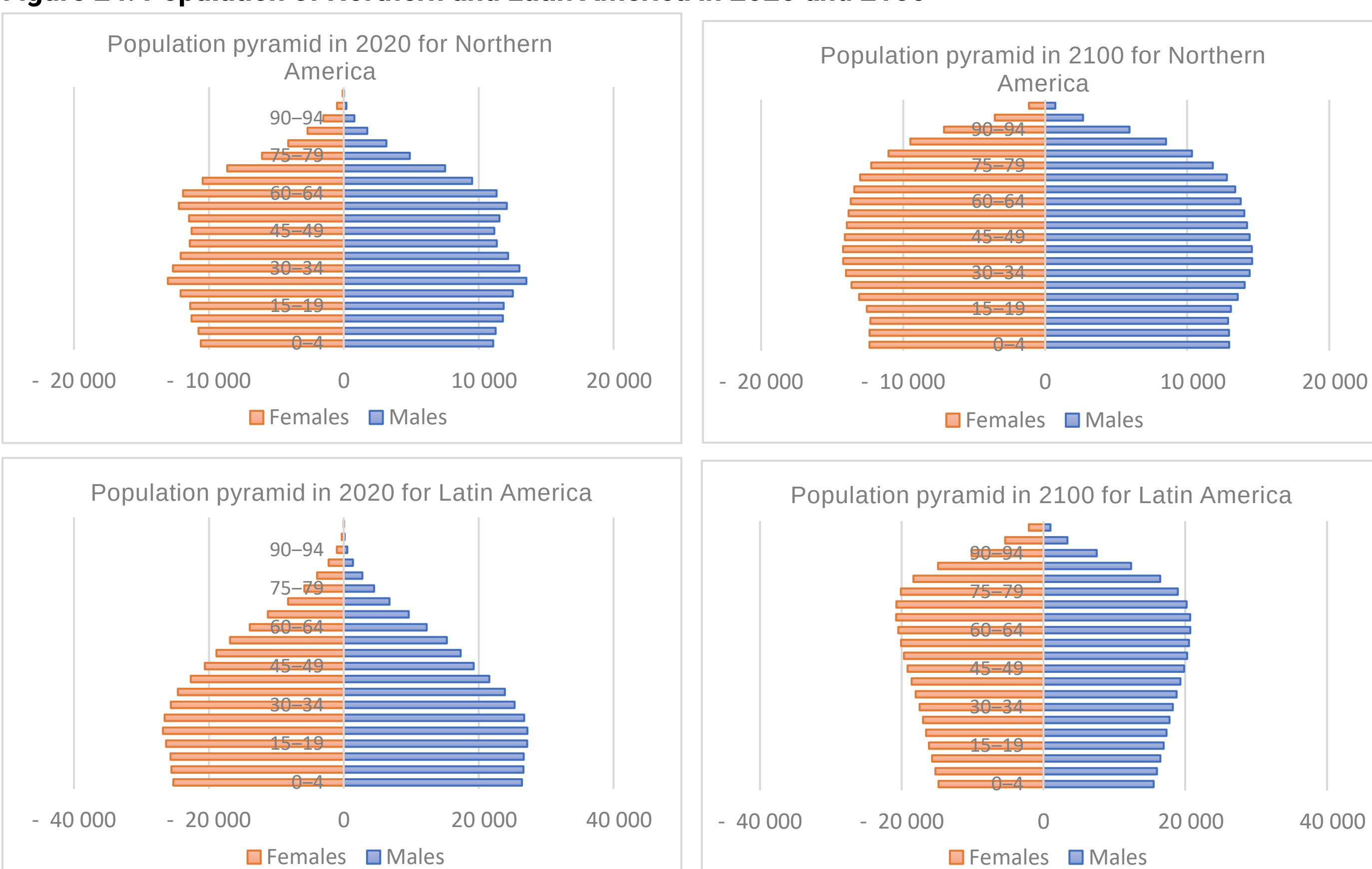
Figure 23. Population of Asia in 2020 and 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.3 The population pyramid shapes for Northern America are fairly similar to Europe, and those for Latin America are similar to Asia, as can be seen in Figure 24.

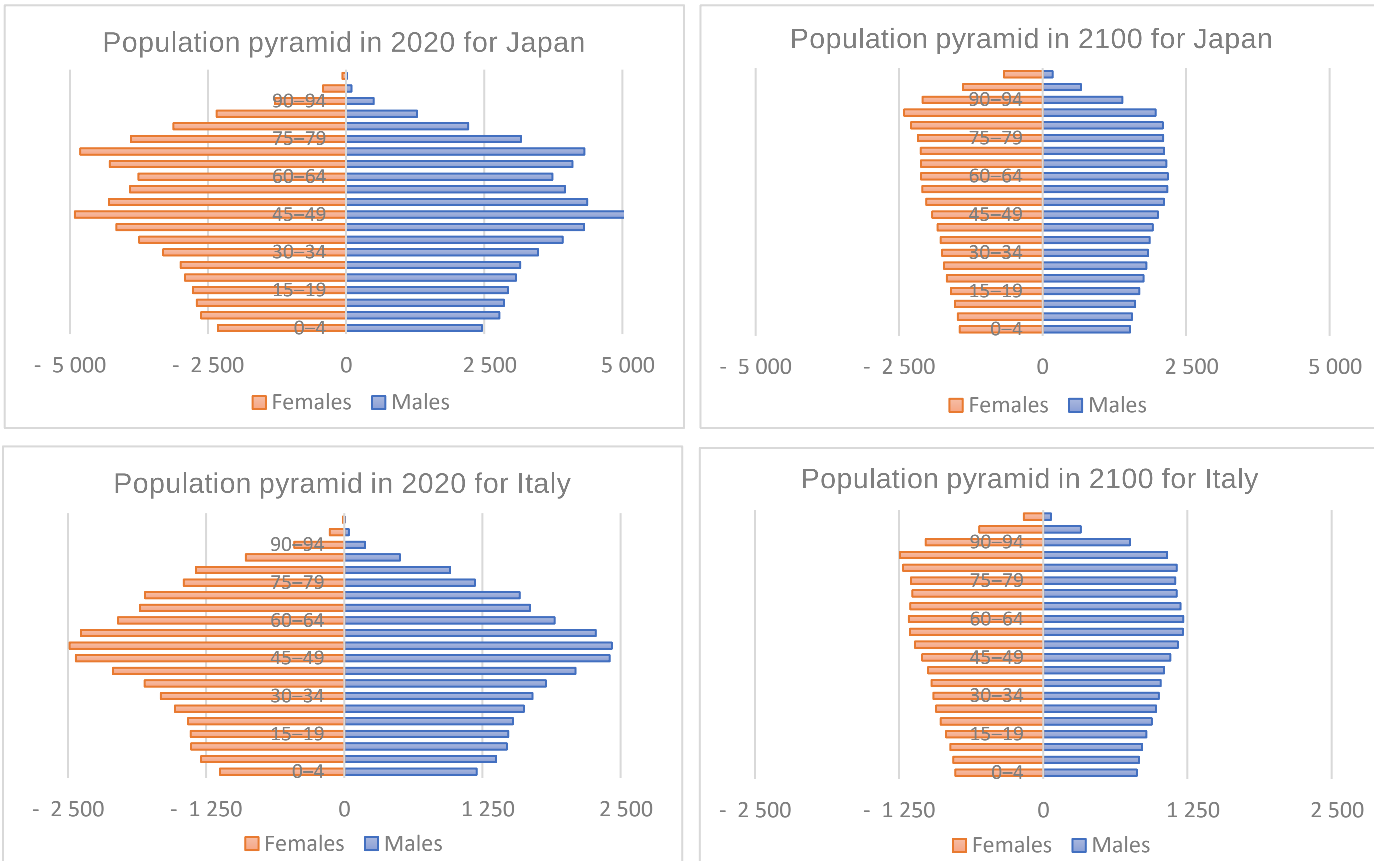
Figure 24. Population of Northern and Latin America in 2020 and 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.4 Pyramids are shown below for Japan and Italy as examples of two countries with the oldest population structure in the world at present, showing an extreme extent of ageing by 2100.

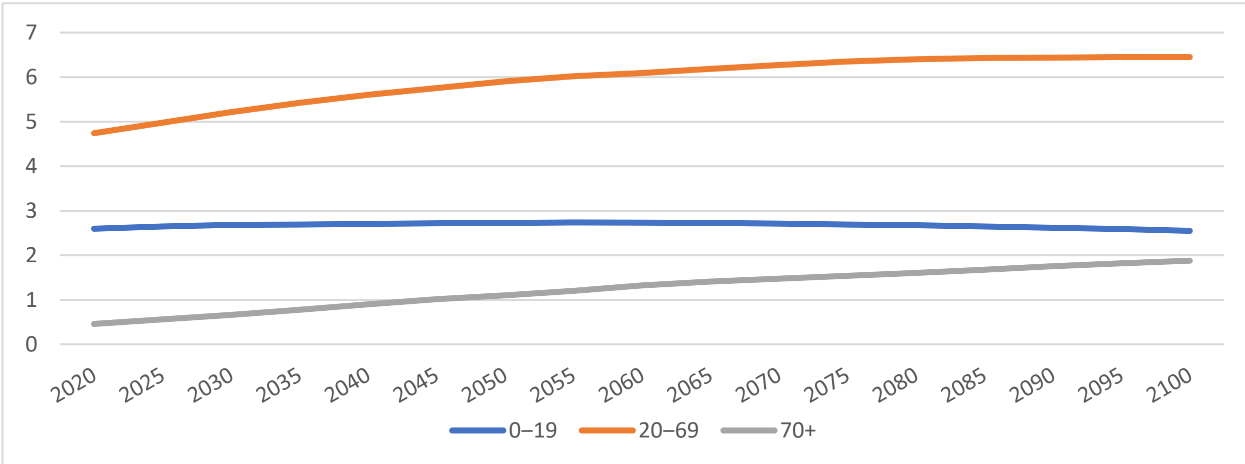
Figure 25. Population of Japan and Italy in 2020 and 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.5 Although population pyramids make it easy to visualize the changing structure of the population, it is also helpful to show the development of the relative size of different age groups. In the paragraphs that follow, we focus on three major age groups: ages under 20 (children and youth), ages 20 to 69 (working population ages) and ages 70 and over (retired). Roughly speaking, the first and third of these represent the two largely financially dependent groups – the young and the elderly – and the second is the primary economically active part of the population. This categorization is not totally distinct, as some in the nominally dependent groups will be economically active and some of the nominally working-age population will be inactive, either through unemployment or disability or by choice. Figure 26 shows the development of these three age groups from 2020 to 2100 for the world population. It can be seen that the youngest group broadly remains about the same size, whereas the working population grows for much of the period and then levels off. The elderly population grows steadily, increasing about fourfold from 458 million to 1,878 million.

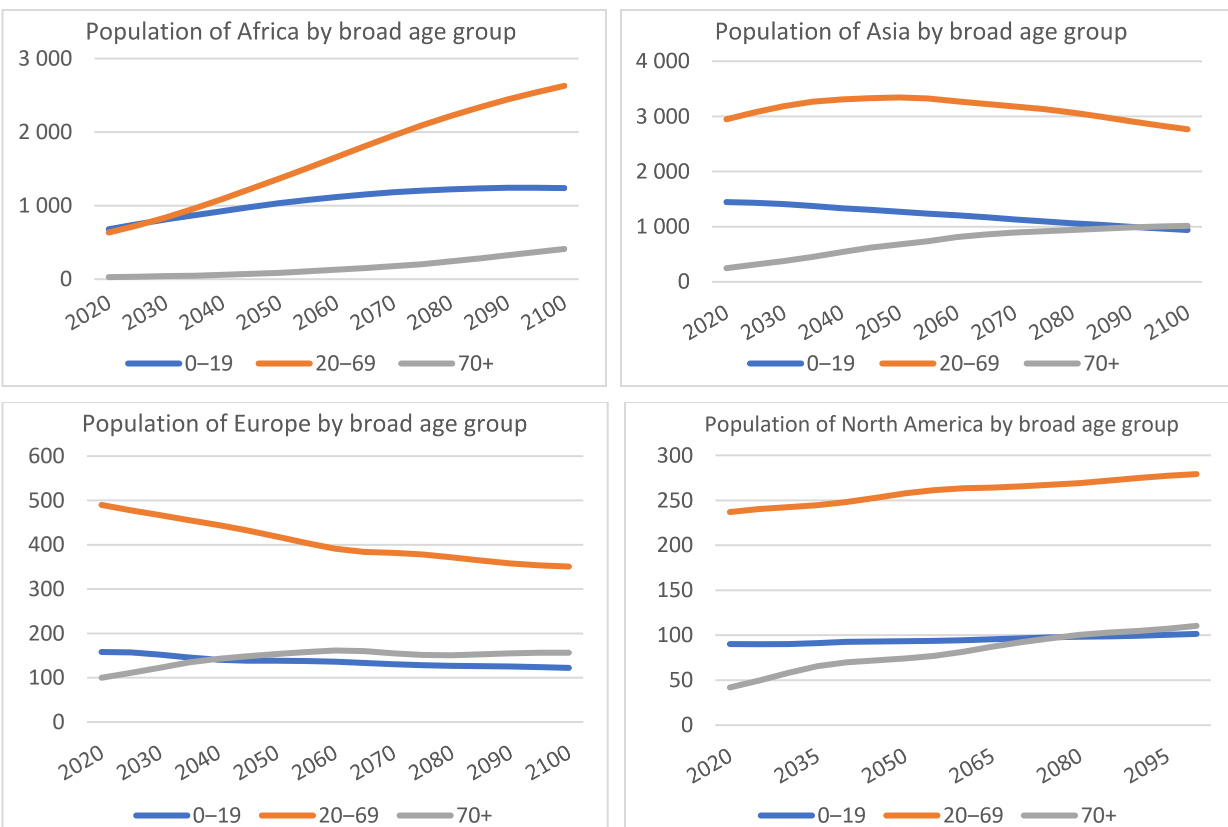
Figure 26. Development of world population from 2020 to 2100 by broad age groups (billions)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.6 The picture is different between the regions and between countries, as illustrated in Figure 27.

Figure 27. Population of regions by broad age groups (millions)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.7 The table below shows the proportions of the population in each of the three broad age groups for each region as they develop from 2020 to 2060.

Table 22. Percentage of the population in each age group, 2020–60

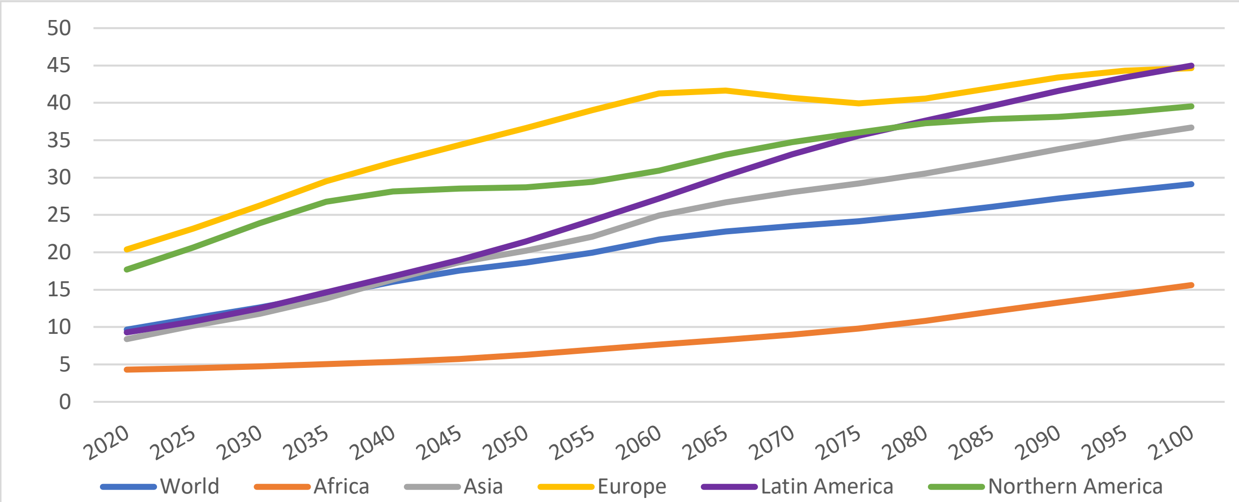
Region	2020	2030	2040	2050	2060
World					
Under 20	33.3	29.4	26.9	25.0	23.4
20 – 69	60.8	60.9	60.0	60.0	59.3
70 and over	5.9	9.8	13.0	15.0	17.3
Africa					
Under 20	50.7	44.6	38.5	33.2	29.0
20 – 69	47.3	52.6	57.1	60.1	61.4
70 and over	2.0	2.8	4.4	6.5	9.6
Asia					
Under 20	31.2	25.8	22.8	21.0	19.9
20 – 69	63.5	63.8	61.8	60.5	58.6
70 and over	5.3	10.4	15.4	18.5	21.5
Europe					
Under 20	21.1	19.3	19.8	19.5	19.4
20 – 69	65.5	61.1	56.8	57.2	55.7
70 and over	13.4	19.6	23.4	23.2	24.9
Latin America and Caribbean					
Under 20	32.1	25.5	21.5	19.5	18.7
20 – 69	62.1	63.8	61.7	58.5	56.1

70 and over	5.8	10.7	16.8	22.0	25.2
Northern America					
Under 20	24.4	22.6	21.5	21.0	20.7
20 – 69	64.2	60.4	60.0	57.6	56.9
70 and over	11.4	17.0	18.5	21.4	22.5

5.8 Africa is the only region where the proportion of the population between 20 and 70 grows steadily over the projection period, although in absolute terms that part of the population grows steadily in Northern America as well, as can be seen in Figure 27. All regions can expect to see growth in the population aged 70 and over, although with Africa starting from quite a low base and Europe largely stagnating in terms of actual numbers over 70, at least from 2050 onwards. A traditional measure of the ageing of the population is the OADR, which is defined as the ratio of the population over retirement age to the population of those of working age. Although age 65 has in the past generally been assumed to be the retirement age for this purpose, the increase in retirement age in many, mostly developed countries, and the increase in expectation of life at 65, means that age 65 may no longer be a sensible point to demarcate between where work ends and retirement begins, especially later on in the projection period. In the analysis that follows we have taken the retired or pensioner population as those age 70 and over. In view of the increasing time spent by young people studying at university or in job-related training, activity rates below age 20 are relatively low in many countries, so we have indicated for this purpose that the working-age population is from 20 to 69 (but see 5.14 and Figure 31 for an alternative view).

5.9 Although a crude measure, the OADR provides an indication for many countries of the financial burden on a population of supporting the elderly. If this is provided through a social security system, there will be direct financial transfers from (and by employers in respect of) those working to those who are in receipt of retirement income or pension. Where pensions are provided through funded private-sector plans, the mechanism for transferring wealth is less explicit, as it occurs through the value of investments held. Since those under age 20 are also mainly financially dependent, for some purposes the total dependency ratio, the ratio of the sum of the population at younger ages and at older ages to the working population, is useful. However, we consider here only the OADR.

Figure 28. OADRs (as %) based on age 70 from 2020 to 2100 by region



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

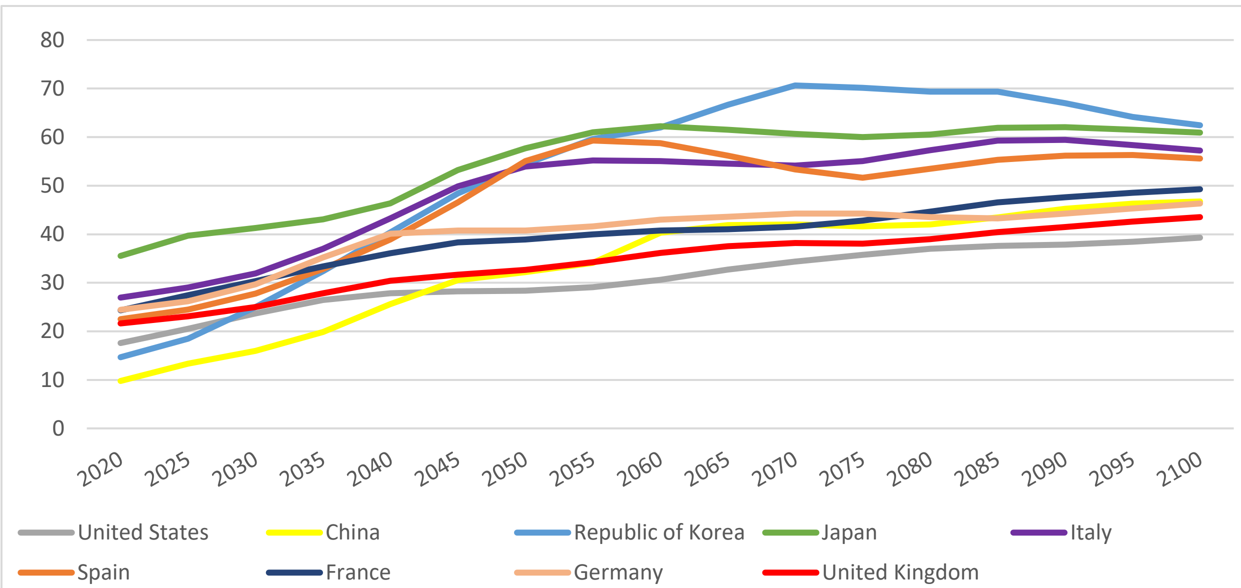
5.10 For Europe, Latin America and the Caribbean, the OADR rises to about 45% in 2100, which represents a doubling from 2020 for Europe, whilst for Latin America and the Caribbean it is nearly a five-fold increase. For Asia and Africa, the increase is about four times, albeit from a fairly low base in the case of Africa. The countries for which the OADR will increase by the largest multiple from 2020 to 2100 and those with the highest resulting OADR are shown in Table 23.

Table 23. Countries with large increases in OADR and highest OADRs in 2100

Countries with largest multiple change of OADR from 2020 to 2100		Countries with highest OADR in 2100	
Qatar	36.1	US Virgin Islands	86.7%
United Arab Emirates	27.8	Albania	84.3%
Oman	20.8	Puerto Rico	72.0%
Bahrain	20.1	Republic of Korea	62.4%
Maldives	16.2	Japan	60.9%
Saudi Arabia	13.5	Martinique	58.8%
Kuwait	12.7	Italy	57.2%
Western Sahara	10.7	Cuba	56.5%
Brunei	10.4	Greece	55.8%
Cabo Verde	8.7	Spain	55.6%

5.11 The Republic of Korea (South Korea) is projected to have one of the largest increases in the OADR over the projection period, ending up higher than Japan, although starting at less than half the Japanese level in 2020, due to an extremely low fertility rate. Other countries, such as Albania, are projected to have high OADRs as a result of outwards migration. Of the larger European countries, Italy and Spain are also expected to be at a very high level by 2100. France, Germany and the United Kingdom are on broadly similar tracks, starting in 2020 between 20% and 25% and projected to reach between 40% and 50% in 2100. The United States is on a parallel but slightly lower trajectory, reaching just short of 40% in 2100. China starts lower at about 10% in 2020 but increases to 47% by 2100. The development of OADRs for these countries is shown in Figure 29.

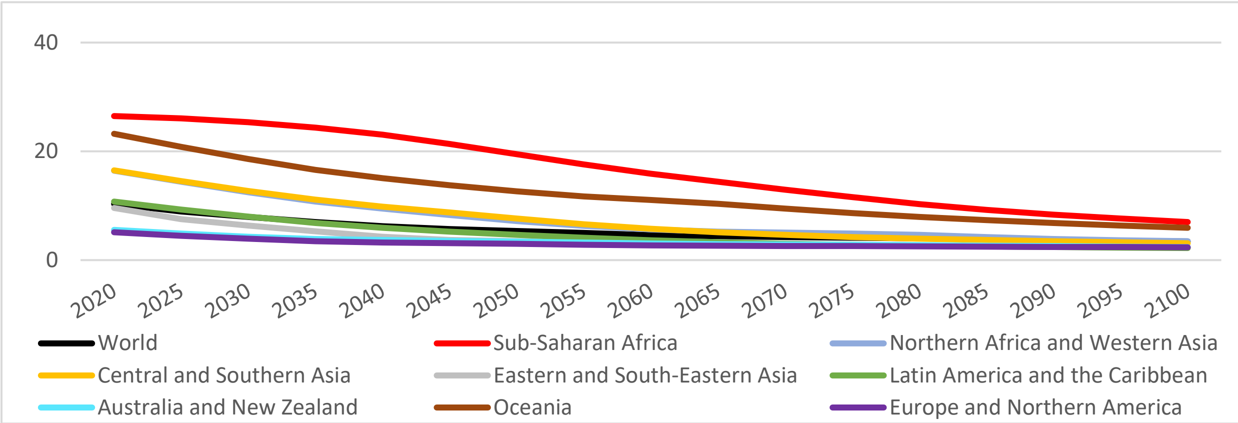
Figure 29. OADRs (%) based on age 70 from 2020 to 2100 for some countries



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.12 Some prefer to focus on the elderly support ratio, which is the inverse of the OADR. Figure 30 shows, by region, the support ratios based on the numbers in the population aged between 20 and 69 available in theory to support the population aged 70 and over.

Figure 30. Support ratios based on age 70 from 2020 to 2100 by regions



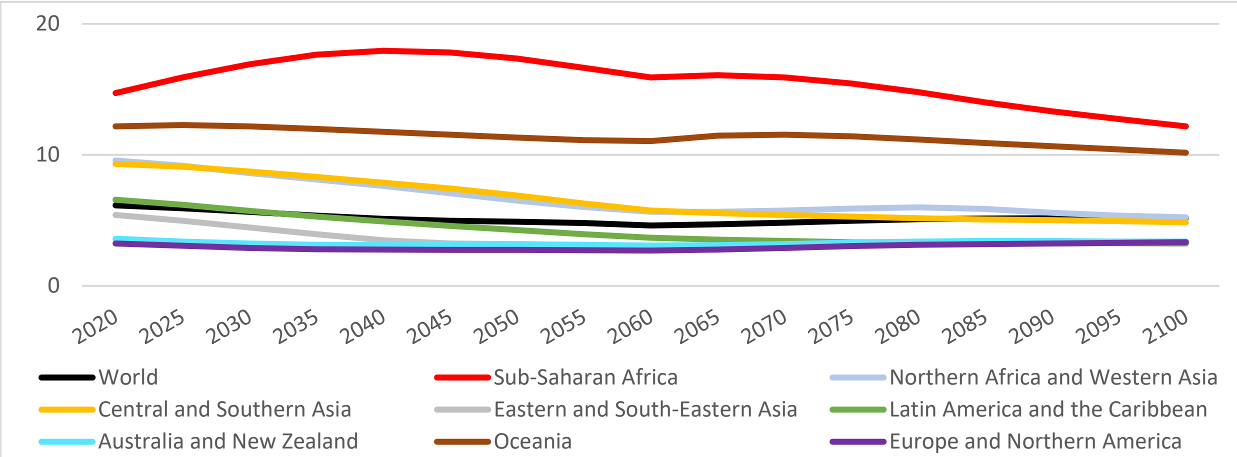
Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.13 For Europe and Northern America and Australia and New Zealand the support ratio on the Medium Projection falls from over 5 in 2020 to 2.4 in 2100. For Eastern and South-Eastern Asia and Latin America and the Caribbean it falls from around 10 in 2020 to 2.2 or 2.3 in 2100. For Central and Southern Asia and Northern Africa and Western Asia it falls from over 16 in 2020 to around 3 to 3.5 in 2100. Only Sub-Saharan Africa and Oceania are expected to have relatively high support ratios in 2100 at 7.0 and 5.9 respectively.

5.14 WPP2019 indicates OADRs and support ratios for deemed retirement ages of 65 and 70, combined with starting ages for working life of 15, 20 and 25. As we have seen in the chapter on mortality, life expectancy is increasing in some regions by about a year every 10 to 15 years. It does not seem appropriate, therefore, to assume a constant deemed retirement age for the next 80 years. Indeed, many countries have already enacted legislation to raise retirement age. To illustrate the impact that a rising retirement age has on the progression of support ratios, Figure 31 shows the support ratios on the assumption that the deemed retirement age rises from 65 in 2020 to 70 in 2060, and then to 75 in 2100. This broadly has the effect of flattening the support ratio curve for the four most demographically mature SDG regions and also, at a significantly higher level, for Oceania. As calculated here, the adjustment to retirement age is somewhat over-simplified, but it serves to illustrate how support ratios may not in practice experience such significant declines as would appear from using a fixed age of deemed retirement throughout the projection. [19]

[19] For further discussion see IAA PIWG (2016)

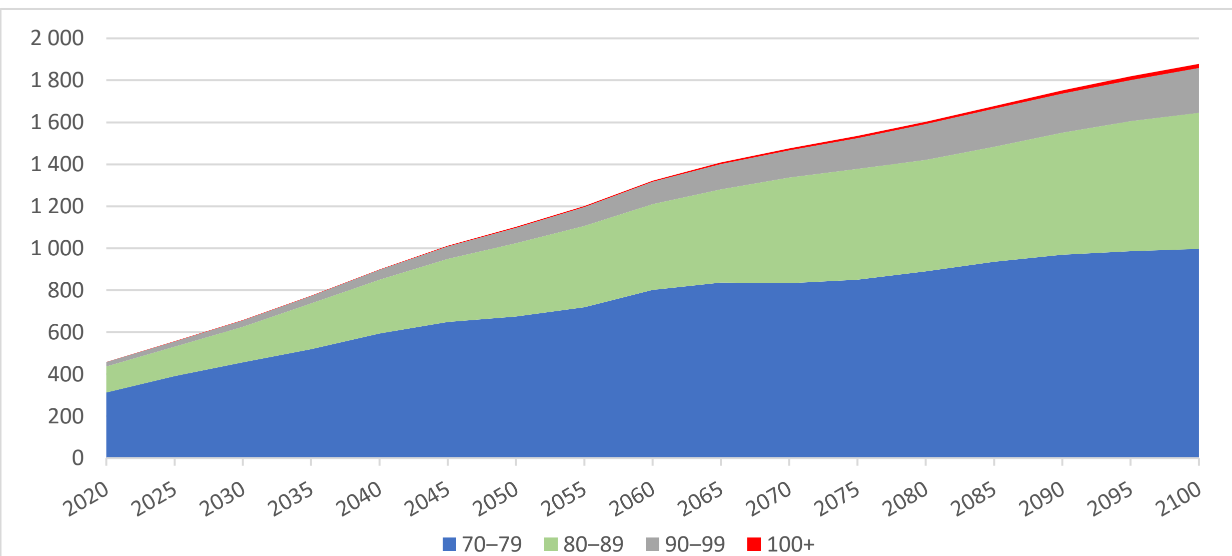
Figure 31. Retired support ratio by SDG region with retirement age rising from 65 to 75 by 2100



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.15 While the OADR based on a constant retirement age of 70 provides some insight into the likely pressures of financing income for the elderly, it is well known that health care expenses rise steeply with age, and so the rapidly growing population aged 80 and above is particularly significant. Figure 32 shows the growth of the 70–79, 80–89, 90–99 and 100-and-over components of the projected world population on the Medium Projection in millions.

Figure 32. Graph showing growth of components of world over 70 population, 2020–2100 (millions)



Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.16 The different growth patterns for the over-70 population are illustrated separately for the regions below in Figure 33.

Figure 33. Graph showing growth of components of over-70 population by region, 2020–2100 (millions)

Source: Graph drawn by the authors from WPP2019. See page 1 for citation.

5.17 All countries are projected to see a considerable growth in those over 80 and over 90, even if the population over 70 is already quite mature and not expected to increase much (indeed, the population aged 70 and over in Japan is expected to fall from 27.5 million to 23.7 million between 2020 and 2100). Table 24 shows the projected increases between 2020 and 2100 for a selection of larger countries.

Table 24. Growth of very elderly population from 2020 to 2100 (millions)

	Population 80 and over			Population 90 and over			Population 100 and over		
Country	**2020**	**2100**	**Multiple**	**2020**	**2100**	**Multiple**	**2020**	**2100**	**Multiple**
Brazil	4.2	28.2	6.8	0.7	9.8	14.8	0.02	1.23	58.0
China	26.6	151.1	5.7	2.9	45.3	15.9	0.07	4.55	60.9
Germany	5.9	10.7	1.8	1.0	3.6	3.6	0.02	0.33	17.2
India	13.3	128.2	9.7	1.3	29.1	23.0	0.05	1.72	35.9
Italy	4.5	7.6	1.7	0.8	2.9	3.5	0.02	0.24	14.3
Japan	11.4	15.1	1.3	2.4	6.4	2.7	0.08	0.85	10.8
United States	13.1	53.0	4.0	2.8	18.7	6.8	0.10	1.73	17.8

5.18 Those countries with the highest proportion of their total population in the 80-and-over, 90-and-over and 100-and-over age categories are shown in Table 25.

Table 25. Countries with highest proportion of population over 80, 90 and 100 in 2100

Largest proportion of population aged 80+		**Largest proportion of population aged 90+**		**Largest proportion of population aged 100+**	
Country	**Percentage**	**Country**	**Percentage**	**Country**	**Percentage**
US Virgin Islands	25.3	Puerto Rico	13.1	Republic of Korea	1.5
Puerto Rico	24.1	US Virgin Islands	10.0	China, Hong Kong	1.4
Albania	22.5	Martinique	8.8	Martinique	1.4
Republic of Korea	20.5	Republic of Korea	8.7	US Virgin Islands	1.3

Japan	20.2	Japan	8.5	Singapore	1.2
Italy	18.9	Guadeloupe	7.4	Puerto Rico	1.2
Greece	18.8	Greece	7.4	Japan	1.1
Martinique	18.6	Italy	7.2	Guadeloupe	1.1
Spain	18.3	Singapore	7.0	Chinese Taipei	1.0
Cuba	17.6	Albania	6.9	China, Macao	1.0

5.19 Globally, the population of centenarians, which was only 34,000 in 1950, is expected to grow from 573,000 in 2020 to 19.1 million in 2100. Just over half of these will be living in China, the United States, India, Brazil and Japan.

5.20 While health care expenditure increases significantly with age, in many populations the increase in expectation of life might be expected to be associated with an increase in healthy expectation of life. Many people may remain physically fit for longer, with serious deterioration in health status tending to start later and later as time goes on. At the same time, other segments of the population are in a state of ill health; for example, from obesity and other significant non-communicable diseases. To the extent that expectation of life increases as a result of successfully combating cancers, diabetes and cardiovascular problems while not delaying the physical ageing process, the result could be very large populations of elderly people with an increasing number of multi-morbidities requiring significant levels of support through social care, especially as all countries may have less informal care available within family units as a consequence of families not living closely together as they did in the past.[20]

[20] For further discussion see PIWG (2017)

Appendix 1. Description of WPP2019 Methodology

A1 Overall methodology

A1.1 The WPP2019 projections are carried out using a standard component methodology, whereby the estimates of population by age and gender at one mid-year point for a country are moved forward twelve months by adding births generated by the fertility model, subtracting deaths generated by the mortality model and adjusting for estimated net international migration into (or out of) the country. This is in line with the approach taken by most actuaries and demographers for population projections. The key methodological issues concern the selection of assumptions for fertility, mortality and migration.

A2 Fertility

A2.1 The UN Population Division assumes that there are three phases to fertility and that each country can be categorized into one of these phases:

1. High-fertility/pre-transition period. During this period, the TFR is greater than 5.5 per female. Countries in phase 1 often had a high percentage of their population in rural areas. However, for the purposes of WPP2019 there are no countries still in phase 1.
2. Phase 2 is the fertility-transition phase between phase 1 and phase 3. Most countries are in this phase at various times.
3. Low-fertility/post-transition period. During this period, the TFR is usually below the long-term replacement rate of about 2.1. In WPP2019 there are 40 countries considered to be in phase 3, this number having risen from 25 in WPP2012.

A2.2 Phase 2 is modelled as a systematic decline in fertility, accompanied by random noise terms. The pace of the systematic decline is modelled as a function of its current level by a double-logistic decline function, with the parameters estimated using a Bayesian hierarchical model in order to provide country-specific distributions for the decline parameters. These distributions are informed by historical trends within the country, as well as by the variability in historical fertility trends of all countries which have already experienced a fertility transition from high to low fertility.

A2.3 The methodology followed was firstly to project the TFR of each country and then to sub-divide that rate by age of mother. For each country in phase 2 that has experienced a decline in fertility through 2015–20, the UN Population Division generated 186,000 double-logistic curves, representing the uncertainty in the double-logistic decline function of those countries. Then, during a country's transition phase, these curves were used to calculate 100,000 probabilistic projections of TFRs for each country. In general, TFRs that were not already in phase 3 by 2015–20 were projected to converge ultimately to 2.1.

A2.4 The pace of fertility change, the level of fertility and the timing of the end of phase 2 and the start of phase 3 vary for each of the 100,000 projected fertility trajectories for a country that has not reached phase 3 by 2015–20. Future trajectories consist of a combination of cases with total fertility in phase 2 or 3, until eventually all trajectories are in phase 3.

A2.5 In phase 3 the projection procedure uses a time series model based on the assumption that fertility will in the long run approach and fluctuate around country-specific ultimate levels based on a Bayesian hierarchical model. The long-run fertility levels reflect each country's own historical experience, but are also informed by statistical distributions that incorporate the empirical experience of all low-fertility countries that have already experienced a recovery from sub-replacement levels. The unweighted mean value for the global distribution based on the 40 countries or areas that have already entered phase 3 is 1.78 children per woman in 2095–2100.

A2.6 Some countries with fertility below replacement level have experienced recent downward trends in total fertility after a period of modest but sustained increase. To ensure a smooth transition between the last estimation periods and the first projection intervals, the level of fertility projected for 2020–25 and 2025–30 was adjusted by blending the most recent observed trend with the unadjusted model prediction respectively, by weights given to the most recent country trend of two-thirds in 2020–25 and one-third in 2025–30, and the complement used as the weight for the model prediction. Such post-adjustment was applied to five countries (Finland, Italy, Japan, Luxembourg and Ukraine) and all probabilistic trajectories were proportionately adjusted based on these adjustment factors for the median trajectory of each country.

A2.7 To project age-specific fertility rates (for female five-year age groups for every five calendar years), a standard approach was applied to each country for all future years, based on the most recent national trends. Age-specific fertility rates by five-year age group were calculated, consistent with the total fertility for each five-year period by means of a standard approach.

A2.8 It was assumed that the transition in each trajectory from the observed national trend to the global model age pattern of fertility was dependent on (a) when the TFR entered phase 3, and the country's trajectory reached its lowest level of fertility and (b) whether the projected fertility for a given period is higher than the TFR in 2095–2100 in the Medium variant projection. For some countries with low fertility that already have a later mean age at childbearing than the global model age pattern, the fertility pattern was held constant when the highest mean age was reached in phase 3.

A3 Mortality

A3.1 The following steps are taken to develop estimates of mortality rates by country, age and gender:

1. estimating and modelling expectations of life of females at birth;
2. modelling the difference (gap) between male and female expectations of life to derive male expectations of life;
3. making adjustments to resulting expectations of life;
4. developing mortality rates by quinquennial age and quinquennial period;
5. modelling reductions in expectations of life due to the impact of HIV/AIDS in countries in which this cause of death is material; and
6. interpolating the quinquennial age/calendar-year mortality rates to derive annual mortality rates for individual years.

A3.2 The primary set of projections is carried out using a probabilistic method based on 100,000 simulations from 2020 to 2100, as described in 1.8, incorporating probabilistic projections of life expectancy at birth for females.

A3.3 It is assumed that the different levels and shape of the mortality curve between countries reflects a mortality transition model, where the first phase of growth in life expectancy is the result of improved hygiene and nutrition, with improvement accelerating as child mortality is reduced by social and economic development, including the adoption of childhood immunization programs to reduce the incidence of infectious diseases. The second phase is characterized by a slower increase in life expectancy, resulting from further progress against most infectious diseases and emphasis on combating non-communicable diseases which mainly affect older people. With the focus being on life expectancy at birth, the impact of improved mortality at older ages is much less than reductions in child mortality.

A3.4 Based on this two-phase approach, the WPP2019 models use a double-logistic improvement function to represent the pace of systematic gains in female life expectancy at birth, with a probabilistic variation specified as a random walk with drift. The random term gives rise to the probabilistic projections of mortality, with 100,000 projected trajectories being generated that create a distribution of outcomes. Individual trajectories are constrained by considerations of avoiding an excessive increase in the maximum life at death and the maximum female life expectancy in countries with high life expectancy. Full details of the methods used are set out in the WPP2019 methodology paper.[21]

A3.5 The next step in the modelling process considers the gap between female and male life expectancy, which was modelled using an autoregressive model with female life expectancy serving as a covariate. The pattern of decline in the gender gap at high levels of life expectancy, which has been observed for high-income countries and for some emerging economies, was assumed to apply also to other countries and for the future. In practice, this results in the gap being projected to widen while female life expectancy is low, but then to narrow once female life expectancy has reached 75 years, continuing until female life expectancy reaches 86 years, after which the gap is assumed to remain constant. The application of this method involved generating 100,000 trajectories of the life expectancy gap for each country, and combining those with paired values of a similar number of trajectories for the female expectation of life at birth, in order to produce a corresponding set of trajectories for male expectation of life at birth.

A3.6 Although this methodology was considered by the UN Population Division to work well for the majority of countries, there were some that have experienced much faster or much slower improvements in recent years for which the methodology did not produce results which the UN considered satisfactory. Various adjustments were made where the projected mortality was deemed to be too high or too low.

A3.7 For another 20 countries, recent trends and levels of life expectancy at birth were considered by the UN Population Division to have been negatively affected by crises, such as political upheaval, armed conflict, public health issues and environmental disasters. These countries were assumed to experience slower mortality improvement over the next five to ten years, resuming a 'normal' trajectory thereafter. As mentioned in 3.24, this seems to ignore the possibility that these countries are experiencing a genuine phenomenon of a reduction in the long-prevailing trend of significant improvement in rates of mortality and reflects an unwillingness to regard this change in trend as a significant feature of the data. A variant projection which treats the

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21 World Population Prospects 2019: Methodology of the United Nations Population Estimates and Projections. https://population.un.org/wpp/Publications/Files/WPP2019_Methodology.pdf

slowing down of mortality improvement as a more general phenomenon across all countries with low levels of mortality might be appropriate.

A3.8 The ‘top-down’ approach to determining mortality assumptions then needs to be converted into sets of mortality rates, which WPP2019 does using five-year age groups by gender and modelling country-specific historical trends, using a modified Lee–Carter model, where there are good-quality data (this is the case only for 25 countries). The assumptions for another 14 countries, together with 25 countries with less than 90,000 inhabitants in 2019, were taken directly from model life tables. For the remaining countries there was a blending of two methods which gave decreasing weight over time to a model of typical age-specific patterns of mortality improvement by level of mortality and increasing weight to a model life table.

A3.9 As discussed in Chapter 3, the approach of WPP2019 to the projection of mortality appears to actuaries to be somewhat back to front. It is generally understood by actuaries that expectations of life at birth are a function of the underlying mortality rates – their behaviour is a consequence of changes in mortality rates, not the driver. We would also question the validity of projecting gender differences in expectation of life at birth as a way of deriving male expectations of life at birth. This measure would also appear to be a function of the underlying changes in mortality rates rather than a driver.

A3.10 A consequence of the approach to mortality assumptions in WPP2019 is that mortality rates by age and gender come out as an afterthought rather than driving the underlying mortality assumptions process. In particular we would argue that the WPP2019 projections give insufficient focus to analysis of future mortality at older ages and so may not represent well the projected future growth of the population over retirement age and at advanced ages. It should also be noted that the WPP projections pay no attention to cohort expectations of life and ignore cohort characteristics in mortality developments, which have been quite pronounced for some countries.

A4 International migration

A4.1 As in previous world population projections, the UN Population Division projects net migration at country level, making use of:

- official country-level estimates of net international migration or its components (immigration and emigration);
- information on labour migration;
- data about undocumented or irregular migrants, refugees and asylum-seekers, as prepared by the Office of the UNHCR, for example; and
- estimates of stocks of foreign-born persons, prepared by the UN Population Division.

A4.2 For international migration, excluding refugees, the UN Population Division assumed that recent levels, if reasonably stable, would continue until 2045–50. For all countries, the projected net migration level in 2045–50 is then assumed to remain constant until the end of the projection period. In other words, for most countries the net migration flow is projected to remain essentially constant throughout the projection period. In our view it would be more realistic to assume that the migration flows reduce in the later years of the projection.

A4.3 It was generally assumed that refugees would return to their country of origin within five to ten years. If a country was expected to experience movements of both refugees and other international migrants, the figures were aggregated to capture total net migration during a given period, except for those countries where refugee movements were already included in international migration data.

A4.5 As it could take a significant time for the underlying conditions giving rise to the refugee flows to stabilize, we suggest that a longer period for the reversal to fully take effect would be more realistic.

A4.6 The total number of net migrants should then be distributed by age and gender. Where it was possible to estimate the age and gender distribution of international migrants, these distributions were used to determine the most suitable model for projecting future migration or, in some cases, used directly as inputs and the distribution of net migrants by age and gender was generally kept constant over the projection period. Where distributions by age and gender were not available, the gender distribution was based on what was known about the typical distribution for different types of migration flow. For example, the gender distribution of those migrating for work would differ from those migrating to achieve family reunification.

A4.7 In order to ensure that globally net migration sums to zero, the bottom-up approach of setting migration assumptions at the country level was adjusted to ensure consistency at the global level.

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Appendix 3. Glossary

Cohort-component projection model. A period-to-period model using the fertility, mortality and international migration components to project population.

Cohort fertility rate (or completed family size). For women born in a given year, the average number of children born to a woman over her lifetime. This is also referred to in Vollset et al. (2020) as the 'completed cohort fertility at age 50 years' (CCF50).

Demographic dividend. The economic growth potential that can result from shifts in a population's age structure, mainly when the share of the working-age population is larger than the non-working-age share of the population.

Dependency ratio. The ratio of the number of dependants to the number of those who are supporting them. The total dependency ratio includes all dependants, including children, the disabled and those who are 'old' (those of at least a certain age, such as 65 or 70).

Elderly support ratio. The inverse of the old-age dependency ratio.

Fertility rate. The probability of a woman bearing a child, sometimes measured relative to a particular age.

Life expectancy. The expected number of years for an individual or group of individuals as of a given period. Cohort life expectancy is the life expectancy of a specified group, usually of those born in a particular calendar year, allowing for changes in mortality over time. Period life expectancy is the life expectancy calculated based on mortality experience during a given year.

Migrants. The number of people who move from one place to another. An emigrant is a person who moves away from a particular location, often a country. An immigrant is a person who moves to particular location, often a country. An international migrant is a migrant from one country to another country. Net migration is the number of immigrants minus the number of emigrants.

Mortality rate. The probability of dying at a particular age and gender during a specified year.

Natural increase. The change in the population as a result of births and deaths without allowing for migration.

Old-age dependency ratio (OADR). The ratio of the population at retirement age and over to the population of those of working age.

Population pyramid. A pictorial chart that usually shows slices of population by quinquennial age grouping and sometimes gender.

Replacement rate. The number of children that a couple would need to have over the course of their reproductive years in order to replace themselves.

Support ratio. The ratio of the population of those of working age to the population at retirement age and over.

Total fertility rate (TFR). The average number of live births a hypothetical cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates by age of a given period and if they were not subject to mortality. It is expressed as live births per woman.

Appendix 4. Comparison of Key Features of WPP2019 and IHME Projections in 2100

	Japan	USA	Canada	UK	Germany	France	Spain	Italy	India	China	Nigeria	Pakistan	DR Congo	Indonesia	Ethiopia
Total fertility rate in 2100															
WPP 2019	**1.67**	**1.82**	**1.71**	**1.78**	**1.74**	**1.83**	**1.69**	**1.63**	**1.71**	**1.77**	**2.26**	**1.81**	**2.07**	**1.78**	**1.80**
IHME	**1.032**	**1.53**	**1.58**	**1.61**	**1.35**	**1.78**	**1.24**	**1.23**	**1.29**	**1.47**	**1.69**	**1.31**	**1.75**	**1.51**	**1.33**
Expectation of life at birth in 2100 – males															
WPP 2019	**90.5**	**87.1**	**90.0**	**89.3**	**89.1**	**89.1**	**90.0**	**90.7**	**80.5**	**86.5**	**67.7**	**75.4**	**70.8**	**82.5**	**80.0**
IHME	**84.8**	**80.6**	**83.8**	**83.7**	**83.7**	**84.8**	**85.4**	**85.4**	**78.0**	**82.6**	**79.0**	**79.2**	**74.1**	**77.3**	**80.1**
Expectation of life at birth in 2100 – females															
WPP 2019	**96.6**	**90.1**	**93.2**	**91.8**	**92.6**	**94.5**	**95.3**	**94.6**	**83.0**	**88.8**	**72.3**	**79.5**	**76.3**	**85.0**	**83.1**
IHME	**89.9**	**84.0**	**86.8**	**86.1**	**86.3**	**88.6**	**88.6**	**88.4**	**80.7**	**86.0**	**81.9**	**79.0**	**79.8**	**81.8**	**85.0**
International migration in 2100															
WPP 2019	**48800**	**1018250**	**253600**	**165800**	**156100**	**68300**	**39000**	**58500**	**494500**	**310100**	**-62000**	**-165400**	**-15000**	**-93900**	**-12000**
IHME	**45100**	**577000**	**90400**	**116000**	**110000**	**44600**	**11900**	**29500**	**520000**	**359000**	**-32400**	**-186000**	**-185000**	**-17100**	**-25000**
Total population in 2100 (millions)															
WPP 2019	**75.0**	**433.9**	**57.0**	**78.1**	**74.7**	**65.5**	**33.2**	**40.0**	**1447.0**	**1065.0**	**732.9**	**403.1**	**362.0**	**320.8**	**294.4**
IHME	**59.7**	**335.8**	**44.1**	**71.4**	**66.4**	**67.2**	**22.9**	**30.5**	**1093.2**	**731.9**	**790.7**	**248.4**	**246.4**	**228.7**	**223.4**