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REPORT

Economic Analysis of the Contributions of Capture Fisheries and Aquaculture to Future Food Security

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ABSTRACT

There is much concern about future food supply and demand on the basis of expected population growth as well as due to the large number of people still suffering from undernourishment. At the same time there may be limits to the potential for expanded production from fisheries, aquaculture and agriculture. What is often overlooked in many studies of future food security is the economic impact of changes in supply and demand, for example due to changes in food prices, household income and consumer preferences. This report takes an economic approach to analysing supply of and demand for food up to 2030, with an emphasis on fisheries and aquaculture. Five scenarios are considered, with the average annual growth rate in production varying between 2.4 and 5 percent, while there is little change in capture fishery production. Variations in the aquaculture grow rates are found to have important consequences not only for future fish prices, but also for per capita fish consumption up to 2030. Sub-Saharan Africa is particularly affected by the growth rate in aquaculture production.

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1. POPULATION AND DEMOGRAPHY

Population size is one of the main drivers for future food demand. This chapter examines the development in population until 2030 and onwards – at the world level as well as some regional and national variations. The chapter also examines various demographic dimensions of the population such as urban and rural settlement, age, sex and level of education – all of which may impact the demand for food.

1.1 Population and future population growth

The 2017 world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to the United Nations (UN) (United Nations, 2017). The global population projections of the World Population Prospects: The 2017 Revision are presented in Table 1. The findings estimate a 95 percent probability that the global population will be between 8.4 and 8.7 billion in 2030, between 9.4 and 10.2 billion in 2050 and between 9.6 and 13.2 billion in 2100.

Table 1: Population of the world and regions. 2017, 2030, 2050 and 2100, according to the UN medium-variant projection

	Population (millions)				
Region	**1950**	**2017**	**2030**	**2050**	**2100**
World	2,536	7,550	8,551	9,772	11,184
Africa	229	1,256	1,704	2,528	4,468
Asia	1,404	4,504	4,947	5,257	4,780
Europe	549	742	739	716	653
Latin America and the Caribbean	169	646	718	780	712
Northern America	173	361	395	435	499
Oceania	13	41	48	57	72

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision. New York: United Nations

Future population growth is highly dependent on the fertility rate, as relatively small changes in the frequency of childbearing can generate large differences in total population when projected over several decades (United Nations, 2017). In the UN's medium-variant projection, it is assumed that the global fertility level will decline from 2.5 births per woman in 2010-15 to 2.2 in 2045-50, and then fall to 2.0 in 2095-2100 (United Nations, 2017).

For comparison, Table 2 presents corresponding global population projections produced in 2015 by the World Population Programme (POP) together with the IIASA and Wittgenstein Centre for Demography and Global Human Capital (Wittgenstein Centre, 2015; IIASA, 2016). Although the predictions broadly align up until 2050, the UN and IIASA/Wittgenstein Centre use different assumptions about future fertility and mortality trajectories, which result in divergent population projections in the long run (IIASA, 2016). For 2050, the difference between the predictions is 632 million people, whereas it reaches 2.2 billion by 2100. While the UN expects an increasing global population between 2050-2100, IIASA/Wittgenstein

predicts a population in 2100 that is likely to have declined from its 2050-level. As the tables show, Africa is the major source of the difference in predictions[1].

Table 2: Population of the world and regions. 2015, 2030, 2050 and 2100, according to the Wittgenstein database, Medium (SSP2) scenario

	Population (millions)		
	2030	**2050**	**2100**
World	8,256	9,140	8,948
Africa	1,526	2,017	2,620
Asia	4,828	5,107	4,355
Europe	753	754	702
Latin America and the Caribbean	702	758	684
Northern America	400	447	520
Oceania	47	57	66

***Source**:* Wittgenstein Centre for Demography and Global Human Capital (2015). Wittgenstein Centre Data Explorer Version 1.2. Available at: http://www.wittgensteincentre.org/dataexplorer

More than half of the anticipated growth in global population up to 2050 is expected to occur in Africa, followed by Asia as the second largest contributor. In Latin America and the Caribbean, Northern America and Oceania, growth is projected to be much more modest, whereas Europe is the only region with a smaller population in 2050 than in 2017.

The projections include some notable findings at the country level. The UN notes that around mid-2020s, the population of India is expected to surpass that of China. In 2017, the population of China is estimated at approximately 1.41 billion compared with 1.34 billion in India. In 2024, both countries are expected to have roughly 1.44 billion people. Thereafter, India's population is projected to continue growing for several decades, while the population of China is expected to continue its slow decline (United Nations, 2017). China's working-age population has been declining since 2012: After reaching 925 million in 2011, it declined to 911 million in 2015 and is forecast to reach 830 million in 2030. The number of people aged 16-59 is expected to decline sharply after this – by 7.6 million on average each year from 2030, reaching 700 million in 2050 (Xinying, 2016). At the same time, life expectancy and the population of elderly people is increasing.

Among the current 10 most populous countries of the world (Table 3), one is in Africa (Nigeria), five are in Asia (Bangladesh, China, India, Indonesia, and Pakistan), two are in Latin America (Brazil and Mexico), one is in North America (United States of America), and one is in Europe (Russian Federation). Amongst these, Nigeria's population, currently the seventh largest in the world, is growing most rapidly. Consequently, the population of Nigeria is projected to surpass that of the United States shortly before 2050, at which point it would become the third largest country in the world in terms of population. In 2050, the respective populations in six of the 10 largest countries are expected to exceed 300 million: China, India, Indonesia, Nigeria, Pakistan, and United States of America (in alphabetical order).

[1] Apart from future fertility and mortality assumptions, there are two other factors explaining the difference: An important point is that Wittgenstein/IIASA adds a differentiation by level of education, which tends to relate to the fertility rate. Another difference may lie in the reading of the current fertility levels (IIASA, 2016).

Table 3: Population projections for the current 10 most populous countries in the world. Millions

	1950	2017	2030	2050	2100
Bangladesh	38	165	186	202	174
Brazil	54	209	225	233	190
China	554	1,410	1,441	1,364	1,021
India	376	1,339	1,513	1,659	1,517
Indonesia	70	264	296	322	306
Mexico	28	129	148	164	151
Nigeria	38	191	264	410	794
Pakistan	38	197	244	307	352
Russian Federation	103	144	141	133	124
United States	159	324	355	390	447
Top 10	1,458	4,372	4,813	5,184	5,076
World	2,536	7,550	8,551	9,772	11,184

***Source**:* United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision. New York: United Nations

Much of the overall increase in population between 2017 and 2050 is projected to occur either in high fertility countries, mostly in Africa, or in countries with large populations. From 2017 to 2050, it is expected that half of the world's population growth will be concentrated in just nine countries (Table 4): India, Nigeria, the Democratic Republic of the Congo, Pakistan, Ethiopia, the United Republic of Tanzania, the United States of America, Uganda and Indonesia (ordered by their expected contribution to total growth) (United Nations, 2017).

Table 4: Largest contributions to growth from 2017 to 2050 - nine countries accounting for half of the world's population growth. Millions

	Increase from 2017 to 2050
India	320
Nigeria	219
The Democratic Republic of Congo	116
Pakistan	110
Ethiopia	86
The United Republic of Tanzania	81
the United States of America	66
Uganda	63
Indonesia	58
Top 9	1,119
World	2,222

***Source**:* United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision. New York: United Nations

Population growth remains especially high in the group of 47 countries designated by the United Nations as the least developed countries (LDCs), including 33 countries in Africa[2]. The LDCs continues to have a relatively high level of fertility, which stood at 4.3 births per woman in

[2] The group of least developed countries, as defined by the United Nations General Assembly in its resolutions (59/209, 59/210, 60/33, 62/97, 64/L.55, 67/L.43, 64/295 and 68/18) included 47 countries as of 4 June 2017: 33 in Africa, 9 in Asia, 4 in Oceania and one in Latin America and the Caribbean.

2010-15. As a result, the population of these countries has been growing rapidly, at around 2.4 percent per year (United Nations, 2017). Although this growth rate is projected to slow, the population in this group of countries is expected to nearly double in size from 1 billion inhabitants in 2017 to 1.9 billion in 2050, and further to 3.2 billion in 2100. Among them, the populations of Angola, Burundi, Niger, Somalia, the United Republic of Tanzania and Zambia are projected to be at least five times as large in 2100 as they are today. Between 2017 and 2050, the populations of 26 African countries are projected to expand to at least double their current size (United Nations, 2017).

The concentration of global population growth in the poorest countries presents a considerable challenge to governments in implementing the 2030 Agenda for Sustainable Development, which seeks to end poverty and hunger, expand and update health and education systems, achieve gender equality and women's empowerment, reduce inequality and ensure that no one is left behind (United Nations, 2017).

Fertility has declined in nearly all regions of the world in recent years. Also in Africa, where fertility levels are the highest of any region, total fertility has fallen from 5.1 births per woman in 2000-05 to 4.7 in 2010-15 (United Nations, 2017). Europe has been an exception to this trend in recent years, with total fertility increasing from 1.4 births per woman in 2000-05 to 1.6 in 2010-15 – which is still less than the required replacement rate. More and more countries now have fertility rates below the level required for the replacement of successive generations (roughly 2.1 births per woman), and some have been in this situation for several decades (United Nations, 2017). During 2010-15, fertility was below the replacement level in 83 countries comprising 46 percent of the world's population. The 10 most populous countries in this group are China, the United States of America, Brazil, the Russian Federation, Japan, Viet Nam, Germany, the Islamic Republic of Iran, Thailand, and the United Kingdom (in order of population size).

1.2 Population ageing

A reduction in global fertility levels results not only in a slower pace of population growth but also in an aging population; as the population growth rate has fallen over time, the proportion of older persons has increased while that of younger persons has decreased. Although the projected population growth varies from region to region, a projected increase in life expectancy together with declines in fertility rates will result in significant ageing of the population in all regions in the longer run (United Nations, 2017). In 2017, there are more than twice as many children under the age of 15 in the world as there are older persons aged 60 or above. In 2050, the number of persons aged 60 or above will be roughly equal to the number of children under the age of 15. The number of persons aged 60 or above is expected to more than double by 2050 and to more than triple by 2100, rising from 962 million globally in 2017 to 2.1 billion in 2050 and 3.1 billion in 2100 (United Nations, 2017).

As a proportion of world population, the segment aged 60 or above is expected to increase from 13 percent in 2017 to 33 percent by 2050 (United Nations, 2017). As shown in Table 5, 25 percent of the European population is already aged 60 years or over, and this proportion is projected to reach 34 percent in 2050 and then remain around that level in the second half of the century. Given the reality of demographics, the retirement age will likely have to increase. Populations in other regions are also projected to age significantly over the next several decades and continuing through 2100. Asia and Latin America and the Caribbean will be among the most rapidly ageing regions, where the proportion of inhabitants above 60 will more than

double from the current 12 percent to 25-26 percent by 2050, reaching the current European proportion. Africa, which has the youngest age distribution of any region, is also projected to experience a rapid ageing of its population. Although the African population will remain relatively young for several more decades, the percentage of its population aged 60 or over is expected to rise from 5 percent in 2017 to around 6 percent in 2030, 9 percent in 2050 and then nearly 20 percent by the end of the century (United Nations, 2015, 2017).

Table 5: Percent of population aged 60 and over. Globally and by region

	2017	**2030**	**2050**
World	13	29	33
Africa	5	6	9
Asia	12	17	25
Europe	25	30	34
Latin America and the Caribbean	12	17	26
Northern America	22	26	28
Oceania	17	20	23

Source: United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 and 2017 Revisions. New York: United Nations

Gains in life expectancy have been significant in recent years. Globally, life expectancy at birth rose by 3.6 years between 2000-05 and 2010-15 – from 67.2 to 70.8 years (United Nations, 2017). By 2045-50, it is expected to rise to 77 years. Over the period 2000-15, all regions shared in the increase of life expectancy, with the greatest gains in Africa where life expectancy rose by 6.6 years. In 2010-15, life expectancy in Africa stood at 60.2 years, compared to 71.8 in Asia, 74.6 in Latin America and the Caribbean, 77.2 in Europe, 77.9 in Oceania and 79.2 in Northern America (United Nations, 2017). Africa is projected to gain nearly 11 years of life expectancy by mid-century, reaching 71 years[3]. Asia, Europe and Latin America and the Caribbean are projected to gain around 6 or 7 years by 2045-50, while North America and Oceania are expected to add around 4 or 5 years.

Population ageing is projected to have a profound effect on societies, underscoring the fiscal and political pressures that the health care, old-age pension and social protection systems of many countries are likely to face in the coming decades (United Nations, 2017). In terms of demographics, population ageing affects the support ratio, defined as the number of workers per retiree. Although it is difficult to know the actual number of workers per retiree, a useful proxy is the ratio of the numbers of persons who are likely to be workers or retirees by virtue of their age. Thus, a potential support ratio can be defined as the number of persons aged 20 to 64 divided by the number aged 65 or over.

In 2017, Africa has 12.9 persons aged 20 to 64 for each person aged 65 or above. This ratio is 7.4 for Asia, 7.3 for Latin America and the Caribbean, 4.6 for Oceania, 3.8 for Northern America and 3.3 for Europe (United Nations, 2017). At 2.1, Japan has the lowest potential support ratio in the world in 2017, while those of nine European countries and the United States Virgin Islands are also below 3. By 2050, seven countries in Asia, 24 in Europe, and five in Latin America and the Caribbean are expected to have potential support ratios below two (United Nations, 2017). These low values underscore the fiscal and political pressures that

[3] Such gains are contingent on further reductions in HIV/AIDS, and combating successfully other infectious as well as non-communicable diseases.

many countries are likely to face in the coming decades in relation to public systems of health care, pensions and social protections for a growing older population.

As ageing populations are anticipated to pose significant challenges in the coming decades, governments around the world, including in China, consider raising the retirement age (Myers, 2016). Along with the increased average age of the world population, the average disability-free life expectancy is also increasing. The older people of the future are expected to be in better health and to be better educated than the ones of today, and more likely to retire later in life. With respect to the latter, a well-designed employment incentive structure will be of importance for developed and developing countries alike, and a major priority for the poorest countries where old age support does not exist outside reliance on one's own family. However, even with improvements in the disability-free life expectancy and likely increases in the average retirement age, the aging demographic structure is likely to pose challenges as the number of people in need of health care and social support is high and rising. The needs of this demographic segment involve greater health risk and likelihood of disabilities and disease – even with considerable improvements to longevity and the overall health quality of retirees.

Box 1: Pension planning

Improvements in healthcare are increasing life expectancies – and retirement money funds need to last much longer. A hundred years ago, a person born in a city in what was then the developed world could expect to live to be 51 years old – the average life expectancy in the UK in 1915 (Citi GPS, 2016). In the United States, when Social Security was started in 1935, a 65-year-old man could expect to live 12.7 more years, and that was how long Social Security would have to help support him. That man today could expect to live nearly 20 more years – about 50% longer than the system was intended to support (Citi GPS, 2016).

At the same time, demographic shifts – an increase in the retirement age population accompanied by a decrease in the working age population – are starting to put a strain on government pension schemes such as social security. Contributions from a stagnant or declining working population are supporting an increasing population of retirees – with increasing expectations as to how retired life is supposed to be like (Citi GPS, 2016). The idea of retirement, a concept that barely existed for most people 100 years ago, not only lasts many years longer but may also be increasingly expensive.

The net present value of pension obligations represents the amount that need to be set aside today in order to meet future pension obligations, given an expected rate of interest. Considering pension funds, low and declining global bond yields have presented an additional budgeting and funding challenge for global pensions by causing the net present value of retirement liabilities to balloon (Citi GPS, 2016). The *expected* annual return among US pension plans declined from 8.02 percent in 2001 to 7.60 percent in 2015, indicating rather small changes to average return *assumptions* since 2008 (Saret, Zahn & Mitra, 2017). Meanwhile, from 2001-15 the *actual* average annualized return for these plans was approximately 5.7 percent. Through the power of compound interest, years of lower than budgeted returns generate a gap in funding, as the amount needed to set aside is underestimated.

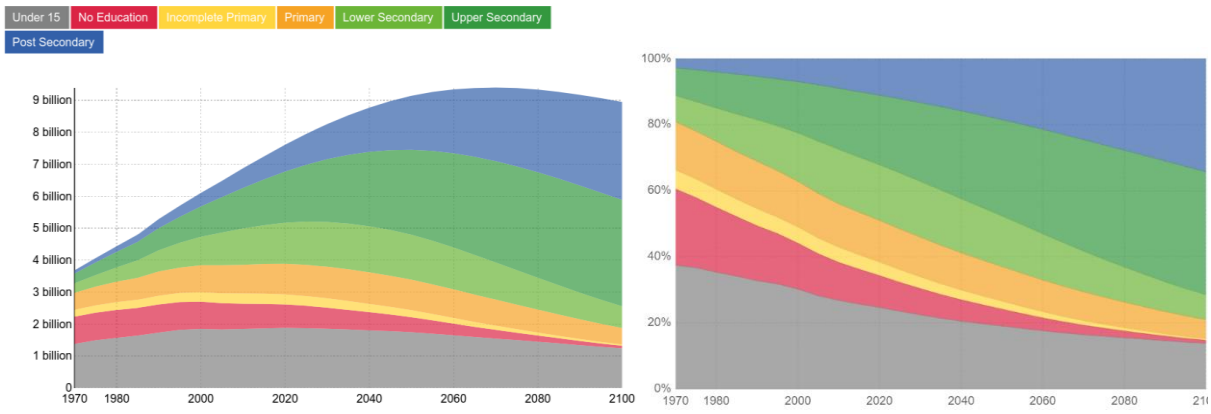
How much of a problem is it? According to Citi GPS estimates, the total value of unfunded or underfunded government pension liabilities for 20 OECD countries is a staggering $78 trillion, or almost double the $44 trillion published national debt number (Citi GPS, 2016). Corporations have also not consistently met their pension obligations and most US and UK corporate pension plans remain underfunded with an aggregate fund status in the US of 82% which implies serious underfunding (Citi GPS, 2016).

As pensioners make up an increasing share of many populations and a large generation is approaching retirement age (the "baby boomers"), the state of pension systems may be of concern for not only the wellbeing and consumption power of pensioners, but also a potential systemic risk to economies, societies and institutions.

1.3 Level of education

A priority for the least-developed countries is to increase the overall level of education as there is a direct correlation between the level of education, health conditions and productivity. As shown in Figure 1 (by the Wittgenstein Centre/IIASA), the composition of the global population by level of education is expected to change considerably over the century.

In 2015, 10 percent of the total world population had post-secondary education; 20 percent upper secondary; 17 percent lower secondary; 13 percent primary; 4 percent incomplete primary; 11 percent no education, while 26 percent were in the category "under 15" and not otherwise included. By 2030, 13 percent of the total world population are expected to have post-secondary education; 24 percent upper secondary; 17 percent lower secondary; 12 percent primary; 3.6 percent incomplete primary; 8 percent no education, while 22 percent are in the category "under 15" and not otherwise included (Roser, 2017). The number and share of people with no education or incomplete primary education almost disappears by 2100, while the majority (roughly two thirds) of the population have either an upper secondary or post-secondary level of education.



***Source*:** See: http://OurWorldInData.org/world-population-growth/. Data published by Wittgenstein Centre for Demography and Global Human Capital (2015). Wittgenstein Centre Data Explorer Version 1.2. IISA (Global Projection – Medium SSP2)

Figure 1. Projected world population by level of education, 1970-2100. Absolute and relative figures

The Wittgenstein Centre emphasises that education plays a central role not only in global population dynamics and fertility[4], but also people's vulnerability and resilience to

[4] Fertility and family planning varies significantly with the level of female education.

environmental risks[5]. Studies have also shown that there exist some thresholds with respect to the effect of education on health and economic growth. In that sense, universal primary education (one of the key Millennium Development Goals) is not sufficient: to help bring countries out of the vicious circle of poverty, high population growth and food insecurity, it requires high proportions of the population to have completed at least junior secondary education (to age 15) (Lutz, Cuaresma & Sanderson, 2008).

Lutz and Samir (2010) projected the proportion of the population with junior secondary or higher education, by gender and region, from the 2000s to 2050. The projections are based on the Global Education Trend Scenario and assume that the countries later in the development process follow the trend of the more advanced countries in terms of the change of proportions in different educational attainment categories. Their study suggests that the level of education will increase almost universally and the proportion of men and women with at least secondary education in the society will be almost aligned by 2030. In some countries, the level of female school enrolment will surpass that of males. Also in Africa, more than 50 percent of boys and girls should have at least secondary education by 2030.

Between China and India, both expected to constitute future centres of gravity in terms of population and economic activity, the composition of human capital will likely differ significantly (Lem, Bjørndal & Lappo, 2014). While 87 percent of males in China and 70 percent of males in India will have at least secondary education by 2030, India will stay behind with regard to the education of females. By 2030, 42 percent of the total adult female population will remain uneducated, compared with only 18 percent in China (Lem, Bjørndal & Lappo, 2014).

1.4 Urbanisation

Among transformational changes to global demography are also the changes in proportions of rural and urban populations. A growing number of people continue to move from rural areas to cities, where they need to be serviced with food, water and energy. In 2016, an estimated 54.5 percent of the world's population lived in urban settlements, a figure projected to rise to 60 percent by 2030 and to 66 percent by 2050[6] (United Nations, 2016).

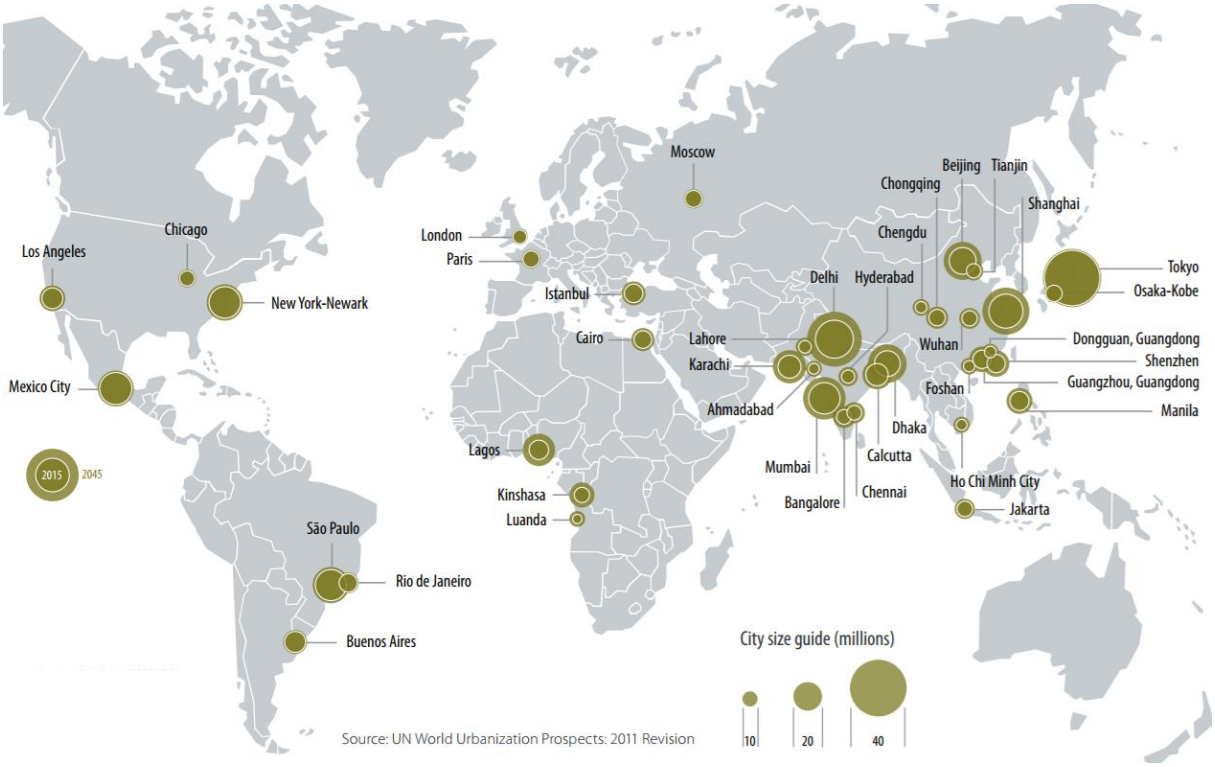
Urbanisation will probably increase most rapidly in the developing world (Ministry of Defence UK, 2014). The greatest increases in urbanisation are likely to be in Asia, with between 250 and 300 million people likely to move from rural to urban areas over the next 15 years in China alone (Ministry of Defence UK, 2014). In wealthy countries a greater proportion of the population live in cities, but the rate of urbanisation is progressing much faster in poorer countries. Asia and Africa (the world's two least urbanised regions) are experiencing the highest rates of urbanisation (Ministry of Defence UK, 2018). By 2050, Asia's urban population is likely to rise from 48.2 percent to 64.2 percent, and Africa's will probably grow from 40.4 percent to 55.9 percent. Unlike Africa, Asia is also building skyscrapers at a rapid rate, allowing

[5] When estimating the relative effects of income and education on disaster vulnerability in the same models, GDP per capita turns out to be insignificant, whereas female education is highly significant, indicating that female education is strongly associated with a reduction in disaster fatalities. Their analysis of national-level time series assess education as the proportion of women aged 20 to 39 with at least junior secondary education.

[6] According to OECD (2012) 'Environmental Outlook to 2050', the proportion of people living in urban areas is likely to have increased to around 70 percent of the world's population) by 2045.

more intensive urbanisation. In the 1980s, 49 percent of the world's tall buildings were in North America, but 66 percent of them are now in Asia (Ministry of Defence UK, 2018).

Figure 2 shows the geography of the top 30 cities by population size in 2015 and 2045, together with those with populations greater than 10 million that are forecasted to increase by more than 40 percent between 2015 and 2045 (London is included for comparison). As the map illustrates, the gravity points in terms of the most populous cities concentrates around east and south Asia – in particular India, China and Japan.



***Source*:** Ministry of Defence, UK (2014). Global Strategic Trends

Figure 2. Major centres of population, illustrated by population size in 2015 and 2045 (inner and outer circle, respectively)

Between 2016 and 2030, the population in all of the United Nations' city size classes is projected to increase (Table 6). The rural population is projected to be almost unchanged, marginally declining in absolute numbers from 3.371 billion people in 2016 to 3.367 billion in 2030. As a share of the world's population, rural inhabitants decline from 45 percent in 2016 to 40 percent by 2030 (United Nations, 2016).

Table 6: World's population by size class of settlement, 2016 and 2030

	2016			2030		
	Number of settlements	Population (millions)	Percentage of world population	Number of settlements	Population (millions)	Percentage of world population
Urban, total	..	4 034	54.5	..	5 058	60.0
10 million or more	31	500	6.8	41	730	8.7
5-10 million	45	308	4.2	63	434	5.2
1-5 million	436	861	11.6	558	1 128	13.4
0.5-1 million	551	380	5.1	731	509	6.0
Fewer than 0.5 million	..	1 985	26.8	..	2 257	26.8
Rural	..	3 371	45.5	..	3 367	40.0

Source: United Nations, Department of Economic and Social Affairs, Population Division (2016). The World's Cities in 2016 – Data Booklet (ST/ESA/ SER.A/392)

The continuing urbanisation combined with the overall growth of the world's population is projected to add 1 billion people to the urban population by 2030 (United Nations, 2016). Over the period to 2050, an additional 1.5 billion people is expected to be added to urban populations which is projected to reach more than 6.5 billion. Nearly 90 percent of the increase will be concentrated in Asia and Africa (United Nations, 2014). The fastest-growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa. Just three countries – India, China and Nigeria – together are expected to account for 35 percent of the projected growth of the world's urban population between 2018 and 2050[7] (United Nations, 2018).

In 2018, it is estimated that close to half of the world's urban dwellers reside in settlements with fewer than 500,000 inhabitants, while around one in eight live in 33 megacities with more than 10 million inhabitants (United Nations, 2018). By 2030, the world is projected to have 43 megacities, most of them in developing regions. Table 7 shows the world's 30 largest megacities in 2015 and 2035, respectively.

[7] Notably, in China this urbanisation growth consists of substitution from rural to urban areas, as the overall population is in decline.

Table 7: The world's 30 largest megacities, 2015 and 2035

No.	City, country	2015 (mill.)	City, country	2035 (mill.)
1	Tokyo, Japan	37	Delhi, India	43
2	Delhi, India	26	Tokyo, Japan	36
3	Shanghai, China	23	Shanghai, China	34
4	Ciudad de México (Mexico City), Mexico	21	Dhaka, Bangladesh	31
5	São Paulo, Brazil	21	Al-Qahirah (Cairo), Egypt	29
6	Mumbai (Bombay), India	19	Mumbai (Bombay), India	27
7	Kinki M.M.A. (Osaka), Japan	19	Kinshasa, Democratic Republic of the Congo	27
8	Al-Qahirah (Cairo), Egypt	19	Ciudad de México (Mexico City), Mexico	25
9	New York-Newark, United States of America	19	Beijing, China	25
10	Beijing, China	18	São Paulo, Brazil	24
11	Dhaka, Bangladesh	18	Lagos, Nigeria	24
12	Buenos Aires, Argentina	15	Karachi, Pakistan	23
13	Kolkata (Calcutta), India	14	New York-Newark, United States of America	21
14	Karachi, Pakistan	14	Chongqing, China	21
15	Istanbul, Turkey	14	Kolkata (Calcutta), India	20
16	Chongqing, China	13	Lahore, Pakistan	19
17	Rio de Janeiro, Brazil	13	Manila, Philippines	19
18	Manila, Philippines	13	Kinki M.M.A. (Osaka), Japan	18
19	Tianjin, China	13	Bangalore, India	18
20	Los Angeles-Long Beach-Santa Ana, United States of America	12	Istanbul, Turkey	18
21	Lagos, Nigeria	12	Buenos Aires, Argentina	17
22	Moskva (Moscow), Russian Federation	12	Guangzhou, Guangdong, China	17
23	Guangzhou, Guangdong, China	12	Tianjin, China	16
24	Kinshasa, Democratic Republic of the Congo	12	Chennai (Madras), India	15
25	Shenzhen, China	11	Shenzhen, China	15
26	Paris, France	11	Rio de Janeiro, Brazil	15
27	Lahore, Pakistan	10	Luanda, Angola	14
28	Jakarta, Indonesia	10	Hyderabad, India	14
29	Bangalore, India	10	Los Angeles-Long Beach-Santa Ana, United States of America	14
30	Seoul, Republic of Korea	10	Jakarta, Indonesia	14

Source: United Nations, Department of Economic and Social Affairs, Population Division (2018). World Urbanization Prospects: The 2018 Revision, Online Edition

Several decades ago, most of the world's largest urban agglomerations were found in the more developed regions. Today's large cities are in contrast concentrated in the "global South". The United Nations (2016) note that 10 cities are projected to become megacities between 2016 and 2030 – whereof all are located in developing countries. They include: Lahore (Pakistan), Hyderabad (India), Bogotá (Colombia), Johannesburg (South Africa), Bangkok (Thailand), Dar es Salaam (Tanzania), Ahmanabad (India), Luanda (Angola), Ho Chi Minh City (Viet Nam) and Chungdu (China).

Box 2: Cities – opportunities and vulnerabilities

Lem et al. (2014) predict that urbanisation will continue to reshape consumption patterns towards higher-value processed products and convenience foods. The process of urbanisation historically has been associated with other important economic and social transformations, which have brought greater geographic mobility, lower fertility, longer life expectancy and population ageing (United Nations, 2014).

Cities are important drivers of development and poverty reduction in both urban and rural areas, as they concentrate much of the national economic activity, government, commerce and transportation, and provide crucial links with rural areas, between cities, and across international borders. Urban

living is often associated with higher levels of literacy and education, better health, greater access to social services, and enhanced opportunities for cultural and political participation (United Nations, 2014). Although those who remain in rural areas may experience increased isolation as rural populations decline, technological advancements are likely to enable better communication and remote working opportunities also for settlements outside of urban centres (Ministry of Defence UK, 2014).

Correctly managed, urban growth could generate greater prosperity and higher tax revenues. But while urbanisation is likely to enhance economic and social development, it may also lead to capacity shortfalls and pressure on infrastructure and the environment which could contribute to social tensions within the urban population (Ministry of Defence UK, 2014). Rapid and unplanned urban growth threatens sustainable development when the necessary infrastructure is not developed or when policies are not implemented to ensure that the benefits of city life are equitably shared (United Nations, 2014).

Much of the rapid urban growth in developing countries, particularly in sub-Saharan Africa, is unlikely to be matched by investment in essential services and infrastructure (Ministry of Defence UK, 2014). One billion people throughout the world already live in slums, lacking basic amenities – and there could be almost three billion people living in these conditions by 2045 if mitigating action is not taken (Ministry of Defence UK, 2014). Today, despite the advantage of cities, urban areas are more unequal than rural areas and hundreds of millions of the world's urban poor live in sub-standard conditions. Unless there is sufficient opportunity for bettering their lives, the urban poor are likely to become frustrated – and with increasing access to information, there is likely to be a growing awareness of inequality. If not dealt with effectively, this could lead to violent protest and possibly full-blown urban insurgencies (Ministry of Defence UK, 2014). In some cities, unplanned or inadequately managed urban expansion leads to rapid sprawl, pollution and environmental degradation together with unsustainable production and consumption patterns (United Nations, 2014).

On the other hand, while older cities are likely to have established links to resources, new and growing cities may enjoy an infrastructural advantage. If well managed, they may be able to build transport and communication networks suitable for modern vehicles and ways of working, without the constraints of historic buildings, narrow streets and obsolete infrastructure. Densely-populated areas often lead to shorter commuting distances and delivery times (Ministry of Defence UK, 2018). Congestion, energy consumption and pollution could be reduced by using advanced technology, such as implementing intelligent traffic management (possibly overseeing fleets of driverless cars). Large buildings have smaller surface-to-volume ratios, conserving heat, and future technology could exploit temperature differences to generate electricity. A decade ago the construction of buildings accounted for 30-40% of global energy use, however, new construction materials and methods, improved urban practices and integration of smart technologies could significantly reduce this figure (Ministry of Defence UK, 2018).

Due to urbanisation, cities will expand and some land that currently is or could be used for agriculture will become urbanised. Taking into account that some of the land is already suffering from erosion, desertification, salinisation and rising sea levels, urbanisation will put strain on aquaculture and agriculture thereby also having a supply side effect. In addition, urbanisation can lengthen the food supply chain and may increase the volume of food waste, especially in countries with poor infrastructure. Thus, the poorest countries, where infrastructure for storage and supply is often inadequate, are at risk of greater losses during post-harvest storage and throughout the food supply chain. Urban people in low-income countries and slum areas who cannot grow their own food or secure access to "wild food" may suffer more from temporary spikes in food prices than their counterparts in richer countries.

Urbanisation and the effects of climate change are likely to result in an increase in the magnitude of humanitarian crises, particularly since the majority of urban areas will almost certainly be either on, or near the coast, making these cities vulnerable to flooding (Ministry of Defence UK, 2014).

1.5 Summary: Population

Population size is one of the main drivers of food demand. The 2017 world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to the United Nations (UN). Corresponding projections by the Wittgenstein Centre for Demography see the world's population at 8.3 billion in 2030, 9.1 billion in 2050 and 8.9 billion by 2100.

More than half of the anticipated growth in global population up to 2050 is expected to occur in Africa, followed by Asia as the second largest contributor. From 2017 to 2050, it is expected that half of the world's population growth will be concentrated in just nine countries: India, Nigeria, the Democratic Republic of the Congo, Pakistan, Ethiopia, the United Republic of Tanzania, the United States of America, Uganda and Indonesia.

Table 8: Projected population changes from 2017 (UN estimate) to 2030 and 2050 (average of UN and Wittgenstein estimates for 2030 and 2050)

Area	**Population change from 2017 to 2030 and 2050**
World	Population growth, although slowing. From 2017 to 2030, a population increase of about 11 percent is expected for the overall global population. From 2017 up to 2050, it is expected to increase by 25 percent.
Africa	The African population is expected to increase 29 percent by 2030; 81 percent by 2050. Highest population growth rate of any region.
Europe	The European population sees a stagnant trend, increasing by 1 percent up to 2030, but losing 1 percent by 2050 compared to 2017. Ageing population.
Asia	From its 2017-level, the Asian population is expected to grow by 9 percent by 2030, and by 15 percent by 2050.
Latin America and the Caribbean	The populations of Latin America and the Caribbean are projected to increase by 10 percent by 2030; 19 percent by 2050.
North America	The North American population is expected to grow 10 percent by 2030; 22 percent by 2050.
China	Estimates diverge as to whether China's population will slightly increase or decrease from 2017 to 2030. Up to 2050, the population is expected to decline by 7 percent.
India	India will surpass China in terms of population by 2030. A 13 percent population growth is projected from 2017 to 2030; 26 percent to 2050.
United States	Projections suggest that the US population will increase by 10 percent from 2017 to 2030; by 22 percent to 2050.

Population growth remains especially high in the group of 47 countries designated by the United Nations as the least developed countries (LDCs), including 33 countries in Africa. The populations of Angola, Burundi, Niger, Somalia, the United Republic of Tanzania and Zambia are projected to be at least five times as large in 2100 as they are today. Between 2017 and

2050, the populations of 26 African countries are projected to expand to at least double their current size. The concentration of global population growth in the poorest countries presents a considerable challenge to governments in implementing the 2030 Agenda for Sustainable Development and ensuring that no one is left behind.

As fertility and population growth rates have fallen over time, the proportion of older people has increased globally. The proportion aged 60 or above is expected to increase from 13 percent in 2017 to 33 percent by 2050. With the average life expectancy also increasing, population ageing is a major global demographic trend. Globally, life expectancy at birth rose by 3.6 years between 2000-05 and 2010-15 – increasing from 67.2 to 70.8 years. Over the period, all regions shared in the increase, with the greatest gains in Africa where life expectancy rose by 6.6 years. By 2045-50, the global average life expectancy is expected to rise another 6.2 years, to reach 77 years.

Population ageing is projected to have a profound effect on societies, underscoring the fiscal and political pressures that the health care, old-age pension and social protection systems of many countries are likely to face in the coming decades.

A high proportion of the population with completed at least junior secondary education is part of helping countries out of the vicious circle of poverty, high population growth and food insecurity. The global population of the future will be increasingly well-educated. By 2030, 13 percent of the global population are expected to have post-secondary education (up from 10 percent in 2015) and 24 percent upper secondary education (up from 20 percent in 2015). The share of people with a lower secondary education is expected to remain similar, while the proportions of people with only primary, incomplete primary or no education will decline in the period up to 2030. Towards the end of the century, the number and share of people with no education or incomplete primary education almost disappears.

A transformational change to global demography is also the change in proportions of rural and urban populations, where growing numbers of people live in cities, which must to be serviced with food, water and energy. In 2016, an estimated 54.5 percent of the world's population lived in urban settlements, a figure projected to rise to 60 percent by 2030 and to 66 percent by 2050.

Urbanisation is expected to increase most rapidly in the developing world. Just three countries – India, China and Nigeria – together are expected to account for 35 percent of the projected growth of the world's urban population between 2018 and 2050. The fastest-growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa.

The 10 cities that are projected to become megacities between 2016 and 2030 are all located in developing countries. They include: Lahore (Pakistan), Hyderabad (India), Bogotá (Colombia), Johannesburg (South Africa), Bangkok (Thailand), Dar es Salaam (Tanzania), Ahmanabad (India), Luanda (Angola), Ho Chi Minh City (Viet Nam) and Chungdu (China).

Part of the rapid urban growth, particularly in sub-Saharan Africa, is unlikely to be matched by investment in essential services and infrastructure. One billion people throughout the world already live in slums – and there could be almost three billion by 2045 unless mitigating action is taken.

2. ECONOMIC DEVELOPMENT – GROSS DOMESTIC PRODUCT (GDP)

Income is one of the most important determinants of food demand. This chapter analyses future growth in GDP as this variable is considered a good measurement of income. It also takes population growth into account (Chapter 2), which combined with the analysis of GDP growth, allows something to be said about the development in GDP per capita and its implications for future food demand. As before, the focus is on the period up to 2030.

2.1 Future GDP Growth

Projections of future GDP growth are available from two sources: the Conference Board[8], and the International Monetary Fund (IMF). This study looks at both. While the Conference Board gives projections up to 2028, the IMF presents forecasts only until 2023. All growth rates presented are annual unless otherwise specified. Note that the two sets of data use different geographical definitions of world regions and procedures for adjusting economic data (the Conference Board adjust current GDP figures using Purchasing Power Parity; the IMF data are based on constant prices).

According to the IMF, world growth is expected to decline from an annual growth rate of 3.7 percent in 2017-20 to 3.6 percent in 2021-23 (Table 9). Thus, global growth is projected to remain steady at its 2017 level, implying a less vigorous forward growth outlook than the previous estimates by the IMF (International Monetary Fund, 2018a). The IMF emphasise that downside risks to global growth have risen in 2018 and the potential for upside surprises has receded. Downward revisions to growth reflect surprises that suppressed activity in early 2018 in some major advanced economies, the negative effects of the trade measures implemented or approved between April and mid-September 2018, as well as a weaker outlook for some key emerging market and developing economies arising from country-specific factors, tighter financial conditions, geopolitical tensions, and higher oil import bills (International Monetary Fund, 2018a).

The growth rate in advanced economies is expected by the IMF to decline from 2.3 percent in 2017 to 1.5 percent in 2023. The major advanced economies (the G7) are expected to grow at an average annual rate of 1.7 percent in the period up to 2022, although slowing down from a rate of 2.1 in 2017 to 1.2 in 2023. Growth in the Euro area[9] is expected to average 1.8 percent, declining from 2.4 in 2017 to 1.4 in 2023. Other advanced economies (excluding the G7 and Euro area) are predicted to grow at 2.5 percent on average over the period, declining from 2.8 percent to 2.4 percent. The European Union[10] as a whole is predicted to grow at 2.0 percent per

[8] The Conference Board is a global, independent business membership and research association working in the public interest. Founded in 1916, the Conference Board works within and across four main subject areas: corporate leadership; economies, markets and value creation; high-performing organizations; and human capital.
The International Monetary Fund is an organisation of 188 countries, working to foster global monetary cooperation, secure financial stability and facilitate economic growth.

[9] The Euro area is composed of 19 countries: Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovak Republic, Slovenia, and Spain.

[10] The European Union is composed of 28 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Romania, and United Kingdom.

year on average between 2017-23, also with a downward trajectory from 2.7 percent to 1.6 percent.

Emerging markets and developing economies have become increasingly important in the global economy in recent years. They now account for more than 75 percent of global growth in output and consumption, almost double the share of just two decades ago. In emerging markets and developing economies, GDP growth is forecast to average 4.8 percent, which is high compared with developed countries. From an annual growth rate of 4.7 in 2017-19, growth is expected to pick up to reach 4.9 percent in the years 2020-21 and 4.8 percent in 2022-23.

The GDP growth rate in emerging and developing Asia is projected at an average of 6.3 percent over the period, declining from 6.5 percent in 2017 to 6.1 percent in 2023. ASEAN-5[11] GDP will grow at an average annual rate of 5.3 percent. For emerging and developing Europe, the economy is expected to grow at an average annual rate of 3.2 percent. Average annual GDP growth in Latin America and the Caribbean is projected to be 2.2 percent, the Middle East, North Africa, Afghanistan, and Pakistan 2.8 percent, the Middle East and North Africa 2.6 percent and Sub-Saharan Africa 3.6 percent.

The two large economies China and United States are both projected to see their growth rate decline over the period. Chinese growth is seen slowing from 6.9 percent to 5.6 percent, while in the United States, the rate of growth is seen to increase from 1.9 percent in 2017 to 2.1 in 2018-19 before slowing down to 1.8 percent in 2023. In India, growth is projected to increase from 6.7 percent to 7.7 percent over the period.

Table 9: GDP growth projection, 2017-23

Country Group Name	2017	2018	2019	2020	2021	2022	2023
World	3.7	3.7	3.7	3.7	3.6	3.6	3.6
Advanced economies	2.3	2.4	2.1	1.7	1.7	1.5	1.5
Euro area	2.4	2.0	1.9	1.7	1.6	1.5	1.4
Major advanced economies (G7)	2.1	2.2	2.0	1.5	1.5	1.3	1.2
Other advanced economies (Advanced economies excl. G7 and euro area)	2.8	2.8	2.5	2.5	2.4	2.4	2.4
European Union	2.7	2.2	2.0	1.8	1.7	1.7	1.6
Emerging market and developing economies	4.7	4.7	4.7	4.9	4.9	4.8	4.8
Commonwealth of Independent States	2.1	2.4	2.4	2.4	2.3	2.1	2.1
Emerging and developing Asia	6.5	6.5	6.3	6.4	6.3	6.2	6.1
ASEAN-5	6.0	3.8	2.0	2.8	2.5	2.6	2.7
Emerging and developing Europe	5.3	5.3	5.2	5.2	5.2	5.3	5.3
Latin America and the Caribbean	1.3	1.2	2.2	2.7	2.7	2.8	2.9
Middle East, North Africa, Afghanistan, and Pakistan	2.2	2.4	2.7	3.0	3.0	3.0	3.0
Middle East and North Africa	1.8	2.0	2.5	2.9	3.0	3.0	3.0
Sub-Saharan Africa	2.7	3.1	3.8	3.9	3.9	3.9	4.1
China	6.9	6.6	6.2	6.2	6.0	5.8	5.6
India	6.7	7.3	7.4	7.7	7.7	7.7	7.7
United States	1.9	2.1	2.1	1.9	1.9	1.8	1.8

Source: (International Monetary Fund, 2018b). World Economic Outlook Database, October 2018 Edition. For a full description of all country groups, see:
http://www.imf.org/external/pubs/ft/weo/2017/01/weodata/weoselagr.aspx
Note: Gross domestic product, constant prices, percentage change. By country groups

[11] ASEAN-5 is composed of 5 countries: Indonesia, Malaysia, Philippines, Thailand, and Vietnam.

The Conference Board Global Economic Outlook 2019 projects GDP growth in different regions for the years 2018, 2019 and the period 2019-23 and 2024-28 (Table 10). World GDP growth is forecast to remain at an average annual rate of 3.0 percent in the period 2019-23, compared to 3.1 percent in the period 2013-17.

Mature economies[12] will see an average annual growth rate of 2.0 percent in 2019-23 and slowing down to 1.7 in 2024-28, according to projections. This compares to an average annual GDP growth of 2.1 percent in 2013-17. The United States economy is expected to grow at 2.2 percent in 2019-23 and 1.7 percent in 2024-28, in contrast to 2.4 percent in 2013-17. The average annual GDP growth in other mature economies[13] is expected to increase by 0.3 percentage point to 2.9 per annum in 2019-23, up from 2.6 percent per annum in 2013-17. Growth is thereafter expected to slow down to 2.5 percent annually in 2024-28. The economy of Japan will probably see a slightly declining growth trajectory in 2019-28, with a forecasted growth of 1.4 percent per annum in 2018-22 and 1.3 percent per annum in 2024-28, down from 1.5 percent per annum in 2013-17.

In Europe[14], the average annual GDP growth rate in 2019-23 is projected at 1.6 percent, down from its 2013-17 level of 1.7 percent per annum. In the period 2024-28, the growth rate is expected to slow again to 1.1 percent per annum. The growth rate in the Euro Area is estimated to be aligned with Europe as a whole over the projected period 2018-27.

The emerging markets and developing economies are estimated to grow at an average annual rate of 3.8 percent in 2019-23 and 3.6 percent in the period 2024-28 according to the Conference Board. This compares to a growth rate of 4 percent per annum in 2013-17.

[12] The Conference Board defines "Mature economies" as composed of the United States, Europe, Japan and "Other mature economies" (see below).
[13] "Other mature economies" includes Australia, Canada, Israel, Hong Kong, South Korea, New Zealand, Singapore, and Taiwan.
[14] Here, the term Europe includes all 28 members of the European Union, as well as Iceland, Switzerland and Norway.

Table 10: GDP Annual Growth Rates (Percent Change). Actual growth 2013-17, estimated growth 2018, forecast 2019, projected growth 2019-23 and 2024-28

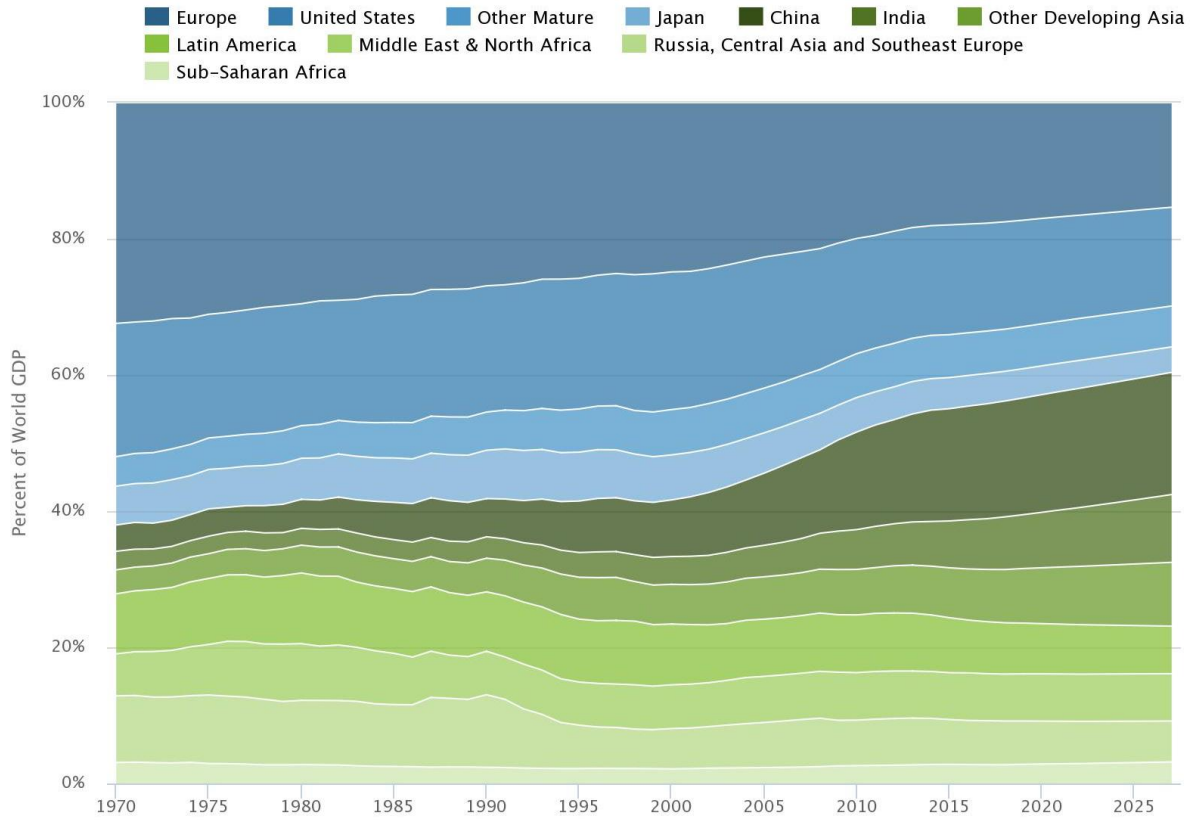
	Actual 2013-17	Estimate 2018	Forecast 2019	Projected 2019-23	Trend 2024-28	Regional Distribution of GDP 2028
United States	2.4	3.1	3.2	2.2	2	14.7%
Europe*	1.7	2	1.9	1.6	1.1	15.4%
of which: Euro Area	1.4	2	1.9	1.6	1.1	
of which: United Kingdom	2.2	1.2	1.2	1.3	1.2	
Japan	1.5	1.1	0.9	1.4	1.3	3.8%
Other mature**	2.6	2.8	2.5	2.9	2.5	6.2%
Mature Economies	2.1	2.4	2.4	2	1.7	**40%**
China	5.1	4.1	3.8	3.8	3.4	18.0%
India	7	7.2	6.8	5.9	5.5	9.7%
Other developing Asia	4.9	5.2	4.9	4.9	4.6	9.2%
Latin America	0.4	0.3	1.7	1.9	1.9	6.8%
of which: Brazil	-0.5	0.9	2	1.7	1.8	
of which: Mexico	2.5	1.9	2.3	2.1	1.9	
Middle East & North Africa	3	2.6	2.5	3.1	3	6.9%
Sub-Saharan Africa	3.3	2.6	2.9	3.8	3.9	3.0%
Russia, Central Asia, and Southeast Europe***	2.3	2.5	1.3	2.3	2.2	6.2%
of which: Russia	0.3	1.6	1.3	0.6	0.5	
of which: Turkey	6.1	3.2	0.2	4.4	3.9	
Emerging Markets and Developing Economies	4	3.8	3.7	3.8	3.6	**60%**
World Total	3.1	3.2	3.1	3	2.8	**100%**

***Source**:* (The Conference Board, 2017). Global Economic Outlook 2017 – Charts & Tables. May 2017 update.

* Europe includes all 28 members of the European Union, as well as Iceland, Switzerland and Norway.
** Other mature economies are Australia, Canada, Israel, Hong Kong, South Korea, New Zealand, Singapore, and Taiwan.
*** Russia, Central Asia, and Southeast Europe include projections for Russia, Kazakhstan, Turkmenistan, Uzbekistan, Belarus and Turkey.
Note: The model projects estimates of individual country GDP growth rates. Regional aggregates are computed using Purchasing Power Parity (PPP) converted current price GDP weights averaged for the beginning and the end of each period as weights. The PPPs, obtained from the International Comparison Program 2011, are extrapolated forward and backward in time using movements in national GDP deflators relative to the GDP deflator for the United States.

Among the emerging and developing economies, a lower growth rate in China is the most noticeable change. Its GDP is projected to grow on average by 3.8 percent per annum in 2019-23 and 3.4 percent in 2024-28, compared to a 2013-17 growth rate of 5.1 percent per annum. India is also expected to experience a decrease in GDP growth, from 7.0 percent in 2013-17 to 5.9 percent in 2019-23 and 5.5 percent in 2024-28 – which is still the highest projected growth rate among the regions analysed. A lower growth rate is expected in other developing Asia? as well, first rising from 4.9 percent per year in 2013-17 to 4.9 per annum in 2019-23, then declining to 4.6 percent per year in 2024-28. Russia, Central Asia and Southeast Europe is estimated to see an average annual growth of 2.3 percent in 2019-23 and 2.2 percent in 2024-28, slightly slowing from 2.3 percent in 2013-17.

In Latin America, growth is estimated to recover in the period 2019-28, reaching an average annual growth rate of 1.9 percent, up from 0.4 percent in 2013-17. The Middle East and North African economies are expected to grow at an average annual rate of 3.0-3.1 percent in 2019-28, compared to 3.0 percent in 2013-17. Sub-Saharan Africa is estimated to achieve an annual growth rate of 3.8-3.9 percent in the period 2019-28, up from 3.3 in 2013-17. The changes to the distribution of global GDP among regions over time are illustrated in Figure 3.



Source: (The Conference Board, 2018). The Conference Board Global Economic Outlook 2019 (November 2018 Edition)
Note: Shares are based on GDP in US$ at current purchasing power parities.

Figure 3. Regional Distribution of GDP, 1970-2027

According to the Conference Board (2018), mature economies will make up about 40 percent of the global economy in 2027, whereas emerging markets and developing economies constitute about 60 percent. China and India alone will account for about 28 percent of the global economy, while the United States and Europe together will account for about 30 percent.

It is noticeable that the overall global growth estimates by the Conference Board are more modest compared to the projections by the IMF. It is, however, not straightforward to make direct comparisons between the two sets of GDP projections in most cases, owing to differing geographical definitions of world regions and procedures for adjusting economic data (the Conference Board adjust current GDP figures using Purchasing Power Parity; the IMF data are based on constant prices). Looking at world GDP growth for the period from 2018, both sets of projections expect positive growth rates in all countries and regions included in the study. For advanced economies overall, both institutions see slowing rates of growth. Among emerging

and developing regions, the outlook is more mixed, with some regions expected to see their growth rates accelerate while others decline.

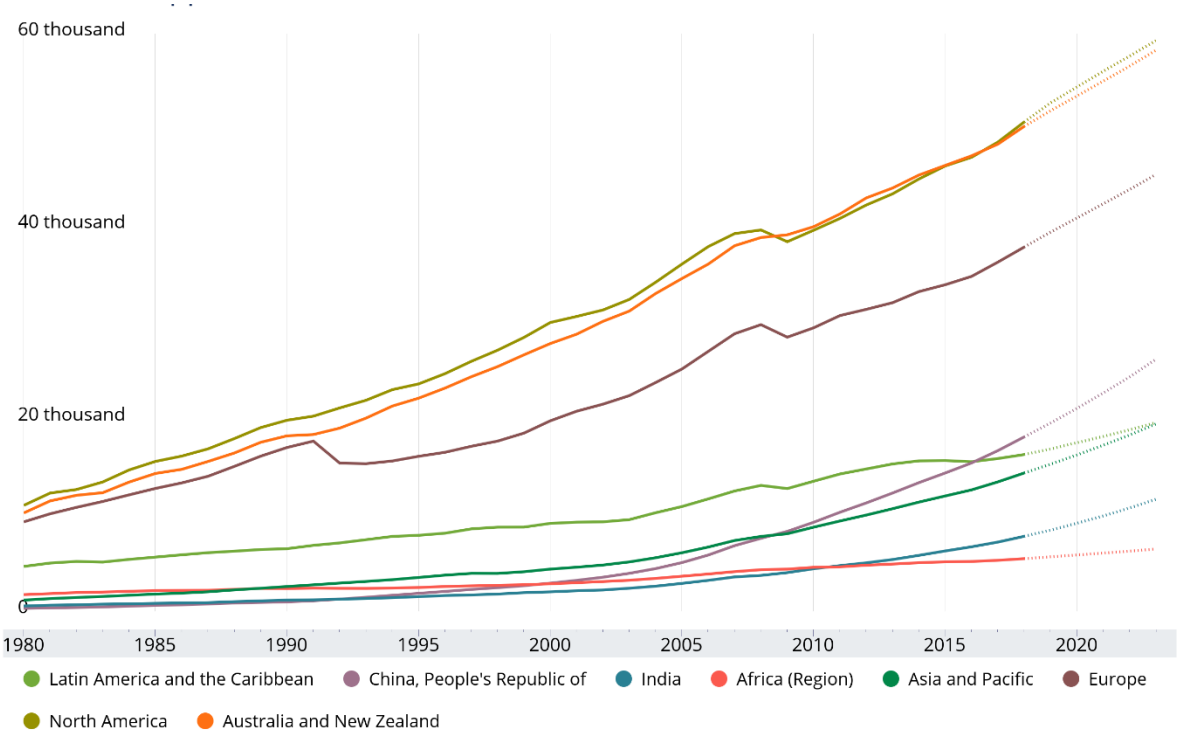
2.2 GDP per capita

This section examines IMF projections for GDP per capita up to 2023. The Conference Board does not provide per capita projections. While size, country level and regional distribution of GDP provide important information about the demographics of economic activity, it is the per capita level GDP that influences individuals' purchasing power which in turn affects behaviour and consumption. For this reason, GDP per capita provides valuable information about the characteristics of food demand[15].

Contemporaneously with the decrease in GDP growth rate, world population growth is also slowing. As outlined in Chapter 2, the world's population is predicted to reach a plateau and possibly decline in the second half of the century although the total size of the world population is projected to increase from 7.6 billion in 2017 to 8.6 billion 2030, and perhaps to more than 9.6 billion in 2050 (United Nations, 2017).

GDP per capita and consumer's purchasing power has developed substantially over time and differs among countries and regions. Figure 4 shows how GDP per capita has been on a strong, rising trend in North America, Australia and New Zealand and Europe (growing at a similar trend since the 2000s, but at a lower level than the former two). These regions are in the lead with respect to the level of GDP per capita – with a considerable gap between these regions and the rest (i.e., Latin America and the Caribbean, Asia and Pacific and Africa). In China, India and in Asia and the Pacific, the level of GDP per capita is on a steep rise – especially in China. Chinese economic growth is distributed across a stable, soon declining, population, whereas India is growing both its overall population and per capita GDP. Latin America and the Caribbean has seen a slower growth of its per capita GDP in recent years, and is expected to be overtaken by that of Asia and Pacific in the early 2020s. At the lowest end in terms of both level and growth is Africa, where the ratio of population growth to economic growth has led the average GDP per capita to remain relatively flat.

[15] Average GDP per capita is a good measure in this respect – although the insights generated fall short of detecting the distribution of GDP among inhabitants and the level and development of income, spending and wealth inequality over time.



Source: IMF (2018). World Economic Outlook (October 2018) - GDP per capita, current prices (PPP)

Figure 4. GDP per capita, current prices at purchasing power parity (PPP); international dollars per capita. 1980-2023, estimates from 2018

Average per capita GDP growth rates varies considerably also among countries within the regions (see Chapter 2). Table 11 provides projections of GDP per capita change in selected countries of major regions in 2017-23. Predictions for 2023-30 are not available for further comparison.

Table 11: Average per capita GDP growth rates for selected countries, 2017-23

Country	2017	2018	2019	2020	2021	2022	2023	2017-23
European Union								
France	3.9%	3.4%	3.3%	3.0%	3.1%	3.0%	3.1%	**25%**
Germany	4.0%	4.1%	3.9%	3.5%	3.4%	3.2%	3.2%	**28%**
Greece	3.4%	4.7%	4.8%	4.4%	3.8%	3.4%	3.5%	**32%**
Italy	3.6%	3.2%	3.2%	2.8%	2.7%	2.7%	2.7%	**23%**
Portugal	4.9%	5.0%	4.3%	3.8%	3.6%	3.6%	3.7%	**33%**
Romania	9.6%	6.4%	5.6%	5.2%	5.2%	5.1%	5.1%	**51%**
Spain	5.1%	5.2%	4.5%	3.9%	3.8%	3.7%	3.8%	**34%**
Advanced economies								
Canada	3.7%	3.2%	3.2%	2.8%	2.7%	2.6%	2.6%	**23%**
Japan	3.8%	3.7%	3.4%	2.6%	3.0%	2.8%	2.9%	**24%**
Korea	4.6%	4.7%	4.3%	4.3%	4.3%	4.2%	4.2%	**35%**
New Zealand	2.9%	3.2%	3.1%	3.2%	3.2%	3.0%	3.1%	**24%**
Sweden	2.8%	3.0%	3.3%	2.9%	2.9%	2.9%	2.9%	**23%**
Switzerland	2.5%	4.6%	2.8%	2.4%	2.3%	2.3%	2.4%	**21%**
United Kingdom	3.0%	3.0%	3.1%	2.9%	3.0%	3.1%	3.2%	**23%**
United States	3.4%	4.6%	4.1%	3.1%	3.0%	2.7%	2.7%	**26%**
Developing Asia								
India	7.3%	8.4%	8.3%	8.4%	8.3%	8.3%	8.4%	**74%**
China	8.3%	8.5%	7.9%	7.8%	7.6%	7.4%	7.5%	**70%**
Latin America								
Argentina	3.7%	-1.5%	-0.6%	3.0%	3.3%	3.9%	4.1%	**17%**
Brazil	2.1%	3.0%	3.8%	3.5%	3.5%	3.5%	3.6%	**25%**
Chile	2.3%	5.3%	4.5%	4.0%	3.8%	3.8%	3.9%	**31%**
Venezuela	-11.7%	-12.3%	0.9%	3.3%	0.3%	0.3%	0.4%	**-18%**
Middle East								
Egypt	1.0%	5.3%	5.3%	5.5%	5.5%	5.5%	5.6%	**39%**
Saudi Arabia	-1.5%	2.6%	2.6%	1.8%	2.0%	2.1%	2.2%	**12%**
Africa								
Algeria	1.4%	2.9%	3.0%	2.0%	1.3%	1.0%	0.8%	**13%**
Angola	-3.5%	-0.8%	2.2%	2.1%	2.1%	2.6%	2.7%	**7%**
Botswana	2.4%	5.1%	3.9%	4.1%	4.1%	4.2%	5.6%	**33 %**
Ethiopia	11.2%	8.3%	9.1%	8.9%	8.3%	7.8%	7.8%	**80%**
Mozambique	2.9%	3.1%	3.4%	3.2%	3.2%	3.2%	10.3%	**33%**
Nigeria	0.0%	1.5%	1.6%	1.7%	1.7%	1.5%	1.6%	**10%**
South Africa	1.6%	1.5%	1.9%	2.1%	2.1%	2.1%	2.2%	**14%**
Russia and Eastern Europe								
Russia	3.5%	4.1%	4.0%	3.8%	3.6%	3.3%	3.3%	**29%**
Ukraine	5.0%	4.9%	5.5%	5.6%	5.8%	5.8%	6.0%	**45%**

***Source**:* IMF (2018). World Economic Outlook Database, October 2018
Note: Expressed in per capita GDP and purchasing-power-parity (PPP), based on current international dollar.

The sample of selected countries in Europe suggests that all countries will experience positive annual growth in average GDP per capita in each of the years from 2017-23. Among the countries, the total increase over the period ranges from 25 percent in France to 51 percent in Romania. The rate of growth in average GDP per capita is expected to decline from its 2017-level for all countries shown, except Greece.

Among other advanced economies, GDP per capita is also expected to grow in all of the years (2017-23) for each of the countries presented. Total per capita GDP growth over the period ranges from 21 to 26 percent for the countries listed – except for the Republic of Korea, where it is projected to increase by 35 percent over the period. Its annual rate of growth is expected to vary between 4.7 percent in 2018 to 4.2 percent in 2022, making it the fastest growing country among the advanced economies presented. In New Zealand, Sweden, Switzerland and United

Kingdom, the rate of change is expected to remain fairly flat over the period. The remaining advanced economies listed – Canada, Japan, Korea and United States – are expected to see their growth rates declining from their respective 2017-level. In the United States of America, the IMF expects GDP per capita to grow by 2.7 percent in 2023, down from 3.4 percent in 2017.

China and India are projected to continue their rapid growth paths in the 2017-23 period, with annual GDP per capita growth ranging from 7.3 to 8.4 percent in India (increasing) and from 8.3 percent to 7.5 percent in China (declining). Over the period, total per capital GDP is expected to rise substantially – by 74 percent in India and by 70 percent in China.

The outlook for Latin America is mixed. Both Argentina and Venezuela are expected to show years of negative GDP per capita growth. In Argentina, growth is projected to decline from positive 3.7 percent growth in 2017 to a negative -1.5 percent contraction in 2018, contracting slightly still in 2019 (-0.6 percent), before growing at an increasingly positive rate, ranging from 3.0 percent in 2020 to 4.1 percent in 2023. In the case of Venezuela, GDP per capita declined steeply by -11.7 percent in 2017, before continuing to contract substantially by -12.0 percent in 2018. Between 2019-23, growth rates are mainly predicted to remain below 1 percent year-on-year (from suppressed levels), except for a 3.3 percent recovery year in 2020. Over the period, Argentina's average per capita GDP is projected to increase by a total of 17 percent, while Venezuelan GDP per capita is expected to contract in total by -18 percent between 2017-23. Brazil is expected to grow by 25 percent over the same period, with annual growth rates ranging from 3.0 to 3.8 percent (increasing), up from 2.1 percent in 2017. In Chile, average GDP per capita growth is expected to have increased from 2.3 percent in 2017 to 5.3 percent in 2018, before declining again to 3.9 percent by 2023.

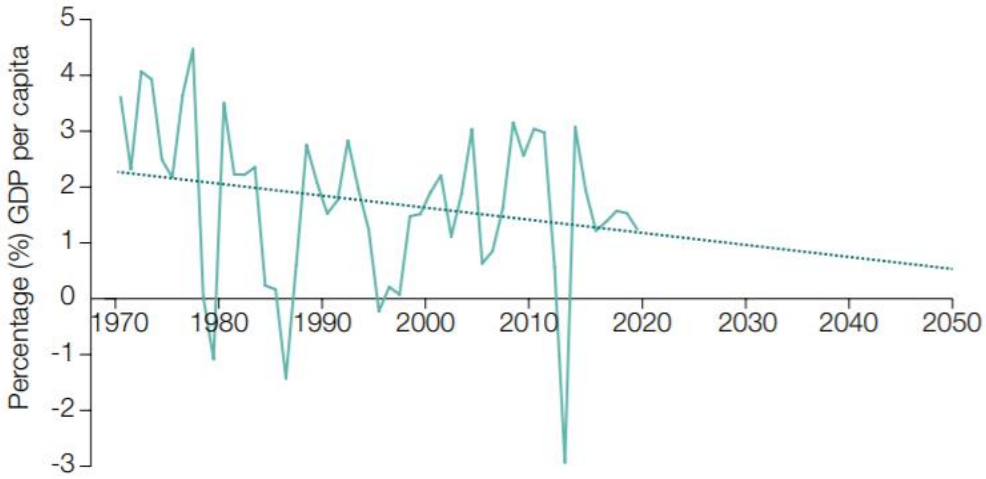
In the Middle East, Egyptian GDP per capita is estimated to grow between 5.3 to 5.6 percent per year between 2018-23, up from 1 percent in 2017. In total, average GDP per capita is expected to grow by 39 percent over the period. Saudi Arabian GDP per capita contracted by 1.5 percent in 2017, but is expected to increase by 1.8 to 2.6 percent annually between 2018-23, adding 12 percent to average per capita GDP over the period.

The outlook for per capita GDP growth among the listed African countries is very mixed. Over the period from 2017-23, Angola, Nigeria, Algeria and South Africa are projected to add between 7-14 percent to their average GDP per capita. Botswana and Mozambique are each expected to add a total of 33 percent to their respective GDP per capita. Ethiopia's average per capita GDP is expected to increase by 80 percent over the period, with annual growth rates from 11.2 percent in 2017 to 7.8 percent in 2023 (slowing).

Among Eastern European countries, the Russian Federation is projected to increase its per capita GDP by 3.3-4.1 percent annually in 2017-23 (with growth rates declining from 2018), increasing its average GDP per capita by a total of 29 percent. Per capita GDP in Ukraine will increase by 45 percent over the same period, with annual growth rates between 4.9-6.0 percent (increasing from 2018).

Globally, the long-term trend in per capita GDP rate of growth is slowing (Figure 5). On current trends, it will have fallen to 0.7 percent a year by 2050 although if the field of view is limited to the last 30 years the rate of growth appears to be increasing, reflecting the uncertainty of future growth rates. In the economically developed countries of the Organisation for Economic Co-operation and Development (OECD) the decline is even more pronounced (although recovering in the last five years). Falling growth rates may have several drivers – for example,

many developed countries have ageing populations and as people grow older, particularly if they retire, they tend to spend and consume less (Ministry of Defence UK, 2018). High levels of investment in financial products and property, another feature of developed economies, can also reduce economic growth since money is, in effect, being hoarded. Moreover, developed countries frequently have high levels of both consumer and government debts and money is often spent on servicing those debts rather than on growth-boosting consumption and infrastructure investments (Ministry of Defence UK, 2018).



Source: Ministry of Defence UK (2018). Global strategic trends: The future starts today

Figure 5. Percentage growth rate, global GDP per capita

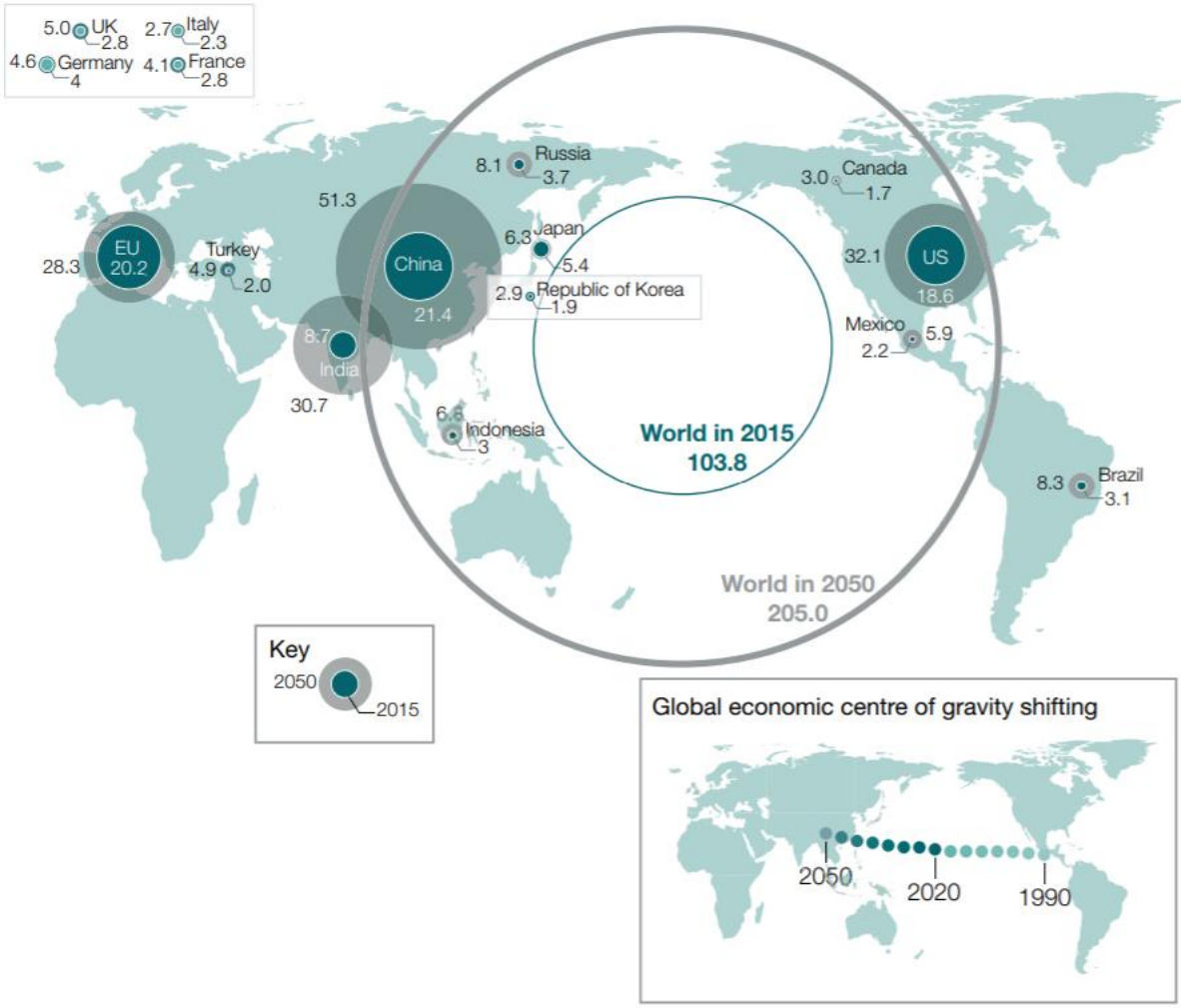
Owing to population ageing and increased life expectancy, spending on public services and pensions are likely to increase significantly. Thus, despite expected increases in GDP per capita, corresponding increases in the personal spending power and wealth of individuals may be uncertain. For instance, health care spending in OECD countries is likely to double to around 15 percent of gross domestic product (GDP) by 2050 (Ministry of Defence UK, 2018). If US spending on health care continues to grow at current rates, it could reach around 30 percent of GDP over the same period. Ageing populations and the increasing cost of health care are likely to make current levels of welfare provision unaffordable in some places, while reducing funds available for other public services.

Meanwhile, developing countries could see greater access to health care as their economies improve. Ingenuity, innovation and better governance should also provide opportunities to improve and expand health care provision. For example, over 90 percent of Rwanda's population have access to health care, despite a comparatively low GDP of around US $750 per person (Ministry of Defence UK, 2018).

2.3 Economic geography - Shifting centre of gravity and a growing consumer class in Asia

By 2050, the world economy is likely to have doubled, although the rate of growth will probably have slowed. The seven largest emerging economies, the E7 (Brazil, China, India, Indonesia, Mexico, Russia and Turkey) are likely to have increased their share of the global economy from around 35 percent to almost 50 percent by 2050, surpassing the G7 (Canada, France, Germany, Italy, Japan, the UK and the US). According to some predictions, China's GDP (at market value) could overtake that of the US by 2020, and by 2050 it is likely to be around 40 percent larger, accounting for 20 percent of global GDP (Ministry of Defence, UK, 2018). India's

economy is also expected to grow substantially in the coming decades, with some estimating that by 2050 its GDP (at market value) will be about 85 percent the size of that of the US. Europe's share of the global economy is likely to decline in the next 30 years, with the European Union 27 countries[16] expected to have a combined share of around 10 percent of world GDP by 2050 – less than India's share (Figure 6).



Source: Ministry of Defence UK (2018). Global strategic trends: The future starts today

Figure 6. Gross domestic product (adjusted for purchasing power parity) expressed in US $ trillion at 2016 values

As the centre of economic power shifts eastward, Asia will become an increasingly important centre for commerce, finance, economic and soft power, while reducing the relative power of the West (Ministry of Defence UK, 2018). As increasing numbers of people (particularly in Asia) escape poverty and become consumers, the global economic centre of gravity is likely to continue to shift eastwards with Bangladesh, India and Vietnam likely to be the fastest growing economies. The share of trade between developing economies (known as South-South trade) is also expected to increase. Demands for a greater variety of products, improved communications and better customs arrangements have seen increases in trade between and within Africa, Asia,

[16] EU27: Although there are currently 28 EU members, EU27 refers to the 2018 membership minus the UK following Brexit (Ministry of Defence UK, 2018).

the Middle East and South America that can be expected to endure. Although the value of trade between developed economies will probably continue to grow, their share of world trade is likely to decline from approximately 30 percent today to around 20 percent by 2050. A similar pattern is occurring in intra-regional trade, where the Asia-Pacific's proportion is expected to grow from 17 percent today to around 27 percent by 2050, while Europe's and North America's share is expected to reduce from around 23 percent to 14 percent (Ministry of Defence UK, 2018).

A rapidly growing consumer class[17] will be a key driver of the global economy (Ministry of Defence UK, 2014). By 2030, this group is likely to grow to more than five billion. At the same time, the proportion of consumers who are European and North American is likely to shrink, while Asia's share of the global consumer class is anticipated to more than double to around 64 percent by 2030 (Ministry of Defence UK, 2014). The likely growth of the consumer class may, however, mask a rise in global income inequality. 70 percent of the world's population live in countries where disparities between the wealthiest and poorest have grown over the last 30 years (Ministry of Defence UK, 2014). In South Asia for instance, absolute poverty is likely to have been virtually eliminated by 2050, although relative poverty and inequality will endure (Ministry of Defence UK, 2018).

2.4 Summary: Impact on food demand

The size and growth of the economy, population growth and GDP per capita have a major effect on gross food demand (Lem, Bjørndal & Lappo, 2014). Changes in local and aggregate consumer demand occur as per capita incomes rise – and along with trends such as economic geography, urbanisation and developments in the broader economy, the structure of the food system changes over time. Diets change along with per capita income, not only in terms of the amount of food demanded, but also the type of food.

Based on developments in the broader economies, Table 12 summarises some main changes in food demand that are expected to occur in different regions and selected countries up to 2025. The change in per capita food consumption driven by the change in income is, however, difficult to estimate. The Foresight report (2011) suggests that the relationship between income and demand is non-linear. According to Engel's law, with a given set of tastes and preferences, as income rises, consumers increase their expenditures on food products (in percentage terms) less than their increases in income. Thus, demand in richer and more mature economies is not expected to increase significantly.

The OECD-FAO Agricultural Outlook (2018) suggest that in higher-income countries where food expenditure represents a small share of income (10-15 percent), per capita food consumption is reaching a plateau. Increased GDP per capita in advanced economies and in wealthy regions affect the composition of consumption rather than cause an overall increase in food consumption. The GDP per capita increase in some emerging economies (developing Asia, Latin America, developing regions of the Middle East and Eastern Europe) result in both food consumption increase and composition change.

[17] Here, the consumer class is defined as those who spend more than ten US dollars a day (Ministry of Defence UK, 2014).

It is difficult to predict the exact magnitude of the expected consumption increase in developing regions owing to the differing rates of economic growth seen throughout these regions. An increase in consumption of some particular products will depend not only on income but on the cultural and religious traditions of a particular country – these add a degree of uncertainty to a prediction based purely on income gain. Nevertheless, income growth in the least developed countries is likely to cause a relative increase in food consumption of nearly the same change as in income per capita. This will be examined further in Chapter 4.

While the economic projections from the IMF extend to 2023 and those of the Conference Board to 2028, the focus of this analysis is the situation up to 2030. It is inherently difficult to make good predictions for such a long period.

Table 12: Projected impact of GDP per capita on food consumption in regions and selected countries, 2013-25

Region	GDP and GDP per capita change	Impact on food demand
Europe	• Europe will contribute around 15 percent to world GDP by 2028, down from 18 percent in 2017 (Table 10). • GDP growth is expected at an average annual rate of 1.6 percent in 2019-23 and 1.1 percent in 2024-28 (Table 10). • A selection of European countries (Table 11) will add between 23 to 51 percent to their GDP per capita from 2017 to 2023. • Greece, Portugal, Spain and Romania are expected to add 32 percent, 33 percent, 34 percent and 51 percent, respectively, to their GDP per capita by 2023. Germany, France and Italy are expected to add less to their average purchasing power: 28 percent, 25 percent and 23 percent (Table 10).	• Increase in disposable income will not have significant impact on food composition in majority of countries as current income levels are already sufficient to meet dietary needs. Per capita GDP is likely to bring the consumption of higher value, convenience and luxury foods up. • Trends such as ageing populations and health consciousness will probably shift diet composition towards healthier foods.
Advanced economies	• Mature economies will contribute 40 percent to world output by 2028, down from 44 percent in 2017 (Table 10). • GDP growth for mature economies is expected at an average annual rate of 2 percent in 2019-23 and 1.7 percent in 2024-28 (Table 10). • The predicted increase in GDP per capita by 2023 of selected mature economies vary from 21 percent in Switzerland to 35 percent in the Republic of Korea (Table 11).	• Similar to Europe, the increase in disposable income will not be accompanied by a significant increase in food consumption. • There will probably be a shift in diet composition owing to the healthy eating trend, more conscious food choices of consumers and higher consumption of higher value, convenience and luxury foods.
China	• China's economy will continue to grow, although at decreased pace. Its economy will contribute 18 percent to world GDP by 2028, up from 17 percent in 2017 (Table 10). • GDP growth is expected at an average annual rate of 3.8 percent in	• High income growth will lead to food consumption increase in many or most product categories. • Luxury food products will become an increasingly important component of food expenditure for upper-middle-class families.

Region	GDP and GDP per capita change	Impact on food demand
	2019-23 and 3.4 percent in 2024-28 (Table 10). • China's GDP per capita growth rate will decline slightly but continue to be high, exceeding 7 percent on a yearly basis in 2017-23, adding 70 percent to its GDP per capita by 2023 (Table 11).	
India	• India will contribute almost 10 percent to world GDP by 2028, compared to 7.5 percent in 2017 (Table 10). • GDP growth is expected at an average annual rate of 5.9 percent in 2019-23 and 5.5 percent in 2024-28 (Table 10). • GDP per capita growth in India will rise from 7.3 percent in 2017 to 8.4 percent in 2023, and GDP per capita will have increased by 74 percent by 2023 (Table 11).	• As in China, high income growth should lead to food consumption increase in many or most product categories – in India not only following economic growth, but also from a growing population. • Luxury food products may become an increasingly important component of food expenditure for upper-middle-class families.
Latin America	• Latin American countries will grow at different speeds and contribute less than 7 percent to world GDP by 2028, down from 7.6 percent in 2017 (Table 10). • GDP growth is expected at an average annual rate of 1.9 percent in 2019-23 and 2024-28 (Table 10). • GDP per capita in Argentina, Brazil and Chile is expected to increase by 17 percent, 25 percent and 31 percent, respectively, by 2023. Venezuela's GDP per capita is predicted to decline by 18 percent over the same period (Table 11).	• Similar to developing Asia, increases in food demand is to be expected in Latin America – although purchasing power in this region is not as rapidly increasing. • Demand for higher value and luxury food products may become more important, owing to increases in GDP per capita.
Middle East and North Africa	• The Middle East and North Africa will contribute 7 percent of world GDP output by 2028, maintaining their share in 2017 (Table 10). • GDP growth is expected at an average annual rate of 3.1 percent in 2019-23 and 3 percent in 2024-28 (Table 10). • GDP per capita growth rate will vary among countries in the region. • An increasing trend in GDP per capita growth in Egypt will add 39 percent to its GDP per capita by 2023, whereas Saudi Arabia is expected to add 12 percent over the same period (Table 11).	• Rich countries such as Saudi Arabia will not experience much increase in food consumption although there will probably be shifts in diet composition. Developing countries such as Egypt will experience a food consumption increase in the majority of categories owing to higher income.
Sub-Saharan Africa	• Sub-Saharan Africa is predicted to contribute 3 percent to the World GDP output by 2028, compared to 2.7 percent in 2017.	• Increased disposable income in Africa will cause an increase in consumption. • The increase will be especially noticeable in consumption of

Region	GDP and GDP per capita change	Impact on food demand
	• GDP growth is expected at an average annual rate of 3.8 percent in 2019-23 and 3.9 percent in 2024-28 (Table 10). • GDP per capita in Botswana, Ethiopia and Mozambique will increase by 33, 80 and 33 percent, respectively, by 2023 (Table 11).	important nutrients such as proteins. • The magnitude of this increase is unclear owing to the differing rates of economic development within the continent.
Russia, Central Asia, and Southeast Europe	• The region is predicted to contribute 6.2 percent to world GDP by 2028, compared to 6.5 percent in 2017. • GDP growth is expected at an average annual rate of 2.3 percent in 2019-23 and 2.2 percent in 2024-28 (Table 10). • The countries are expected to grow their GDP at an average annual rate of 2.3 percent in 2019-23 and 2.2 percent in 2024-28. • GDP per capita growth in Russia is expected at an annual rate between 3.3-4.1 percent per year in 2017-23, increasing purchasing power by 29 percent over the period. Ukraine is expected to add 45 percent to its GDP per capita over the same period, with annual growth rates from 4.9-6.0 percent (Table 11).	• The extent to which increases in disposable income will translate into a significant increase in food consumption may vary among countries. • A shift in consumption towards healthier and more expensive food products is predicted owing to increases in income and the influence of food and health trends from developed countries.

3. TRENDS IN FOOD DEMAND

This chapter will discuss some global developments in food demand that are expected to take on importance in the future. Chapter 3.1 reviews consumer trends and preferences, while Chapter 3.2 looks at recent developments in food consumption. In spite of major advances over the past decades, poverty, hunger and food security still require attention in any discussion of global food demand. Chapter 3.3 is devoted to these issues.

3.1 Consumer trends and preferences

This section will be based on Lem, Bjørndal and Lappo (2014) and Bjørndal et al. (2014) that both give a very thorough analysis of this topic. These two publications identify five consumer trends that they believe will attain increased importance in the future, viz. food safety and health benefits, corporate social responsibility, production systems and innovations, sustainability and country and region of origin. Some key findings about each of the major identified trends will be reviewed in this section (as summarised in Table 13).

Healthy eating will be a dominant trend in food consumption in the coming decades. Driven by concerns about a global rise in the proportion of overweight and obese consumers and obesity-related diseases, governments will play an important role in promoting healthy eating habits to the public through campaigns, advertisements and targeted programmes in schools and workplaces. As a consequence, demand for food that is certified by an authorised body, labelled with safety assurances, whether public or private, or labelled organic, will increase, and the consumption of fast and fatty food will decline. The adoption and consumption of healthy foods will not be universal among countries and individuals owing to differing abilities to process information and understand health benefits and consumer involvement in personal health care.

Consumers' concerns about health relate closely to *food safety* concerns. Consumers will demand more information about food products and the possibility to trace their movements through the value chain. *Corporate social responsibility* is a rising trend among consumers and retailers. Consumers will demand more transparency from producers about food products, and will pay more attention to production sustainability, ethical sourcing, carbon footprint and food miles, among other factors. An abundance of publicly available information related to the food industry, product flaws, production mistakes, failures and unattained social responsibility goals will motivate producers to fully disclose information about their products. The reliability and honesty of the producer will increasingly influence consumers' choice of food. Corporations will progressively change their practices to become more socially responsible as a response to media, NGOs and consumer demands.

Food production and processing procedures will be affected by consumers. In some cases, such as the production of organic foods, production systems may revert towards more traditional ones. In other cases, developments in nanotechnology and genetic modification will stimulate the production of new foods. However, the acceptance of genetically modified products and nanotechnology may continue to be low owing to the negative perception by consumers of modified foods. These developments in the food industry should further facilitate the growth in relevant ecolabelling and certification schemes among producers.

Consumers' interest in the *sustainable production* of foods will continue to be an increasing trend, especially in wealthy developed countries. Fish stock and forest depletion as well as the

effect of production on climate are among consumers' areas of concerns. Legislation will reinforce the trend towards sustainable production, and awareness and popularity of sustainable and "socially responsible" products should increase as a result.

The concept of buying *local products* is heavily promoted among consumers. Attitudes, traditions, and special production methods that distinguish the food in national and international markets are elements that influence the selection of local foods over imported products among consumers.

Table 13: Consumer trends up to 2030

Trends	**Actions**	**Impact on food demand**
Food safety and health benefits	State intervention in the diets and lifestyles of citizens in order to control obesity. Campaigns to change individual behaviour involving public education, advertising, targeted programmes in school and workplaces. Established systems for food traceability.	Increased demand for food that is ecolabelled and/or certified by authorised bodies. Increasing popularity of organic food. Decreased consumption of fast food.
Product systems and innovations	Change of food production processes. Revert towards traditional production processes in cases such as organic foods. Application of genetic modification and nanotechnology to production of new foods.	Further adaptation to new foods, although slow in cases where genetic modification, nanotechnology, aquaculture and convenience apply. Growth in relevant certification and ecolabelling.
Corporate social responsibility	Increased awareness about social issues in food production by media, NGOs, consumer brands and other stakeholders. Full information about the product and its movement through the value chain provided by producers. Increased availability of information about product flaws, production mistakes, failures and unreached social responsibility goals provided by producers. A tendency to shift business practices toward social responsibility by producers and other stakeholders involved.	Increased preference of consumers to buy "socially responsible" products. More informed consumer choice about food products. Increased demand for products from reliable brands/producers. Affinity with "honest" brands/producers.
Sustainability	Established legislation towards sustainable and safe food production. Ecolabels.	Increase production and demand for products that are produced sustainably and certified.
Country and region of origin	Promotional actions towards local food by social agents (governments and NGOs).	Choice of local foods over exported by consumers if product prices are competitive.

Source: Lem, Bjørndal and Lappo (2014)

The extent to which the consumer trends will in fact affect food demand in the future is conditioned by the level of involvement of retailers in promotional efforts as well as the size and the economic value of the consumer segments. Unless the segments reach a minimum profitable size for producers and retailers, the main drivers in global food consumption will remain price, health and safety and product quality.

Increasing consumer awareness relate closely to promotional efforts undertaken by stakeholders, including governments and NGOs as well as the media and other influencers. These stakeholders and lobbies do not always share the same messages, interests and goals, sometimes resulting in increased confusion rather than improved decisions (Lem et al., 2014). Price sensitivity is a major constraint in the market development of these food trends, given the need to charge premium prices for premium products and production practices. Finally, even in countries with similar levels of income, cultural issues may result in differences in terms of consumer concerns and consumption patterns.

3.2 Food consumption

This section reviews recent developments in global food demand and consumption, as reported by the OECD-FAO Agricultural Outlook 2018-2027 (2018). Given the outlook period of the OECD-FAO Agricultural Outlook 2018-2027, this section is focused on the period up until 2027, which is as far as the projections are available.

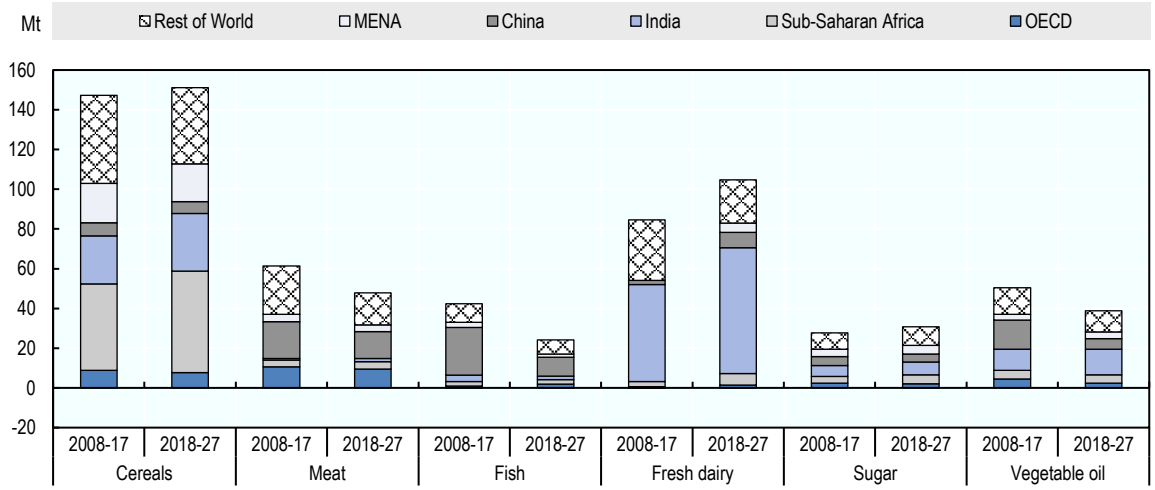
Agricultural commodities are consumed mainly as food, feed, and in industrial applications including fuel. Food demand is influenced by population and income growth, as outlined in Chapters 1 and 2 and increasingly also by trends in dietary patterns and consumer preferences, as discussed above. Demand for animal feed is closely linked to the human consumption of livestock products, such as meat, eggs and milk, but also by the evolution of livestock production technology. Industrial uses of agricultural commodities (mostly as biofuel and as input in the chemical industry) are shaped by general economic conditions, as well as regulatory policies and technological advances. Moreover, the relative importance of each use varies by commodity, by region, and by level of economic development.

3.2.1 Global growth of overall food demand: slowing compared to the previous decade

Over the last ten years, agricultural markets experienced a strong increase in demand across a wide range of commodities. Much of that growth was attributable to non-food uses of agricultural commodities, mostly for biofuel and animal feed. While food demand stagnated in the developed world, biofuel mandates led to increased demand for maize, sugarcane and vegetable oils as feedstock. In parallel, rising incomes in China and other emerging economies raised demand for meat.

Food consumption will continue to expand due to population growth and higher per capita income for most commodities with the developing world as the source of most demand growth over the coming ten years. Since around 2013, the rate of global population growth has been slowing in relative as well as absolute terms. Yet, world population is still expected to grow by around 54-77 million people per year by 2030 (see Chapter 1). Most of this growth occurs in Sub-Saharan Africa and India, as well as the Middle East and North Africa.

Sub-Saharan Africa and India will account for a large share of the additional food demand in the coming decade, reflecting in large measure continued strong population growth in these regions. Population growth in Sub-Saharan Africa is accelerating in absolute terms: while the region's population increased by 27 million in 2017, this rate will increase to 32 million people per year in 2027. Consumption of dairy products and vegetable oil in India will underpin growth in these commodities over the next ten years, while China continues to account for a large share of demand growth for meat and fish. (Figure 7).



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/888933741941
Note: Each column shows the increase in global demand over a ten-year period, split by region, for food uses only. MENA stands for Middle East and North Africa.

Figure 7. Regional contributions to food demand growth, 2008-17 and 2018-27

In addition to population growth, food demand is influenced by the growth of per capita incomes. Per capita consumption of many commodities is expected to be flat at a global level. This is not only expected for staple foods such as cereals and roots and tubers, where consumption levels are close to saturation levels in many countries, but also for meat. Some low-income regions which currently have low per capita consumption levels of meat, such as Sub-Saharan Africa, are not expected to increase these levels significantly due to a lack of sufficient income growth. Some emerging economies, in particular China, have already transitioned to relatively high levels of per capita meat consumption. In India, where income growth is stronger, dietary preferences are expected to translate rising incomes into an increased per capita demand for dairy as the preferred animal protein, rather than meat.

One implication of relatively flat per capita food consumption is that population growth will be the principal determinant of food demand growth, even though global population is projected to grow at a lower rate in the coming decade. The bulk of additional food consumption in the coming decade therefore originate in regions with high population growth such as Sub-Saharan Africa, India, and the Middle East and North Africa – and demand patterns in these regions will increasingly influence international agricultural markets.

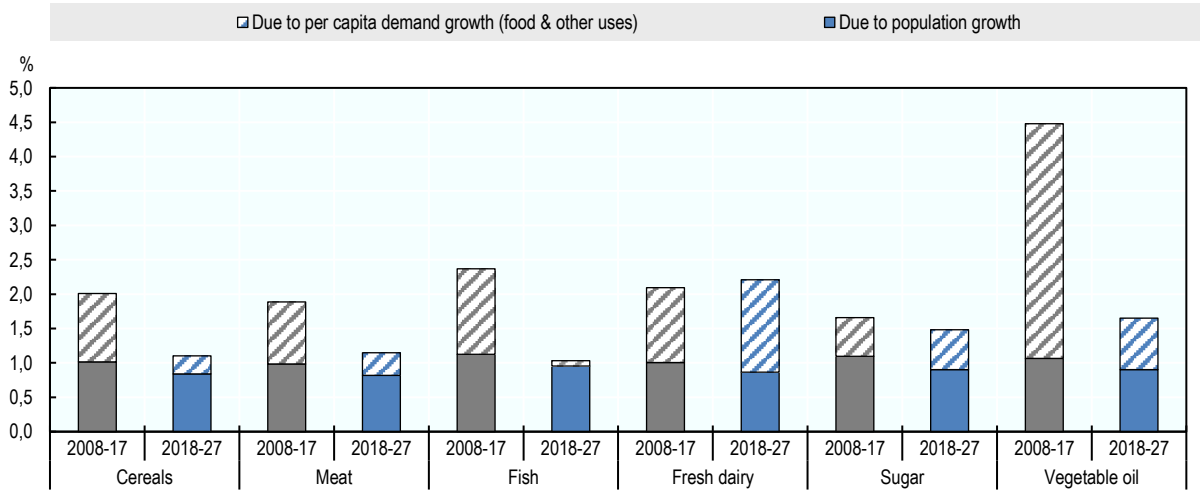
The macro-economic assumptions underlying the OECD-FAO Agricultural Outlook 2018-2027 suggest strong growth in per capita GDP in India (6.3 percent p.a.) and China (5.9 percent p.a.). For Sub-Saharan Africa, 2.9 percent p.a. per capita growth is expected over the coming

decade, but with variations across the continent. However, high growth in average incomes does not necessarily translate to income growth for poorer households. Per capita food demand in Sub-Saharan Africa is therefore expected to remain at relatively low levels.

Finally, differences in dietary preferences shape demand patterns. While income growth in China in the last decade led to increased demand for meat and fish, rising incomes in India are mostly expected to lead to higher consumption of dairy products as the preferred source of animal proteins. The interplay of regional differences in population growth, income growth and dietary preferences thus result in different developments for individual commodities.

Biofuels and Chinese demand growth will continue to play a role in global agricultural markets. However, their relevance is diminishing and may not fully be replaced by new sources of demand growth. Recent developments in biofuel policies combined with the assumption of a relatively moderate increase in the crude oil price suggest a more modest growth in the use of agricultural commodities in the production of biofuels.

The demand for feed, meanwhile, will continue to outpace food demand as livestock production intensifies. A large share of additional feed demand will come from China, as in the previous decade. Yet, compared with the previous decade, demand growth for feed slows down. As a result, slower growth in global demand for agricultural commodities is expected in the coming decade (Figure 8).



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/888933741922
Note: The population growth component is calculated assuming per capita demand remains constant at the level of the year preceding the decade. Growth rates refer to total demand (for food, feed and other uses).

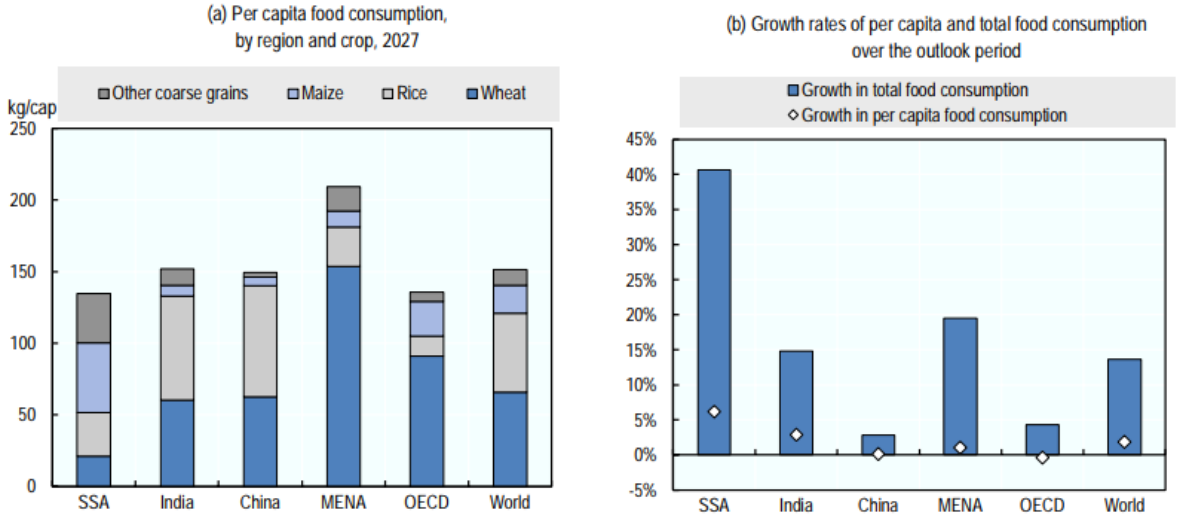
Figure 8. Annual growth in demand for key commodity groups, 2008-17 and 2018-27

For cereals, meat, fish, and vegetable oil, growth rates are projected to be around half their rates in the previous decade. The anticipated slowdown is particularly pronounced for vegetable oil, which was the fastest-growing commodity over the past decade, as biofuel policies, industrial uses (for paints, lubricants, detergents, etc.) and growth in food use supported demand.

3.2.2 Cereals: Growth in food consumption of cereals determined mainly by population growth

Per capita consumption of cereals is expected to increase globally by less than 2 percent over the coming decade (OECD-FAO, 2018). The slow growth is explained in large part due to the near-saturation level of cereals consumption in many regions across the world. Per capita food consumption of cereals is expected to grow only in low-income regions such as Sub-Saharan Africa, where it should increase by 6 percent over the next decade. In such low-income regions, cereals account for about two-thirds of dietary energy, compared to about one third in developed regions.

Figure 9 shows the level and composition of per capita consumption of cereals in main regions. As illustrated in Figure 9 (a) to the left, per capita consumption of cereals around the world is high – especially in the Middle East and North Africa. The continued dominance of wheat and rice across regions is also notable, except in Sub-Saharan Africa. In this region, white maize plays a major role in cereals consumption and calorie intake.



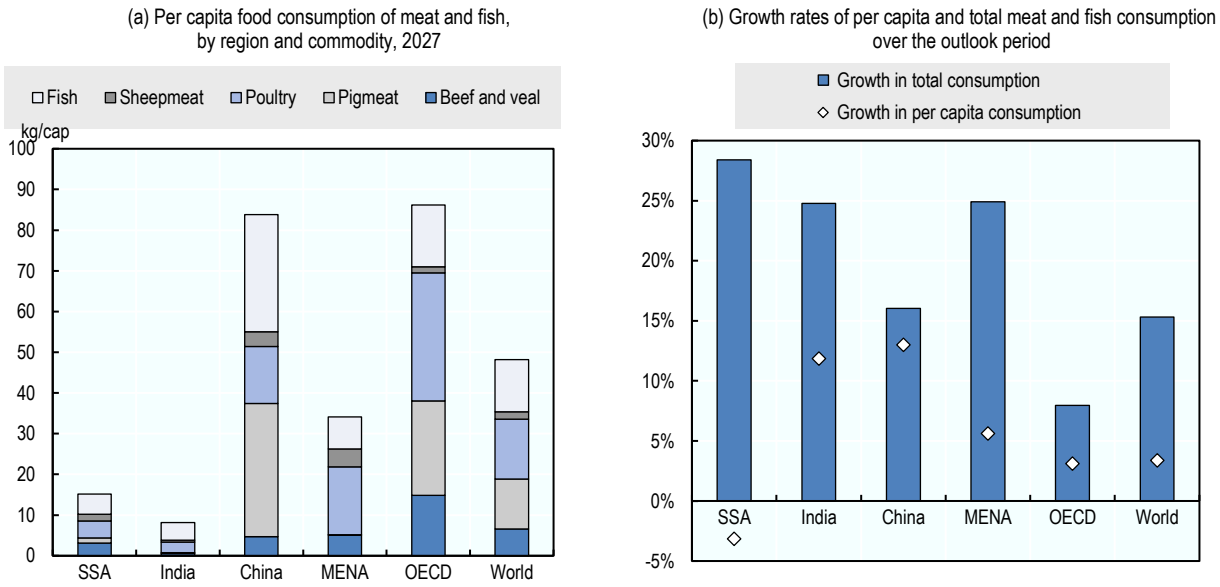
Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"
Note: SSA is Sub-Saharan Africa; MENA is Middle East and North Africa. The Agricultural Outlook measures consumption in terms of food availability and hence does not account for waste.

Figure 9. Cereals: Availability for food consumption

Given relatively flat per capita cereals consumption (Figure 9 (b)), population growth is the main determinant of growth in the coming decade, and the regions with the greatest population expansion (Sub-Saharan Africa, India, the Middle East and North Africa) account for the bulk of the additional food consumption of cereals.

3.2.3 Meat and fish: Global convergence in consumption patterns remains limited

Consumption of meat and fish differs significantly across regions according to income levels and dietary patterns (Figure 10 (a)). The availability of meat and fish is particularly low in Sub-Saharan Africa, where low incomes limit consumption, and in India, where dairy constitutes an important part of protein intake. Availability is high in advanced economies (OECD) and in Latin America (not shown on the chart), but also in China.



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"
Note: SSA is Sub-Saharan Africa; MENA is Middle East and North Africa. Consumption is defined here in terms of food availability, and hence does not account for waste. Per capita consumption data refers to edible weight, estimated using conversion factors of 0.7 for beef and veal; 0.78 for pigmeat; 0.88 for poultry and sheep; and 0.6 for fish.

Figure 10. Meat and fish: Per capita availability for food consumption

At a global level, total consumption of meat and fish is expected to increase by 15 percent over the outlook period, while per capita consumption of meat and fish rises by only 3 percent – with stark variations across regions (Figure 10 (b)) (see Chapter 7 for current and future fish production). The strongest growth in total consumption is expected in Sub-Saharan Africa (+28 percent), although this reflects exclusively the impact of population growth; per capita consumption is expected to decline by 3 percent. By contrast, per capita consumption growth is higher in India (+12 percent, albeit from a low base) and China (+13 percent).

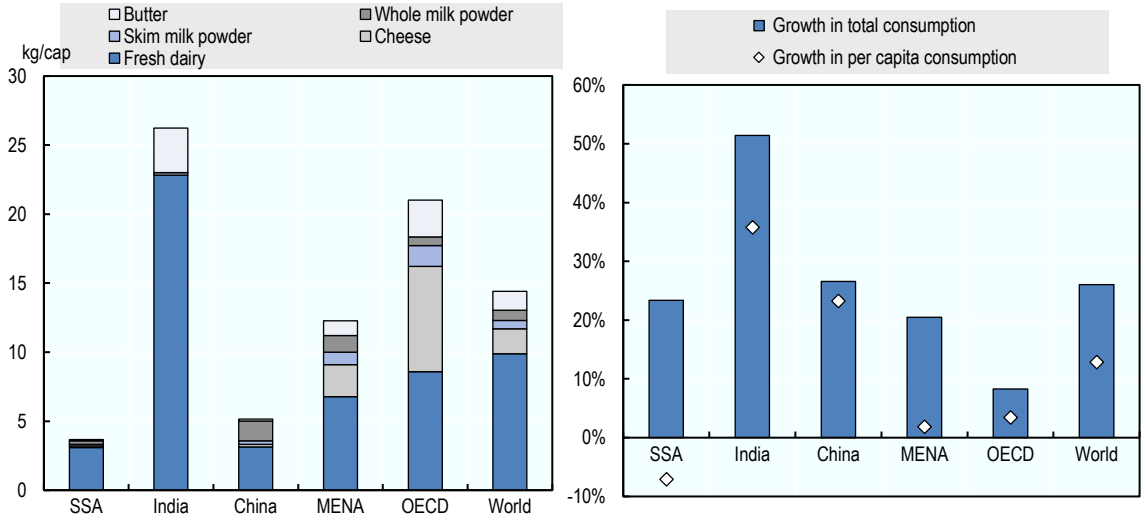
For meat, per capita consumption will grow most strongly in absolute terms in the developed world (+2.9 kg/capita over the outlook period), facilitated by lower prices. A growing gap thus exists with developing countries, which expand availability by 1.4 kg/capita. This smaller expansion is partly a reflection of income constraints, supply chain issues in some areas (e.g. lack of a cold chain infrastructure) and, in some regions, dietary preferences where protein is obtained more from non-meat sources. Within the developing world, least developed countries will add only 0.3 kg/capita, due to slow growth in disposable income. Asian countries in this group are projected to show some growth while Sub-Saharan Africa is expected to experience declining per capita consumption of both meat and fish.

The past decade saw strong growth in per capita consumption of poultry (+16 percent), while per capita consumption of beef and veal decreased by almost 5 percent between 2008 and 2017. For the coming decade, per capita consumption of poultry (typically the least expensive meat) is expected to increase by 5.5 percent, while beef and veal is projected to recover, with growth of 3.5 percent over the next decade, notably in China. Per capita pig meat consumption will be flat at the global level, but growth is expected to be strong in regions and countries where pork is popular, such as Latin America and the Philippines, Thailand and Viet Nam. The role of China in global pork consumption growth is anticipated to diminish due to an already high level

of per capita consumption. Whereas China accounted for 65 percent of the increase in the previous decade, it will only contribute 45 percent of the expansion in the next ten years. Mutton will remain a niche market in most countries, despite per capita consumption growth of 8 percent over the next ten years, concentrated mostly in China and other Asian countries as diets in the region diversify.

3.2.4 Dairy: Consumption of fresh dairy products expands in emerging economies

Dairy products can be consumed as fresh dairy products, butter, cheese or milk powders (e.g. for use in food processing). Fresh dairy products dominate consumption in developing regions and at a global level, while processed products such as butter and cheese dominate dairy consumption in the developed world (panel (a), Figure 11).



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"
Note: Food consumption of dairy products in milk solid (fat and non-fat solid) equivalents. SSA is Sub-Saharan Africa; MENA is Middle East and North Africa. The Agricultural Outlook measures consumption in terms of food availability and hence does not account for waste.

Figure 11. Global consumption of dairy (in milk solids)

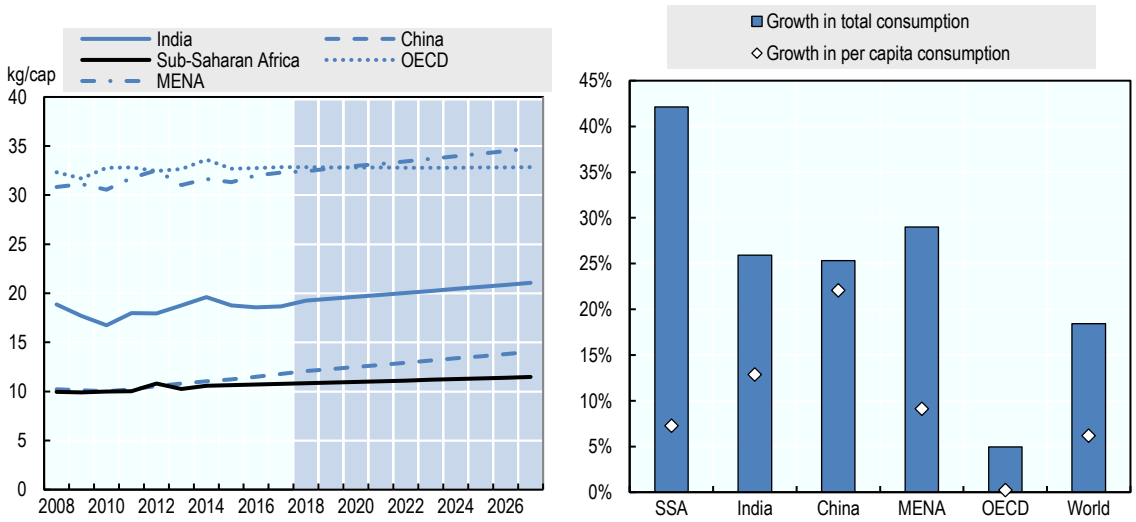
The dominance of fresh dairy products will increase in the coming decade, with 2.2 percent p.a. growth in consumption. This increase can be attributed largely to India, where dairy is an integral component of the diet, and the growth is pronounced both in terms of overall and per capita consumption.

While developing countries are increasingly consuming fresh dairy products, adding 8.4 kg/capita by 2027, fresh dairy consumption in developed countries will fall by 1.7 kg/capita as consumers continue shifting towards processed dairy products, such as milk powders, cheese and butter.

A growing preference for butter in higher-income countries has been attributed in part to changing perceptions of the health implications of consuming dairy fat. Despite strong price movements, global demand for butter is expected to grow at nearly 2.2 percent per year, supported by high and expanding consumption in India.

3.2.5 Sugar and vegetable oil: Consumption rising despite mounting health concerns

Relatively high growth rates are also expected for sugar and vegetable oil, as urbanisation in developing countries leads to greater demand for convenience foods, typically characterised by a higher sugar and oil content. Most of the additional demand for sugar will originate from the developing world (94 percent), in particular Asia (60 percent) and Africa (25 percent), two sugar-importing regions. Per capita consumption is projected to grow by 2.4 kg/capita in India, 2.5 kg/capita in China and 2.9 kg/capita in the Middle East and North Africa, compared with flat consumption in developed countries (Figure 12). In Sub-Saharan Africa, per capita consumption is projected to increase by 7 percent or 0.8 kg/capita over the next decade. Combined with strong population growth, total consumption in the region is expected to grow by 42 percent. While the increase in per capita consumption in Sub-Saharan Africa is relatively small, it contrasts with the projected decline in per capita consumption of meat, fish and dairy.



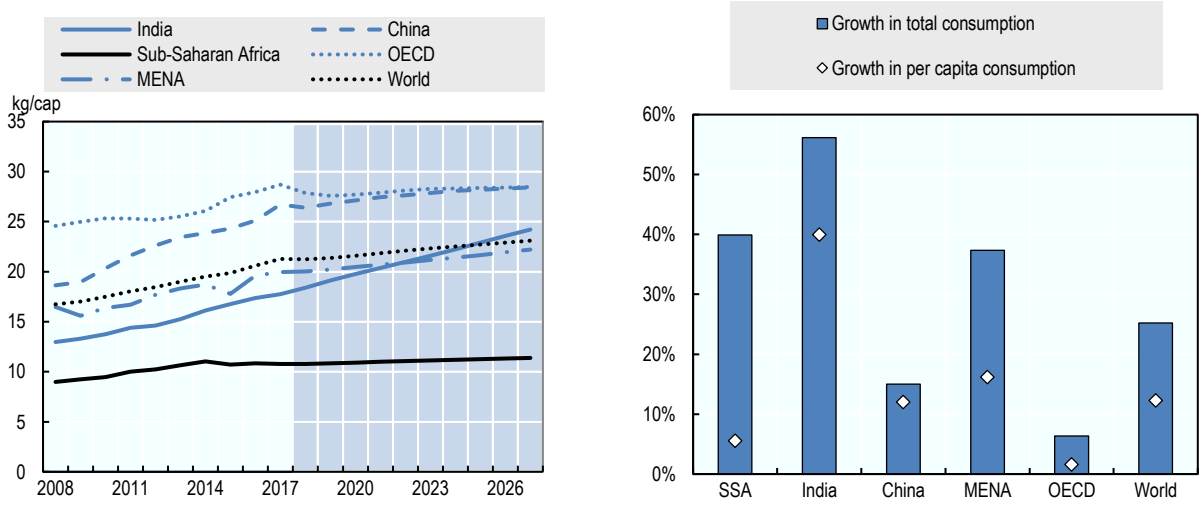
Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"
Note: Charts show food consumption of sugar from sugarcane and sugar beet (i.e. excluding other sweeteners such as high-fructose corn syrup). SSA is Sub-Saharan Africa; MENA is Middle East and North Africa. The Agricultural Outlook measures consumption here in terms of food availability and hence does not account for waste.

Figure 12. Food consumption of sugar

As for other commodities, patterns of sugar consumption are influenced by local factors as well as by incomes and preferences. For instance, per capita consumption is high in Brazil (the world's largest sugar producer) and other Latin American countries, and projected to continue increasing. Per capita consumption levels are also high in OECD countries, but projected to remain flat. This stagnation may partly be due to the identification of high levels of sugar consumption as a contributory factor to rising rates of obesity and non-communicable diseases (also related to consumer trends and awareness, as well as public/promotional efforts to increase awareness, as discussed in Chapter 3.1). By contrast, those factors are not expected to limit sugar consumption in the Middle East and North Africa over the next ten years, even though per capita consumption levels are similar to those in OECD countries. In this region, per capita consumption levels are assumed to rise.

Compared with other commodities, expected growth in food demand is strong for vegetable oil, at 2.0 percent per year, although this represents a considerable slowdown compared with last

decade's 3.9 percent annual growth rate. For the world as a whole, per capita food use of vegetable oil is projected to increase from 21 to 23 kg per capita (Figure 13). In several developing countries, per capita consumption is approaching levels seen in the developed world. This is especially true for China, but also for India and the Middle East and North Africa. By contrast, per capita consumption in Sub-Saharan Africa will remain at levels much below those in the rest of the world, although it is projected to increase by 6 percent over the outlook period, or 0.6 kg/capita.



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"
Note: Charts show food consumption of vegetable oil (i.e. excluding use as feedstock for biodiesel and other uses). SSA is Sub-Saharan Africa; MENA is Middle East and North Africa. The Agricultural Outlook measures consumption here in terms of food availability and hence does not account for waste.

Figure 13. Food consumption of vegetable oil

Strong demand growth in the developing world does not always correspond to increasing per capita availability of food. In Sub-Saharan Africa, high growth rates for fish and meat are the result of strong population growth, while per capita availability is expected to fall. In the Middle East and North Africa, per capita availability of meat and fish is not expected to increase much. By contrast, per capita availability of sugar and vegetable oil are expected to increase in these regions. More generally, Least Developed Countries (LDCs) are expected to increase their calorie availability at a slower rate in the coming decade, and the increase is due mostly to increased sugar and oil consumption while per capita intake of animal proteins is expected to remain low. As a result, malnutrition will remain an important problem.

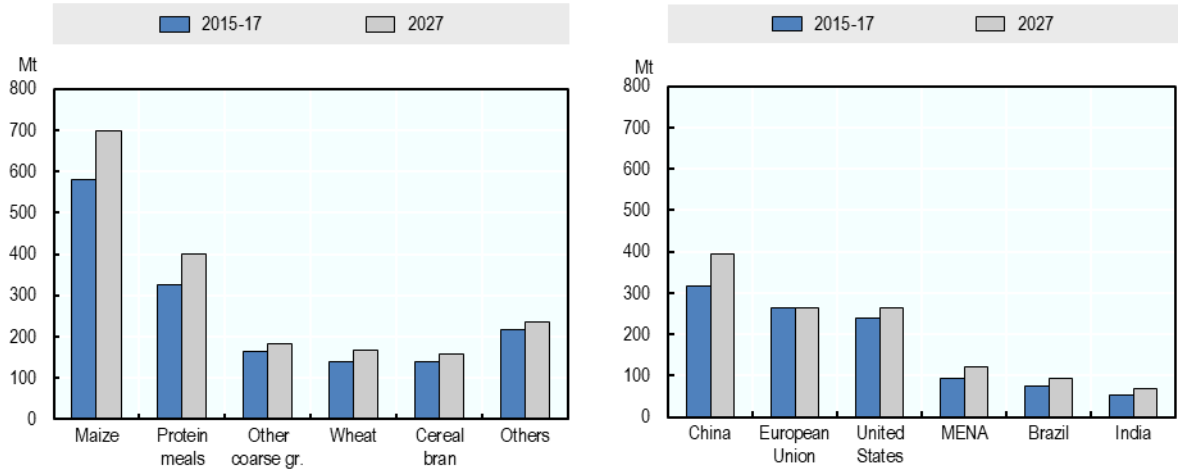
3.2.6 Feed and fuel: Non-food uses affect demand for several agricultural commodities

For most agricultural commodities reviewed in the OECD-FAO Agricultural Outlook, the demand for food uses dominates overall demand. However, non-food uses, particularly feed and fuel, are important for several agricultural commodities, and often show faster growth rates than food demand. In the case of feed, this will remain true in the coming decade. Biofuels by contrast were a major factor stimulating demand for agricultural commodities in the past decade, but growth is slowing down in the coming decade.

The global demand for feed reached 1.6 billion tonnes in 2015-17 and is expected to increase further to 1.9 billion tonnes by 2027, at an annual growth rate of around 1.7 percent. Demand

for feed is thus expected to grow faster than the demand for several commodities and markedly faster than food demand for cereals, for which a 1.1 percent per annum growth rate is expected. The growth results in about 260 million tonnes of additional feed demand by 2027; slightly less than the expansion of the previous decade in which demand grew by more than 300 million tonnes.

The main set of agricultural commodities used for feed includes maize, protein meal, other coarse grains (especially barley and sorghum), wheat, and by-products of cereal processing such as cereal bran. As shown in Figure 14, maize and protein meal will remain the most important commodities used as feed, accounting for 60 percent of all feed by 2027 (up from 58 percent in the base period). Feed demand for maize is expected to grow by 21percent over the outlook period, and demand for protein meal is expected to expand by 23 percent, considerably faster than the other commodities used as feed.



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/888933742093
Note: MENA stands for the Middle East and North Africa.

Figure 14. Demand for feed

Projections for protein meal, which is derived from crushing oilseeds, will be influenced by developments in feed systems and in agricultural policies. For instance, Least Developed Countries' total demand is expected to grow around 45 percent between 2015-17 and 2027, reflecting the intensification of livestock production as these countries move towards compound feed-based livestock production. Yet, global demand growth for protein meal is expected to fall below the average annual rate of the past decade (1.7 percent compared to 4.2 percent). That high growth rate was in large part due to China, where the intensification of meat production coincided with a high support price for grains. This discouraged the use of maize as feed. The reduction of maize support prices in China since 2016 means that maize will play a more important role in the Chinese feed mix in the next decade.

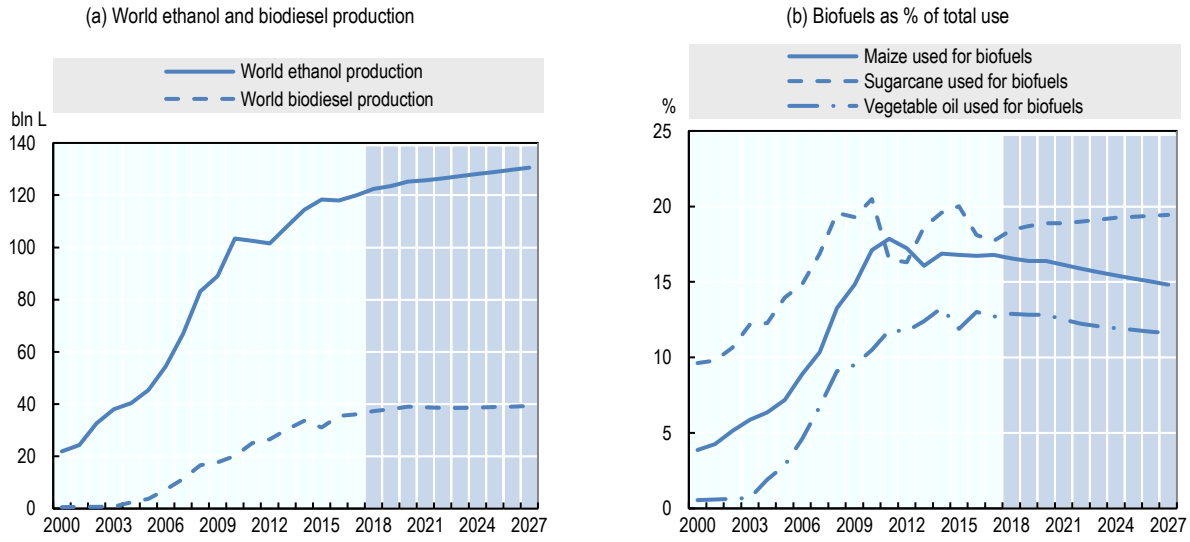
Overall growth patterns in the demand for feed will vary across geographic regions. Around 30 percent of the additional demand for feed will originate in China, where feed demand is expected to grow 25 percent over the outlook period. Strong growth in feed demand is also expected in the Middle East and North Africa (+29 percent with the region expected to account for around 10 percent of additional global demand), as well as Brazil (+25 percent) and India (+31 percent). Growth rates in the European Union and the United States are considerably lower

at 0.4 percent and 11 percent, respectively, over the outlook period. For the European Union, this rate reflects the expected decline in domestic meat consumption over the outlook period.

Agricultural commodities are not only used as food and feed, but also as fuel in the form of biofuels. These include ethanol, based mostly on maize and sugarcane, and biodiesel, produced mostly from vegetable oil. The evolution of biofuels is highly sensitive to potential changes in policy, as well as to overall demand for transport fuel, which in turn depends on the crude oil price. In many countries, mandatory blending rules impose a minimum share of ethanol and biodiesel to be used in transport fuel. The link between oil prices and biofuel prices is therefore complex. The baseline projections in the OECD-FAO Outlook are based on the policies currently in place in the key regions and are clearly sensitive to changes in that policy environment.

In the second half of the 2000s, various policies started to stimulate biofuel production, leading to a strong increase in world ethanol and biodiesel output. As a result, a growing share of global sugarcane and maize production was used for ethanol production, while a growing share of vegetable oil was used for biodiesel production (Figure 15). This policy-induced expansion of biofuels was a major driver of increased demand for maize, sugarcane and vegetable oil over the past decade.

Over the next 10 years, the demand for these commodities as inputs to biofuel production is expected to stabilise, as mandatory blending requirements are not expected to rise at the same pace as over the past decade. As such, the production of biofuels is expected to grow more slowly over the coming decade. In the past 10 years, global production of ethanol grew by 64 billion litres, equivalent to 3.9 percent p.a. growth; over the next ten years, only an addition of 12 billion litres (0.7 percent p.a.) is projected. For biodiesel, the past decade saw an increase of 29 billion litres (9.5 percent p.a.), whereas only 5 billion litres (0.4 percent p.a.) is expected to be added over the outlook period.



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027"

Figure 15. Biofuels and the demand for feedstock, 2000-27

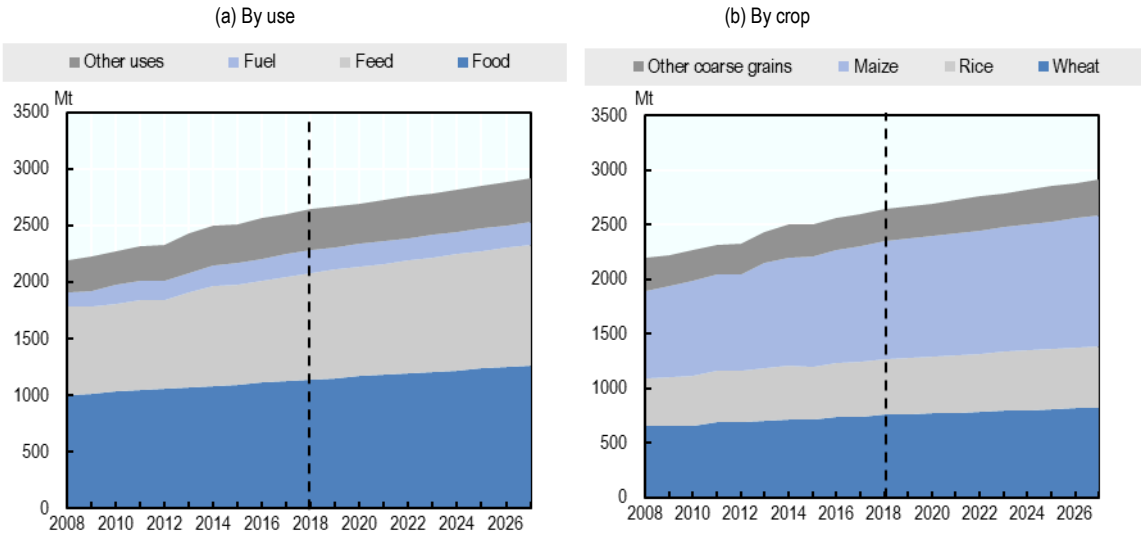
The composition of the demand for biofuels is also changing, with a shift towards developing countries which are increasingly putting in place policies favouring the domestic biofuel market. For ethanol, the main markets are the United States, Brazil, China, and the European Union. Declining demand for transport fuel is expected to decrease the demand for ethanol in the United States and the European Union, while strong growth is expected in Brazil, China, and Thailand, spurred by favourable policies. The demand in China could increase further with the implementation of the country's proposed new ethanol mandate. Overall, 84 percent of the additional demand for ethanol in the coming decade will come from developing countries.

For biodiesel, the main markets are the European Union, the United States, Brazil, Argentina and Indonesia. As with ethanol, demand is expected to decline in the European Union and the United States, which will drive down demand for vegetable oil as feedstock. Instead, an expansion is expected in Brazil, Argentina, Indonesia, and other developing countries, again mainly through favourable policy measures.

Food, feed and fuel: Competing sources of cereal demand

In addition to being an important and relatively low-cost source of calories, cereals are widely used for feed and fuel, in large part because of the ease with which cereals can be processed into other forms. This versatility also implies that food use of cereals may come into competition with non-food uses, especially when non-food uses expand rapidly.

As shown in Figure 16, between 2005-07 and 2017 the global demand for cereals increased by around 520 million tonnes to around 2.6 billion tonnes. Over the coming decade, demand will grow by around 360 million tonnes, but the composition of this demand growth is changing. While fuel was a major component of demand growth in the past decade (contributing more than 120 million tonnes to demand), this is no longer expected to be the case over the outlook period. Instead, food and feed uses are driving growth, together accounting for almost all additional demand over the coming decade.



Source: OECD/FAO (2018), "OECD-FAO Agricultural Outlook 2018-2027", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/888933742131
Note: The Agricultural Outlook measures demand in terms of availability, and hence does not account for waste.

Figure 16. Global demand for cereals, 2008-27

Panel (b) of Figure 16 shows cereal demand by crop. In the past decade, maize accounted for almost 330 million tonnes of the 520 Mt of additional cereals demand, or more than 60 percent. Over the outlook period, demand for maize is expected to grow by 164 million tonnes, accounting for 46 percent of demand growth only. This slowdown in growth is consistent with the evolution of biofuel markets over the coming decade. For both rice and wheat, demand growth is expected to be more robust, with 97 million tonnes of additional wheat demand and 66 million tonnes of additional rice demand, most of it for food uses. Following flat demand over the last decade, renewed interest is expected in other coarse grains, which are projected to grow by more than 32 million tonnes over the coming decade. The projected trends in cereals are thus a reflection of the demand trends in food, feed and fuel.

3.3 Poverty, undernourishment and hunger

This section provides an overview of the current state of undernourishment in the world, its development over time and the goal of eradicating hunger, shared by governments and international organisations.

3.3.1 Food security, hunger and poverty

FAO defines food insecurity as "a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life" (FAO, undated). Food insecurity may be chronic, seasonal or transitory[18].

Hunger is usually understood as an uncomfortable or painful sensation caused by insufficient food energy consumption (FAO, 2008). The measure for hunger compiled by FAO, defined as undernourishment, refers to the proportion of the population whose dietary energy consumption is less than a pre-determined threshold (FAO, 2008). The threshold is country specific and is measured in terms of the number of kilocalories required to conduct sedentary or light activities (FAO, 2008). The undernourished are also referred to as suffering from food deprivation (FAO, 2008).

It is important to understand how the concepts food insecurity, hunger and poverty[19] are interrelated. By the definitions of FAO (2008), all hungry people are food insecure, but not all food insecure people are hungry. There are also other causes of food insecurity, including poor intakes of micronutrients[20]. While poverty is a cause of hunger, lack of adequate and proper nutrition is also an underlying cause of poverty. Hunger "leads to distress behaviour that undermines development, including the sale of assets, the withdrawal of children from school (particularly girls) and into the labour force, the prompting of outmigration and, at worst,

[18] Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (FAO, undated).

[19] The international poverty line is set to US$1.90 per person per day (World Bank, 2016). In 2013, the year of the latest comprehensive data on global poverty, 767 million people are estimated to have been living below the poverty line (corresponding to almost 11 people in every 100 in the world, 10.7 percent of the global population).

[20] Malnutrition is another related concept, which results from deficiencies, excesses or imbalances in the consumption of macro- and/or micronutrients. Malnutrition may be an outcome of food insecurity, or it may relate to non-food factors, such as inadequate care practices for children, insufficient health services or an unhealthy environment.

permanent destitution, prostitution and child trafficking. It also contributes to the onset of armed conflict" (Foresight, 2011).

Undernourishment makes it difficult to perform physical and mental activities such as study and work, while undernourishment in children prevents those affected from ever reaching their full physical and cognitive potential – costing lives, livelihoods and economic growth. Moreover, constantly hungry people are vulnerable to diseases and infections due to a weakened immune system.

Achieving a world without hunger and malnutrition is an aim set by the 2030 Agenda for Sustainable Development (2030 Agenda) (FAO, 2017). On 25 September 2015, the 193 Member States of the United Nations adopted the 2030 Agenda - including 17 Sustainable Development Goals (SDGs) and 169 targets. The second Sustainable Development Goal (SDG 2) calls on countries to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" by 2030 (FAO, 2017). Composed of eight targets, the SDG 2 unites hunger, food security, nutrition and sustainable agriculture under a single objective, compelling the international community to move towards an understanding of how they are interrelated and promoting integrated policy approaches and actions (FAO, 2017). The start of the 2030 Agenda coincided with the launch of the United Nations Decade of Action on Nutrition (2016-2025), adding impetus to joint efforts at eradicating hunger and preventing all forms of malnutrition worldwide (FAO, 2017).

The traditional FAO indicator used to monitor hunger at the global and regional level is "the prevalence of undernourishment" (PoU). Historic data of hunger by this measure is presented in section 3.1.2. As countries in the world increasingly collect information on people's access to food in periodic national population surveys, the data are increasingly being used to improve FAO country-level PoU estimates (FAO, 2018). However, most household surveys do not provide direct evidence on individual food consumption, so a caveat of the approach is that interpretation can only be made at population group level and disaggregated only to the point allowed by the representativeness of the surveys in which the data were collected. PoU estimates cannot be produced at sufficiently disaggregated levels to be able to identify specific vulnerable populations within countries, which is a limitation for monitoring the very ambitious goal of zero hunger in an agenda that aims to "leave no one behind".

To complement the information provided by the PoU and to allow for monitoring SDG Target 2.1 globally in a more effective way, FAO has recently adopted a different approach to measuring food insecurity, based on the Food Insecurity Experience Scale (FIES). The approach is based on asking people, directly in a survey, to report on the occurrence of conditions and behaviours that are known to reflect constraints on access to food. The Food Insecurity Experience Scale (FIES) survey module is composed of eight questions to measure the severity of the food insecurity situation of respondents. When included in large-scale national population surveys, results can be disaggregated, thus helping identify which subpopulations within a country are most affected by food insecurity. It also seeks to estimate the prevalence of food insecurity at different levels of severity. A review of the state of food insecurity using the Food Insecurity Experience Scale (FIES) scale is presented in section 3.1.3.

Finally, section 3.2.4 reviews how food insecurity contributes to overweight and obesity in many modern societies and discusses the seeming paradox where undernutrition and high rates of these forms of malnutrition coexist in many countries (as highlighted in the most recent FAO report "The State of Food Security and Nutrition in the World 2018").

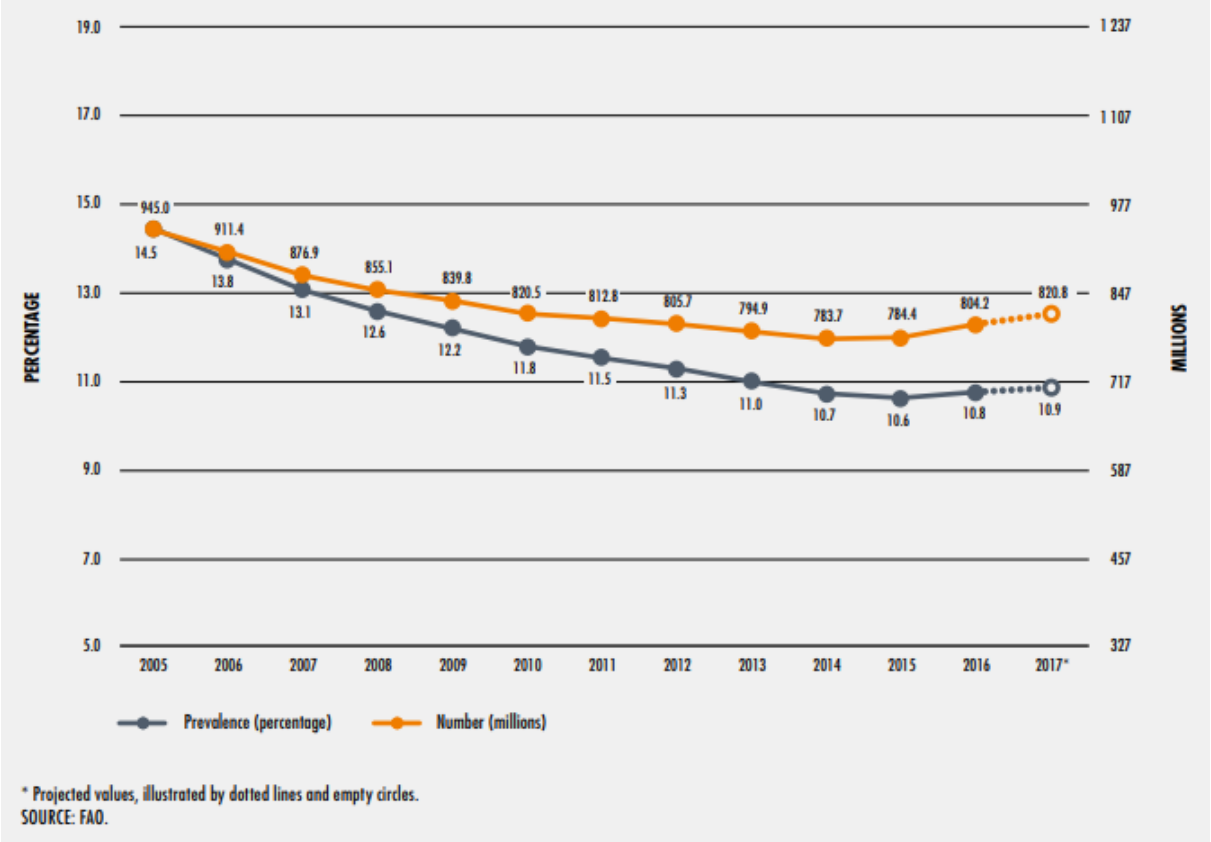
3.3.2 Prevalence of undernourishment and its development over time

This section reviews recent trends in the prevalence of hunger and undernourishment, as reported by the FAO, IFAD, UNICEF, WFP and WHO (2018), in their annual report *The State of Food Security and Nutrition in the World*.

In spite of significant global population growth, the number and share of undernourished people in the world have decreased over time, long-term. The number of undernourished people declined from 900 million in 2000 to 775 million in 2013, while the relative prevalence (share) of undernourished people declined from 14.7 percent in 2000 to 10.8 percent in 2013.

However, the 2017 edition of The State of Food Security and Nutrition in the World projected that the decade-long decline in the prevalence of undernourishment in the world had reached an end and was possibly in reverse (Figure 17). Following decades of improvement, the rate of reduction in the number of undernourished people came to a virtual halt between 2010 and 2015. This was largely attributed to persistent instability in conflict-ridden regions, adverse climate events in many regions of the world and economic slowdowns that affected more peaceful settings and worsened the food security situation.

New evidence confirms lower levels of per capita food consumption in some countries, and increased inequality in the ability to access food in the populations of other countries. This contributes to what is projected to be a further increase in the percentage of people in the world having insufficient dietary energy consumption in 2017. The 2017 FAO estimates show that the share of undernourished people in the world population – the prevalence of undernourishment – appears to have been growing for two years in a row and may have reached 10.9 percent in 2017 (Figure 17 and Table 14).



Source: FAO (2018). The State of Food Security and Nutrition in the World 2018

Figure 17: The number and share of undernourished people in the world. 2000-16

Even though the increase in relative share may seem negligible from a historical perspective, considering continuing population growth it implies that the number of people who suffer from hunger has been growing over the past three years, returning to levels from almost a decade ago. The absolute number of undernourished people in the world is now estimated to have increased from around 804 million in 2016 to almost 821 million in 2017. This trend sends a clear warning that unless efforts are enhanced, the Sustainable Development Goals (SDG) target of hunger eradication will not be achieved by 2030.

In 2017, 515 million people in Asia, more than 256 million in Africa, and more than 39 million in Latin America and the Caribbean were estimated not to have access to sufficient food energy (Table 14). The highest absolute number of undernourished people is in Asia, much due to the size of its population. Although the relative prevalence (share) of undernourishment is highest in Africa, the number of people suffering from undernourishment in Asia is about double the number in Africa. While the share of undernourished people in Asia has been declining, both the absolute number and the population share suffering from undernourishment in Africa has been increased since 2013 (FAO, 2017). Eastern, Middle and Sub-Saharan Africa remains the regions with the highest prevalence of undernourishment, affecting an alarming 31.4, 26.1 and 23.2 percent of the population in 2017. Other regions where the prevalence of undernourishment is estimated to affect more than 10 percent of the population in 2017 include Western Africa, Southern Asia, Western Asia and the Caribbean.

The estimates up to 2017 included in The State of Food Security and Nutrition in the World 2018 unfortunately confirm that the prevalence of undernourishment in Africa and Oceania has

been increasing for a number of years (Table 14). Africa remains the continent with the highest prevalence of undernourishment, affecting over 20 percent of the population (more than 256 million people). The estimates also reveal that the decreasing trend that characterised Asia until recently may have come to an end. The projected prevalence of undernourishment for Asia in 2017 shows that 11.4 percent of the population is estimated to be undernourished, which represents more than 515.1 million people – confirming it as the region with the highest number of undernourished people in the world. While this is a slight reduction in share from 2016 (11.5 percent), the number of people affected has increased (from 514.5 million people in 2016). Countries in South-Eastern Asia have been affected by adverse climate conditions with impacts on food availability and prices, while countries in Western Asia have been affected by prolonged armed conflicts (see box 3).

Table 14: The number and share of undernourished people in the world. Selected years from 2005-17

	2005		2010		2012		2014		2016		2017[1)]	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
WORLD	**945**	**14.5**	**820.5**	**11.8**	**805.7**	**11.3**	**783.7**	**10.7**	**804.2**	**10.8**	**820.8**	**10.9**
AFRICA	**196**	**21.2**	**200.2**	**19.1**	**205.2**	**18.6**	**212.5**	**18.3**	**241.3**	**19.7**	**256.5**	**20.4**
Northern Africa	9.7	6.2	8.5	5	17.6	8.3	17.8	8.1	19.5	8.5	20	8.5
Sub-Saharan Africa	176.7	24.3	181	21.7	187.6	21	194.7	20.7	221.9	22.3	236.5	23.2
Eastern Africa	113.5	34.3	119.1	31.3	113.3	30.9	117.1	30.2	129.6	31.6	132.2	31.4
Middle Africa	36.2	32.4	36.5	27.8	36.4	26	36.1	24.2	40.8	25.7	42.7	26.1
Southern Africa	3.6	6.5	4.2	7.1	4.2	6.9	4.6	7.4	5.2	8.2	5.4	8.4
Western Africa	33	12.3	31.9	10.4	33.7	10.4	36.9	10.7	46.3	12.8	56.1	15.1
ASIA	**686.4**	**17.3**	**569.9**	**13.6**	**552.2**	**12.9**	**523.1**	**12**	**514.5**	**11.5**	**515.1**	**11.4**
Central Asia	6.5	11.1	4.6	7.3	4	6.2	4	5.9	4.2	6	4.4	6.2
Eastern Asia	219.1	14.1	178.4	11.2	160.4	9.9	142.6	8.8	139.5	8.5	139.6	8.5
South-Eastern Asia	101.7	18.1	73.7	12.3	65.1	10.6	60.6	9.7	63.6	9.9	63.7	9.8
Southern Asia	339.8	21.5	293.1	17.2	299.6	17.1	289.4	16.1	278.1	15.1	277.2	14.8
Western Asia	19.4	9.4	20.1	8.6	23.1	9.5	26.5	10.4	29.1	11.1	30.2	11.3
LATIN AMERICA AND THE CARIBBEAN	**51.1**	**9.1**	**40.7**	**6.8**	**38.9**	**6.4**	**38.5**	**6.2**	**38.9**	**6.1**	**39.3**	**6.1**
Caribbean	9.1	23.3	8	19.8	7.9	19.3	7.7	18.5	7.2	17.1	7	16.5
Latin America	42.1	8.1	32.6	5.9	31	5.4	30.8	5.3	31.7	5.3	32.3	5.4
Central America	12.4	8.4	11.6	7.2	11.9	7.2	11.6	6.8	11	6.3	11	6.2
South America	29.6	7.9	21.1	5.3	19.1	4.7	19.3	4.7	20.7	4.9	21.4	5
OCEANIA	**1.8**	**5.5**	**1.9**	**5.2**	**2**	**5.4**	**2.3**	**5.9**	**2.6**	**6.6**	**2.8**	**7**
NORTHERN AMERICA AND EUROPE[2)]	**<26.4**	**<2.5**	**<27.0**	**<2.5**	**<27.2**	**<2.5**	**<27.3**	**<2.5**	**<27.5**	**<2.5**	**<27.6**	**<2.5**

1) Projected values
2) Numbers for NORTHERN AMERICA AND EUROPE refer to less than 2.5 percent of the population each year.

Source: FAO (2018). The State of Food Security and Nutrition in the World 2018

In Africa, the situation is pressing in the region of sub-Saharan Africa where an estimated 23.2 percent of the population – or between one of four and one of five people in the region – may have suffered from chronic food deprivation in 2017. An increase in the prevalence of

undernourishment has been observed in all subregions of sub-Saharan Africa except for Eastern Africa. A further slight increase is seen in Southern Africa, while a significant uptick is seen in Western Africa, possibly reflecting factors such as droughts, rising foods prices and a slowdown of real per capita Gross Domestic Product (GDP) growth. The dynamics in the prevalence of undernourishment, combined with rapid population growth, have led to a dramatic increase in the total number of undernourished people. The number of undernourished people in sub-Saharan Africa rose from 181 million in 2010 to almost 222 million in 2016, an increase of 22.6 percent in six years, and – based on current projections – may have increased further to more than 236 million in 2017.

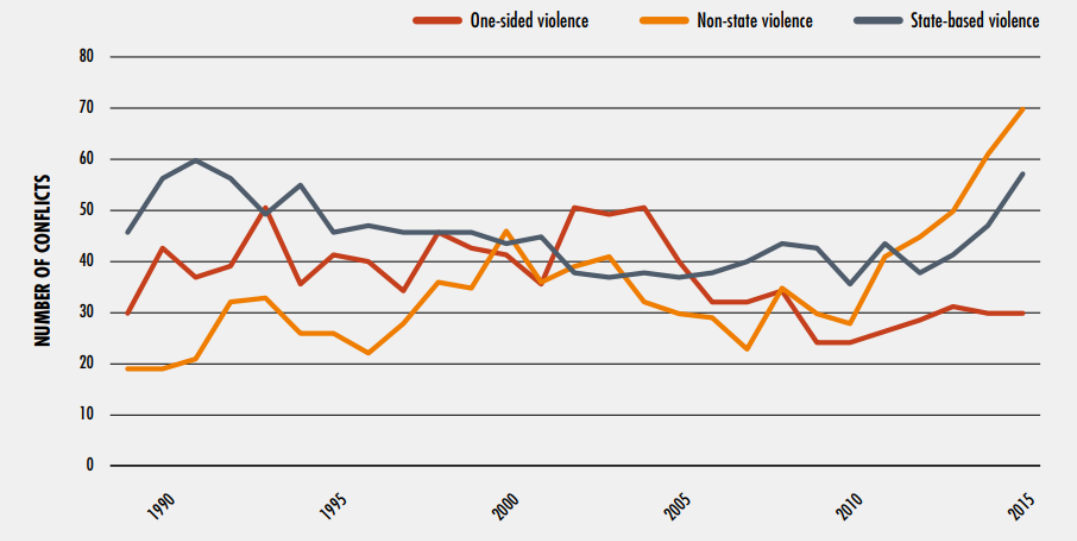
The situation has also deteriorated within South America, where the prevalence of undernourishment increased from 4.7 percent in 2014 to a projected 5.0 percent in 2017. Such trends may be the result of persisting low prices in main export commodities – particularly crude oil – which have drained financial resources for food imports, reduced the capacity of governments to invest in the economy and significantly reduced the fiscal incomes needed to protect the most vulnerable against rising domestic prices and loss of income.

Box 3: Conflict, climate change and food security

The majority of chronically food insecure people live in countries affected by conflict. Recent food security deteriorations have been observed most notably in situations of conflict and conflict combined with droughts or floods (FAO, 2017).

The number of conflicts may be on the rise. Exacerbated by climate-related shocks, conflicts seriously affect food security and are a cause of much of the recent increase in re-emerged famines (United Nations, 2017). Hunger and undernutrition are significantly worse where conflicts are prolonged and institutional capacities weak. In parts of the world, this recent surge in hunger reached an extreme level, with a famine declared in areas of South Sudan in early 2017 and alerts of high risk of famine issued for three other areas (Northeast Nigeria, Somalia and Yemen). In 2016, the food security situation deteriorated sharply in parts of sub-Saharan Africa, South-Eastern Asia and Western Asia – most notably in situations of conflict and in particular where droughts or floods, linked in part to the El Niño phenomenon, compounded the impacts of conflict (FAO, 2017).

Although the frequency of wars has been decreasing in recent decades to reach an all-time low in 2005, there has recently been a surge in the number of violent conflicts and conflict-related deaths (FAO, 2017). The number of conflicts and of displaced populations caused by internal or intrastate conflict are two worrying signs that current trends are likely to continue over the coming years. Violent conflicts have increased dramatically since 2010 and are currently at an all-time high (Figure 18). Of these, non-state conflicts – between two organised armed groups of which neither is the government or a state – have increased by 125 percent since 2010, surpassing all other types of conflict. State based conflict also rose by over 60 percent in the same period.



Source: Uppsala Conflict Data Programme (UCDP), published in FAO (2017). See UCDP for updated data: https://ucdp.uu.se/

Figure 18. Number of conflicts, 1990-2015 – markedly increasing since 2010

Civil wars or internal conflicts have now surpassed the number of interstate or external conflicts between states. In other words, there has been a shift away from conflict between nations to conflicts within nations – although this trend is matched by a rise in the number of internationalised internal conflicts. Coupled with large outflows of displaced people, the entanglement of external international actors in state conflicts shows that even internal conflicts cannot be quarantined, with their repercussions being felt across borders and even continents (FAO, 2017). Similarly, the implications of conflict-induced food insecurity are no longer limited to specific countries or regions – they are now global. The number of displaced people worldwide is also at an all-time high, as war and persecution continue to rise. Currently, one in every 113 people is now either a refugee, internally displaced, or seeking asylum (FAO, 2017).

Political and military institutions have acknowledged the significance of climate change as a conflict threat multiplier, especially in already unstable regions (Asian Development Bank and Potsdam Institute for Climate Impact Research, 2017). However, in the climate change-conflict nexus it remains difficult to isolate single variables and assess their effect on the formation of conflicts. Studies have shown that the frequency of war and the breakdown of previously stable societies are closely interwoven with changes in climate conditions. Yet, there is debate over whether environmental factors contribute to the rise of conflict, or whether political, social, and economic factors dominate (Asian Development Bank and Potsdam Institute for Climate Impact Research, 2017).

The rate of armed conflict outbreaks and climate-related natural disasters has proven to be exceptionally high in ethnically fractionalised societies. Energy resources, natural resources and poverty are also significant variables in the generation of conflict constellations. Their vulnerability to climate change impacts is likely to be a future driver of instabilities (Asian Development Bank and Potsdam Institute for Climate Impact Research, 2017).

Table 15 shows the 10 most populous countries of the world (as shown in Chapter 2), and their respective prevalence of undernourishment. Apart from Nigeria (where the prevalence of undernourishment has increased) and the United States of America (where it has remained stable), the remaining eight most populous countries have reduced their share of people suffering from undernourishment over the time period from 1999 to 2017.

Table 15: The prevalence of undernourishment in the 10 most populous countries. Historic share of undernourishment, 1999-01 to 2015-17

Country	1999-01	2004-06	2009-11	2011-13	2013-15	2015-17
Nigeria	9.3	6.5	6.2	6.7	7.8	11.5
China	15.9	15.2	11.8	10.4	9.1	8.7
Indonesia	17.8	18.5	12.4	8.5	6.9	7.7
Bangladesh	20.8	16.6	16.9	17	16.5	15.2
India	18.2	22.2	17.5	17.2	16	14.8
Pakistan	23.4	23.3	21.1	21	21.2	20.5
Mexico	4.4	5.5	4.6	4.6	4.2	3.8
Brazil	11.9	4.6	<2.5	<2.5	<2.5	<2.5
United States of America	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Russian Federation	5.1	<2.5	<2.5	<2.5	<2.5	<2.5

Source: FAO Statistics. Food Security Indicators, September 11, 2018 Update. Accessed from: http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.XFQadFxKhPZ

As shown in Chapter 2, it is expected that half of the world's population growth between 2017 and 2050 will be concentrated in just nine countries. The historic prevalence of undernourishment in these populations is illustrated in Table 16. Because data are not available for the Democratic Republic of the Congo, the prevalence of undernourishment is shown only for eight out of the nine countries. As can be seen, many of the countries have a relatively high prevalence of undernourishment: In six of the eight countries, the population share suffering from undernourishment ranges from 11.5 percent (Nigeria) to 41.4 percent (Uganda).

Although most of the countries have managed to reduce their share of undernourishment over the period since 1999-01, the prevalence of undernourishment in Uganda increased substantially over the period. In Nigeria, the share of the population suffering from undernourishment declined between 1999-01 and 2005-07 but has been increasing steadily since. In the United Republic of Tanzania and in India and Pakistan, undernourishment was reduced over the period. Ethiopia and Indonesia decreased their prevalence of undernourishment steeply and impressively, although in Indonesia the sharply declining trend has turned over and ticked upwards after 2013. As these countries will be the major contributors to the increase in global population, their high and in some cases increasing proportions of hungry people are alarming.

Table 16: The prevalence of undernourishment in the nine largest contributors to global population growth up towards 2050. Historic share of undernourishment, 2000-02 to 2014-16

Country	1999-01	2004-06	2009-11	2011-13	2013-15	2015-17
Ethiopia	52	39.7	32.1	29	24.7	21.4
Uganda	27.7	24.1	30.9	32.4	35.5	41.4
United Republic of Tanzania	36.5	34.4	34.6	33	32.2	32
Democratic Rep. of the Congo	not available	not available	not available	not available	not available	not available
Nigeria	9.3	6.5	6.2	6.7	7.8	11.5
Indonesia	17.8	18.5	12.4	8.5	6.9	7.7
India	18.2	22.2	17.5	17.2	16	14.8
Pakistan	23.4	23.3	21.1	21	21.2	20.5
United States of America	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5

Source: FAO Statistics. Food Security Indicators, September 11, 2018 Update

3.3.3 Experience and severance of food insecurity

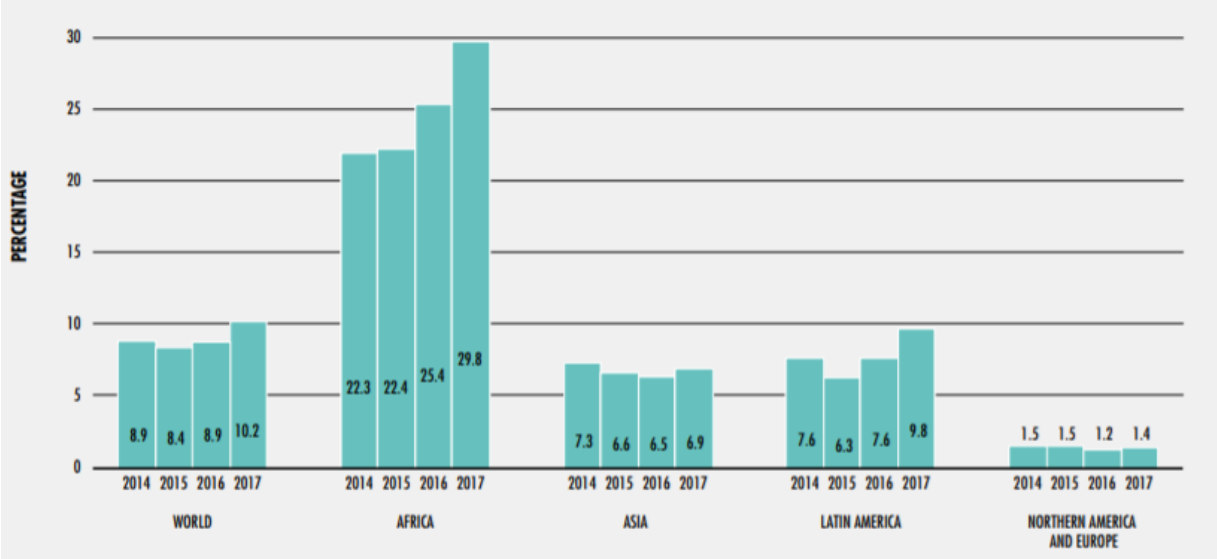
In addition to the measure of the prevalence of undernourishment referred to above (FAO's traditional indicator of the extent of hunger), the Food Insecurity Experience Scale (FIES) is a complimentary measure of people's ability to obtain adequate food[21].This survey-based approach allows segments within the population to be disaggregated, as well as assessment of the level of severity of food insecurity. For instance, someone experiencing severe food insecurity is likely to have gone entire days without eating due to lack of money or other resources (Figure 19).

Source: FAO (2018). The State of Food Security and Nutrition in the World 2018

Figure 19. Food insecurity based on the FIES

According to FAO (2018) estimates, in 2017, close to 10 percent of the world population was exposed to severe food insecurity, corresponding to about 770 million people. Severe food insecurity was higher in 2017 than it was in 2014 in every major region except Northern America and Europe, with notable increases in Africa and Latin America (Figure 20). At the regional level, values range from 1.4 percent in Northern America and Europe to almost 30 percent in Africa. As for the prevalence of undernourishment (as reviewed in section 3.1.2), severe food insecurity has been on the rise at the global level, driven by trends observed in Africa and Latin America. The FAO (2018) also indicate that women are more likely than men to be affected by severe food insecurity in Africa, Asia and Latin America - especially in Latin America, with a prevalence of 6.9 percent among adult men, versus 8.4 percent among adult women.

[21] The prevalence of severe food insecurity is estimated based on data collected from adult individuals in almost 140 countries worldwide using the Food Insecurity Experience Scale (FIES).



Source: FAO (2018). The State of Food Security and Nutrition in the World 2018

Figure 20. Prevalence of severe food insecurity measured by the FIES scale. By region, 2014-17

According to the FAO (2017), the balances for many countries point to recent reductions in food availability and increases in food prices in regions affected by El Niño/La Niña-related phenomena – most notably in Eastern and Southern Africa and in South-Eastern Asia. In addition, the number of conflicts has increased in the past decade (see box 3) in particular in countries already facing high food insecurity and with much of the related violence affecting rural areas and having a negative impact on food production and availability (FAO, 2017).

3.3.4 The nutrition transition, food insecurity and the multiple burden of malnutrition

At the same time as the prevalence of undernutrition and hunger remains unacceptably high in many regions, overweight among children under five is becoming more of a problem in most regions, and adult obesity continues to rise worldwide (FAO, 2017). Malnutrition is defined as an abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients (FAO, 2017). Malnutrition includes under- and overnutrition as well as micronutrient deficiencies. The global state of nutrition and food security thus involves a situation where multiple forms of malnutrition coexist, with countries experiencing for instance simultaneously high rates of child undernutrition and adult obesity.

The simultaneous challenges of food insecurity, obesity and malnutrition can seem paradoxical. To combat these challenges, it may be particularly important to enhance understanding and prevent misunderstandings of the relationship between food insecurity (specifically the experience of not having access to safe, nutritious and sufficient food due to lack of money or other resources) and selected indicators of malnutrition. Importantly, different pathways from food insecurity to malnutrition can also be helpful to dispel misunderstandings about the apparent hunger-obesity paradox.

Rapid demographic, social and economic changes in many low- and middle-income countries have led to increased urbanisation and changes in food systems, lifestyles and eating habits. As a consequence, dietary patterns have shifted toward increased consumption of processed foods

that are often energy-dense, high in saturated fats, sugars and salt, and low in fibre. Such changes bring with them a shift in the profile of nutritional status and diet-related diseases. Before this transition, the predominant nutritional problems among the more vulnerable population groups are undernutrition and nutrient deficiencies (Table 17). However, as the transition into more "urbanised" and "commercialised" environments and systems occur, this gradually tends to bring about increased energy consumption in the population, including among the more vulnerable. Under such conditions, undernutrition and some nutrient deficiencies begin to decline, while the excessive consumption of energy-dense, processed foods high in fats, salt and sugars becomes a major issue. These consumption habits lead to increasing rates of overweight and diet-related non-communicable chronic diseases, such as cardiovascular disease and diabetes. Table 17 shows how dietary and nutritional profiles change over three stages of the nutrition transition.

Table 17: Stages of the nutrition transition

	Stages		
	Pre-transition	**Transition**	**Post-transition**
Diet (prevalent)	Grains, tubers, vegetables	Increased consumption of sugar, fats and processed foods	Processed foods with high content of fat and sugar; low fibre content
Nutritional problems	Undernutrition and nutritional deficiencies predominate	Undernutrition, nutritional deficiencies and obesity coexist	Overweight, obesity and hyperlipidaemia predominate

In this context, while large inequalities in the levels of childhood stunting and wasting persist across regions and countries, a simultaneous increase in overweight and obesity is observed, often in the same countries and communities with relatively high levels of child stunting. This coexistence of undernutrition with overweight and obesity is commonly referred to as the "double burden" of malnutrition. Moreover, overweight and obese individuals can also be affected by micronutrient (vitamin and mineral) deficiencies, often called "hidden hunger" because there may be no visible signs. It is estimated that 1.5 billion people in the world are affected by one or more forms of micronutrient deficiency.

The multiple burden of malnutrition is more prevalent in low-, lower-middle- and middle-income countries and concentrated among the poor. Obesity in high-income countries is similarly concentrated among the poor. The coexistence of multiple forms of malnutrition can occur not only within countries and communities, but also within households – and can even affect the same person over their lifetime. Various examples of such situations are found at the household and individual level. A household may, for instance, have both a stunted child and an overweight or obese mother. At an individual level, a woman could be both overweight and suffer from anaemia, and a child could be simultaneously stunted and overweight.
Food insecurity, in terms of poor food access, contributes to these situations in ways that are not always obvious. Moderate levels of food insecurity are often associated with diets that are energy-dense yet poor in micronutrients, because resource constraints may force people to reduce the nutritional quality of their diets. There are multiple pathways whereby the experience of food insecurity – defined here as uncertain access to sufficient, safe and nutritious food – may contribute to forms of malnutrition as seemingly divergent as undernutrition and obesity.

The link between food insecurity and overweight and obesity passes through diet, which is affected by the cost of food. Nutritious, fresh foods often tend to be expensive. Thus, when household resources for food become scarce, people choose less expensive foods that are often

high in caloric density and low in nutrients, particularly in urban settings and upper-middle and high-income countries. In the context of globalised food markets where the relative cost of foods that are high in fats and sugar is low compared to fresh products such as fruits, vegetables and legumes, the prioritisation of cost for food-insecure families may result in diets high in energy and low in diversity, micronutrients and fibre. Food-insecure consumers are often less likely to have physical access to markets where they can buy nutritious and healthy foods at affordable prices, particularly in high-income countries. The negative effect of food insecurity on diet quality has been documented in low-, middle- and high-income countries alike.

There is also a psychosocial route from food insecurity to obesity. The experience of not having certain or adequate access to food often causes feelings of anxiety, stress and depression, which in turn can lead to behaviour that increases the risk of overweight and obesity. These include patterns of binging or overeating when food is available (and continued availability uncertain), or choosing low-cost, energy-dense "comfort foods" rich in fat, sugar and salt. Such foods have been found to have physiological effects that reduce stress in the short term. Also, the stress of living with food insecurity can have a negative effect on breastfeeding and child feeding practices, which in turn increases the children's risk of obesity in adulthood.

Metabolic changes caused by disordered eating patterns and food deprivation are another component of the obesogenic pathway from food insecurity to malnutrition. Physiological adaptations in response to "feast-and-famine" cycles have been associated with an increase in body fat, decrease in lean muscle mass, and more rapid weight gain when food becomes plentiful. In addition, maternal and infant/child food deprivation can result in foetal and early childhood "metabolic imprinting", which increases the risk of obesity and diet-related non-communicable chronic diseases later in life. Maternal undernutrition – as well as overweight – caused by lack of stable access to adequate diets can programme metabolic, physiological and neuroendocrine functions in offspring, fuelling an intergenerational cycle of malnutrition.

4. IMPACT OF CHANGES IN PRICE AND INCOME ON FOOD DEMAND[22]

The previous chapters analysed shifts in demand up to 2030 caused by population growth, increases in income and in an undernourishment perspective; the next chapter considers the impact of changes in consumer trends and preferences. Changes in demand as well as shifts in supply will affect the prices of food products. An understanding of food demand and the ability to predict potential shifts in demand for food products is essential in an analysis of future food markets. The purpose of this chapter is to investigate what information the food demand literature can provide in this respect, in particular what can be expected in terms of changes in demand caused by changes in prices and income.

According to the OECD-FAO: "On the demand side, growing populations and the rising incomes in the larger emerging economies such as China and India will sustain strong demand for commodities. Rising income will also drive a shift in diets from staple foods to more value-added and higher protein products, especially for consumers in the emerging economies who will increasingly demand meat and dairy products in their consumption choices" (OECD-FAO, 2011, p. 24).

The most common approach in this literature is demand analysis, where demand equations are estimated either individually or in a system of equations. These studies of the demand structure focus on the price sensitivity of demand, on the degree of substitution between potentially competing products and on income/expenditure effects.

This chapter reviews some demand studies with respect to food products, focusing on how this information can be used to predict changes in future demand. To present results from many different studies creates a number of problems that one should be aware of when comparing the results. In addition to the different markets and products studied, a number of different methods have also been used. As the methods used affect the interpretation of the results, it is also important to be aware of the potential differences. Moreover, measuring data at different market levels, e.g. import or retail, has important implications for the interpretation of the results. These issues are not covered in this chapter, but the interested reader is referred to Asche, Bjørndal and Gordon (2005, 2007), who also provide a good overview over relevant methodologies.

Some implications of economic theory for the magnitudes of the elasticities are worth noting. If the price elasticity of demand is between zero and -1, demand is considered inelastic as a price change has little impact on quantity demanded. If, on the other hand, the price elasticity of demand is less than -1 (greater than 1, in absolute value), demand is said to be elastic.

A price elasticity of demand of -1 is a focal point. A good with constant budget share and no substitutes will have a price elasticity of demand of -1, so that a 1 percent increase in the price will lead to a 1 percent reduction in the quantity demanded and vice versa. The value of a market in terms of total revenue is at its highest when the price elasticity is -1. If the supplied quantity increases above the level that gives a price elasticity of demand of -1, the value of the market will fall. Finally, the more elastic the demand for the good, the greater substitution possibilities there will be and therefore the keener the competition.

[22] This chapter is largely based on Lem et al. (2014).

According to what is called Timmer's proposition (Timmer, 1989), own-price elasticities of demand are larger in absolute value for low-income countries than for high-income countries. As this study includes many different countries, it will be interesting to investigate this property.

In general, it is expected that households differing in their characteristics (such as size, age composition, educational and income levels) will also have a different expenditure pattern (Deaton & Muellbauer, 1980). In this sense, Engel (1821-1896) empirically studied the relation between expenditure and income, resulting in what has become known as Engel's law. Engel's law implies that the proportion of food expenditures by a household decreases as the income level increases. This means that the poorer the household, the higher the share of total expenditure spent on food (Deaton & Muellbauer, 1980). Studies such as Huothakker (1957) and Khoja and Pirzada (2009), empirically comparing food consumption by income level for many countries, have corroborated Engel's law. These insights and results are particularly relevant for this study, which encompasses different countries with very different income levels.

When it comes to income elasticities, a good with a value between zero and one is often referred to as a "normal" good, while a good with an elasticity greater than one is called a "luxury" good.

4.1 Empirical demand studies for food products

A comprehensive review of demand studies for food conducted by Andreyeva, Lond and Brownell (2010) demonstrates how price changes affect demand for various types of food. In total, 160 United States studies on the price elasticity of demand for 13 food and beverage categories were reviewed in order to determine mean price elasticities by food category and assess variations in estimates by study design. This included 51 studies for beef and 49 studies for pork, while the number of studies for other categories varied between 13 and 26 (Table 18). The studies in question were published between 1938 and 2007; however, only 38 studies were published before 1970,

Table 18 presents mean price elasticity estimates for the 13 food and beverage groups considered, along with their 95 percent confidence intervals and range of observed elasticities. Absolute values of the elasticity are reported. The table also specifies the number of estimates for each category.

Table 18: United States price elasticity estimates, by food and beverage category, from 1938-2007

Food and beverage category	Absolute value of mean price elasticity estimates (95% CI)	Range	No. of estimates
Food away from home	0.81 (0.56, 1.07)	0.23–1.76	13
Soft drinks	0.79 (0.33, 1.24)	0.13–3.18	14
Juice	0.76 (0.55, 0.98)	0.33–1.77	14
Beef	0.75 (0.67, 0.83)	0.29–1.42	51
Pork	0.72 (0.66, 0.78)	0.17–1.23	49
Fruit	0.70 (0.41, 0.98)	0.16–3.02	20
Poultry	0.68 (0.44, 0.92)	0.16–2.72	23
Dairy	0.65 (0.46, 0.84)	0.19–1.16	13
Cereals	0.60 (0.43, 0.77)	0.07–1.67	24
Milk	0.59 (0.40, 0.79)	0.02–1.68	26
Vegetables	0.58 (0.44, 0.71)	0.21–1.11	20
Fish	0.50 (0.30, 0.69)	0.05–1.41	18
Fats/oils	0.48 (0.29, 0.66)	0.14–1.00	13
Cheese	0.44 (0.25, 0.63)	0.01–1.95	20
Sweets/sugars	0.34 (0.14, 0.53)	0.05–1.00	13
Eggs	0.27 (0.08, 0.45)	0.06–1.28	14

***Source**:* Andreyeva, Lond and Brownell (2010)

The study supports the notion that demand response to food prices is inelastic. All mean price elasticities for the 13 food categories presented are less than 1.0 and range from 0.27 to 0.76. Moreover, the upper limit of the 95 percent confidence limit is in all cases less than one. The estimates are most inelastic for categories such as eggs, cheese, fats and oils, and fish. The most elastic categories are fruit, pork, beef and juice, with vegetables, milk, cereals, dairy and poultry in between. Food away from home, essentially restaurant meals, has the highest own-price elasticity.

Nevertheless, there are point estimates indicating elastic demand for all food categories. There can be many reasons for this. Food categories are broad and are likely to include some products that may be fairly elastic. Also, as pointed out, the studies cover a period going back to 1938, and elasticities are likely to change over the lifecycle of products.

Muhammad et al. (2013) present results from a two-stage demand system using 2005 International Comparison Programme[23] data. In the study, demand is analysed for 144 countries. The study provides own-price and income elasticities for nine broad consumption categories and eight food subcategories.

The 144 countries covered are divided into low-, middle- and high-income countries. Low-income countries represent those with real per capita incomes less than 15 percent of the United States level, middle-income those with incomes of between 15 and 45 percent of the United States level, while high-income countries have incomes equal to or greater than 45 percent of the Unites States level.

[23] Expenditure and price data were obtained from the International Comparison Project (ICP), which is maintained by the ICP Development Data Group of the World Bank.

The average budget shares for the aggregate consumption categories and each of the three country groups are presented in Table 19, along with the conditional budget shares for eight food subcategories[24].

In terms of the broad aggregates, food, beverages and tobacco has a budget share of 0.485 in low-income countries but only 0.204 in high-income countries.

As for the conditional budget shares, it is noticeable that for high-income countries, they are very low for cereals, meats, fish, dairy, oils and fats, and fruits and vegetables; these budget shares are higher for low-income countries, in some cases considerably higher, relatively speaking. For food others, i.e. meals away from home, and beverages and tobacco, high-income countries have the highest shares.

Table 19: Budget shares for broad aggregates and conditional budget shares for food categories

Country group	Food, beverages & tobacco	Clothing & footwear	Housing	Housing furnishing	Medical & health	Transport & communication	Recreation	Education	Other
Low	0.485	0.061	0.135	0.052	0.045	0.102	0.031	0.034	0.054
Middle	0.311	0.055	0.183	0.056	0.059	0.155	0.061	0.033	0.087
High	0.204	0.051	0.187	0.060	0.089	0.149	0.095	0.031	0.134
Income level	**Cereals**	**Meats**	**Fish**	**Dairy**	**Oils & fats**	**Fruits & vegetables**	**Food others**	**Beverages & tobacco**	
Low	0.233	0.134	0.063	0.078	0.049	0.181	0.146	0.116	
Middle	0.124	0.172	0.035	0.099	0.030	0.145	0.208	0.187	
High	0.086	0.118	0.041	0.066	0.014	0.098	0.369	0.208	

***Source**:* Muhammad et al. (2013)

Stepwise demand analysis assumes that consumers spend their income in stages. The first stage (step) involves estimating aggregate demand across nine broad consumption categories: food, clothing, housing, house furnishings, medical care, transportation, recreation and other. Then, in the second stage, a demand system is estimated across eight food subcategories: cereals, meats, fish, dairy products, oils and fats, fruits and vegetables, beverages and tobacco, and other food products.

Average income elasticities[25] for aggregate consumption categories for low-, middle- and high-income countries are presented in Table 20. The elasticities conform to Engel's law for all consumption categories, i.e. income elasticity is lower for high-income countries than middle-income countries, which in turn is lower than for low-income countries.

[24] Conditional budget shares for the eight food categories mean they are conditional on the budget for food, beverages and tobacco.
[25] Technically, these are expenditure elasticities.

Table 20: Income elasticities for aggregate consumption categories: averages for low-, middle- and high-income countries, 2005

Income level	Food, beverages & tobacco	Clothing & footwear	Housing	House furnishing	Medical & health	Transport & communication	Recrecreation	Education	Other
Low income	0.778	0.967	1.074	1.054	1.851	1.211	2.901	0.93	1.795
Middle income	0.655	0.965	1.066	1.05	1.306	1.153	1.401	0.92	1.309
High income	0.495	0.964	1.062	1.047	1.236	1.133	1.288	0.914	1.238

***Source**:* Muhammad et al. (2013)

The income elasticity of demand for food, beverages and tobacco varies greatly among countries and is highest among low-income countries. Indeed, the elasticity is 57 percent higher for low-income countries than for high-income countries.

The unconditional expenditure elasticity measures the percentage change in demand from a percentage change in overall income (or total spending). Table 21 gives the values for the different food subcategories as averages for the three groups of countries.

Table 21: Unconditional expenditure elasticities of demand for food subcategories: averages for low-, middle- and high-income countries

	Per capita food	Cereals	Meats	Fish	Dairy	Oils & fats	Fruits & vegetables	Food other	Beverages & tobacco
Low income	0.13	0.514	0.771	0.65	0.798	0.531	0.615	1.42	1.325
Middle income	0.439	0.253	0.649	0.52	0.671	0.297	0.462	0.882	0.839
High income	0.781	0.019	0.49	0.38	0.506	0.097	0.319	0.636	0.613

***Source**:* Muhammad et al. (2013, Appendix, Table 5)
Note: Per capita food is an index of total food spending per person (normalized to United States food expenditures per person).

When comparing elasticities across country groups, they conform to Engel's law. For high-income countries, the demand for cereals and oils and fats is virtually unaffected by changes in price. The other elasticities vary between 0.379 and 0.636. The two highest are for beverages and tobacco (0.613) and food other (0.636), which includes meals away from home. As such, the results make intuitive sense.

Low-income countries show much larger elasticities, varying between 0.514 and 1.42. An increase in income will lead to fairly substantial increases in demand for all food categories under consideration. Food other and beverages and tobacco are "luxury" products.

Elasticities for middle-income countries are between those for low- and high-income countries. The same pattern can be observed in terms of which elasticities are low and high.

Unconditional own-price elasticities[26] for the different food categories are presented in Table 22. The unconditional own-price elasticities for the food subcategories in question vary with affluence: consumers in low-income countries are more responsive to price changes than consumers in high-income countries. Thus, they conform to Timmer's proposition: own-price

[26] Technically, these are Frisch own-price elasticities. The unconditional own-price elasticities represent elasticities estimated at a point when the marginal utility of income is held constant. See Muhammed et al. (2013) for further details as well as estimates of alternative elasticities.

elasticities of demand are larger in absolute value for low-income countries than for high-income countries.

Table 22: Unconditional own-price elasticities of demand for food subcategories: averages for low-, middle- and high-income countries

Country group	Per capita food	Cereals	Meats	Fish	Dairy	Oils & fats	Fruits & vegetables	Food other	Beverages & tobacco
Low income	0.13	-0.377	-0.566	-0.48	-0.59	-0.39	-0.451	-1.04	-0.972
Middle income	0.439	-0.186	-0.476	-0.38	-0.49	-0.22	-0.339	-0.65	-0.615
High income	0.781	-0.036	-0.359	-0.28	-0.37	-0.08	-0.234	-0.47	-0.45

***Source**:* Muhammad et al. (2013, Appendix, Table 6)
Note: Per capita food is an index of total food spending per person (normalized to United States food expenditures per person).

For high-income countries, the demand for cereals and oils and fats is particularly inelastic: changes in price will have virtually no impact on demand, so that quantity consumed is more or less constant. Demand for other food categories is also inelastic, with the absolute value of the elasticity varying between 0.234 and 0.467.

For low-income countries, the results are very different. Food other and beverages and tobacco have elasticities close to -1, so that quantity demanded varies more or less proportionately with price. Demand for other food subcategories is inelastic, particularly so for cereals and oils and fats, with elasticities of -0.377 and -0.390, respectively.

Information is also available for many countries. Results for selected countries are given in Table 23. Essentially, these figures reinforce what is presented above.

Table 23: Own-price and expenditure elasticity for fish, selected countries

Country	Own-price elasticity for fish	Expenditure elasticity for fish
European Union (Member Organization)		
United Kingdom	-0.258	0.351
France	-0.273	0.372
Spain	-0.281	0.384
Portugal	-0.316	0.431
Hungary	-0.352	0.480
Advanced economies		
Canada	-0.271	0.369
Japan	-0.279	0.380
United States of America	-0.191	0.260
Republic of Korea	-0.351	0.479
New Zealand	-0.299	0.407
Developing Asia		
China	-0.480	0.654
India	-0.484	0.660
Bangladesh	-0.490	0.667
Latin America		
Brazil	-0.419	0.571
Chile	-0.402	0.548
Near East		
Egypt	-0.434	0.592
Saudi Arabia	-0.401	0.546
Africa		
Angola	-0.512	0.698
South Africa	-0.415	0.566
Ethiopia	-0.523	0.713
Nigeria	-0.489	0.667
Mozambique	-0.516	0.703
Russian Federation and Eastern Europe		
Russian Federation	-0.390	0.532
Ukraine	-0.418	0.570
Kazakhstan	-0.403	0.550

Source: Muhammad et al. (2013, Appendix, Table 6 for own-price elasticities, Table 5 for expenditure elasticities)

In Muhammad et al. (2013), various food aggregates including fish are essentially considered homogenous products. Andreyeva, Lond and Brownell (2010) review also disaggregated studies, and Asche, Bjørndal and Gordon (2005, 2007) review demand for different types of fish products. Dey et al. (2008) investigate demand for various types of fish by households with varying incomes in nine different Asian countries. Own-price elasticities are found to vary substantially for different fish types, demonstrating the heterogeneity of fish demand in the region. Moreover, the own-price elasticity of demand was observed to be lower among households with higher incomes. All country income elasticities, on average, were found to be elastic, which implies that Asian consumers generally consider fish a luxury good. As for income, in general, high-income groups exhibited lower income elasticities than low-income households.

Singh, Dey and Surathal (2012) found similar results in the United States of America. Own-price, cross-price and expenditure (income) elasticities were found to vary considerably across species, which indicates the importance of studying consumer demand at the disaggregate level.

In a study of fish demand in inland areas of Bangladesh, Dey, Alam and Paraguas (2011) find that almost all estimated fish type and income class specific income elasticities of demand are positive. Thus, fish demand will increase with population growth and increases in per capita incomes. Moreover, income elasticities tend to be higher among poorer households than among more affluent consumers. Thus, a major share of shifts in the demand for fish is expected to come from poorer households with increasing income. The authors also find that, while demand for low-valued fish is inelastic, demand for high-value products is elastic. This indicates that there will be shifts in the composition of demand over time.

4.2 Summary and Discussion

According to Muhammad et al. (2013), the income elasticity of demand for food, beverages and tobacco varies greatly among countries (Table 19), ranging between 0.778 as an average for low-income countries to 0.495 as is the average for high-income countries. These results imply that for low-income countries increases in income will be accompanied by almost proportional increases in expenditure on food. This is confirmed when looking at food subcategories, with elasticities ranging from 0.514 to 1.42. For high-income countries, elasticities are much lower, and for food groups such as cereals and oils and fats increase in income will have virtually no impact on demand.

Developing and emerging economies are expected to show substantial economic growth over the coming decades (Chapter 2). This means that food demand in these countries will increase substantially.

However, food prices are expected to increase. As food demand in low-income countries is more elastic than in high-income countries, this means that there will be a decline in demand owing to the price effect, and most so in low-income countries. This will to some degree counteract the income effect.

Income distribution is another important variable. Countries such as India and China have substantial middle classes as well as large numbers of very affluent consumers, but at the same time the proportion of low-income earners is large. Thus, even inside developing and emerging economies, the patterns in terms of increased food consumption will be very different.

5. SUMMARY – FOOD DEMAND

This chapter summarizes the main findings from the different aspects of the demand side analysis as presented in Chapters 1-4. The future demand for food is considered through factors such as population growth, demographic trends, income growth and shifting consumer preferences. The future prevalence of undernourishment and malnutrition is also discussed. As this presentation is based on previous chapters, the reader is referred to these chapters for more detailed discussion and references.

Population size is one of the main drivers of food demand. The global population of 7.6 billion in 2017 is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to the United Nations (UN, 2017), while corresponding projections by the Wittgenstein Centre for Demography see the world's population at 8.3 billion in 2030, 9.1 billion in 2050 and 8.9 billion by 2100.

More than half of the anticipated growth in global population up to 2050 is expected to occur in Africa, followed by Asia as the second largest contributor. From 2017 to 2050, it is expected that half of the world's population growth will be concentrated in just nine countries: India, Nigeria, the Democratic Republic of the Congo, Pakistan, Ethiopia, the United Republic of Tanzania, the United States of America, Uganda and Indonesia.

The UN estimate that Africa will grow by 448 million people by 2030 (36 percent) from 1,256 million people in 2017 to 1,704 million – adding the equivalent of more than the entire population of North America as of 2017 (361 million). By this estimate, Africa will account for about 20 percent of the global population in 2030. However. taking the more modest estimate from the Wittgenstein Centre into account (by averaging the two), the African population is expected to increase 29 percent by 2030.

Asia will add about 9 percent to its 2017-population level by 2030 and comprise around 60 percent of the world population in 2030. In 2017, the population of China is estimated at approximately 1.41 billion compared with 1.34 billion in India. By around mid-2020s, the population of India is expected to surpass that of China: In 2024, both countries have roughly 1.44 billion people. Thereafter, India's population is projected to continue growing for several decades, while the population of China is expected to continue its slow decline.

The North American population will still grow by around 10 percent from 2017 to 2030, similar to the population growth of Latin America and the Caribbean.

The population of Europe is expected to decline slightly up to 2030 (from 742 in 2017 to 739 million in 2030 by the UN's estimate). Oceania is projected to increase its population by 17 percent over the same period, from 41 million in 2017 to 48 million in 2030.

Food consumption will continue to expand due to population growth and higher per capita income for most commodities with the developing world as the source of most demand growth over the coming ten years. However, the rate of global population growth is slowing in relative as well as absolute terms. Most of the expected growth occurs in Sub-Saharan Africa and India, as well as the Middle East and North Africa.

Sub-Saharan Africa and India will account for a large share of the additional food demand in the coming decade, reflecting continued strong population growth in these regions. Population growth in Sub-Saharan Africa is accelerating in absolute terms: while the region's population

increased by 27 million in 2017, this rate will increase to 32 million people per year in 2027. Consumption of dairy products and vegetable oil in India will underpin growth in these commodities over the next ten years, while China continues to account for a large share of demand growth for meat and fish.

Different regions will also experience demographic shifts, which combined with economic trends and population growth, will have an impact on food demand (see Table 24). In terms of the average age of the population, Africa has the youngest population structure owing to a high fertility rate and lower life expectancy. The number of older persons, defined as people 65 years and above, will only reach 5 percent of the total population by 2030. Reduced fertility in Europe and Asia will continue to cause significant ageing of these populations – the proportion of older persons in the total population by 2030 is estimated at 23 percent in Europe and 13 percent in Asia – and a similar trend will be observed in most countries of the developed world.

Population ageing around the world, and especially in developed countries, is likely to increase the demand for healthier products and reduce the consumption of starchy staple foods. This will mean a higher demand for fish protein, while meat consumption will level off. However, there is major uncertainty as to the purchasing power of the elderly population of the future, and the societies' ability to support the new demographic structure. Population ageing is projected to have a profound effect on societies, underscoring the fiscal and political pressures that the health care, old-age pension and social protection systems of many countries are likely to face in the coming decades. Prolonged employment periods may increasingly be necessary, and healthier eating habits can support a higher disability-free life expectancy.

The proportion of educated people will rise over time, supporting productivity in production and the economy. Higher levels of education also reinforce trends of healthy eating and more conscious choice of foods. By 2030, 13 percent of the global population are expected to have post-secondary education (up from 10 percent in 2015) and 24 percent upper secondary education (up from 20 percent in 2015). The share of people with a lower secondary education is expected to remain similar, while the proportions of people with only primary, incomplete primary or no education will decline in the period up to 2030.

Table 24: Demographic changes and impact on food demand

Demographic change	Impact on food demand
Population growth	A growing population implies that more people need to be serviced with food, water and nutrition, increasing the total demand for food.
Ageing population	The proportion aged 60 or above is expected to increase from 13 percent in 2017 to 33 percent by 2050 – this demographic is increasing in number as well as in life expectancy per person. Health concerns and long lives may encourage shifts in food consumption towards healthier products, in particular by the population over 65. Overall increased demand for fish protein and healthy fats such as Omega 3. Potentially decreased consumption of starch-based staple foods
Increased level of education	Improved productivity in all sectors of the economy including the food industry More conscious choice of food consumed (healthy trend) Likely reduction in number of children per household in developing countries, limiting the population growth rate Possibly more of both two-income households and single-person household (more single person households may also come as a result of ageing)
Urbanisation	In 2030, 60 percent of the world's population will live in urban areas. Urbanisation is likely to continue to reshape consumption patterns towards higher-value processed products, convenience foods and beverages – as often associated with modern and urban life styles. Fast foods and higher-value convenience products tend to be available in a wide range of price and value propositions: Given economies of scale, even relatively poor people in cities may be able to buy processed foods, though pricing and availability may lead to increased consumption of foods high in fats and sugars (as may and? other sides to the adoption of urban lifestyles and exposure to advertising). Meanwhile, urban citizens with a higher purchasing power may access a wide range of food organic, nutritious and healthy super foods.

A transformational change to global demography is urbanisation, as a growing number and share of people live in cities. In 2016, an estimated 54.5 percent of the world's population lived in urban settlements, a figure projected to rise to 60 percent by 2030 and to 66 percent by 2050.

Urbanisation is expected to increase most rapidly in the developing world. Just three countries – India, China and Nigeria – together are expected to account for 35 percent of the projected growth of the world's urban population between 2018 and 2050. The fastest-growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa.

The 10 cities that are projected to become megacities between 2016 and 2030 are all located in developing countries. They include: Lahore (Pakistan), Hyderabad (India), Bogotá (Colombia), Johannesburg (South Africa), Bangkok (Thailand), Dar es Salaam (Tanzania), Ahmanabad (India), Luanda (Angola), Ho Chi Minh City (Viet Nam) and Chungdu (China).

The growing urban agglomerations can offer opportunities and clusters of consumers, innovation and business opportunities. Yet, modern life and prosperity require infrastructure and the cities must be serviced with food, water and energy. Part of the rapid urban growth,

particularly in Sub-Saharan Africa, is unlikely to be matched by investment in essential services and infrastructure. One billion people throughout the world already live in slums – and there could be almost three billion by 2045 unless mitigating action is taken.

Along with population growth and demographics, economic growth and per capita demand has a major effect on gross demand for food. According to Engel's law, the proportion of food expenditures by a household decreases as the income level increases. Income elasticities varies greatly among countries: In low-income countries, increases in income will be accompanied by almost proportional increases in expenditure on food. In high-income countries, elasticities are much lower, and for food groups such as cereals and oils and fats, increases in income will have virtually no impact on demand.

Therefore, demand in richer and more mature economies is not predicted to increase significantly. Especially in higher income countries where food expenditure represents a small share of income (10-15 percent), per capita food consumption is reaching a plateau. Instead, increased GDP per capita in these advanced economies will affect the composition of consumption, that is, what products people are consuming, rather than cause an overall increase in food consumption. With more disposable income, people can choose to be more particular about what they eat and choose convenience products, organic produce and healthier protein sources, such as meat and fish.

GDP per capita growth in some emerging economies will result in both an increase in food consumption and a composition change (developing Asia, Latin America, developing regions of the Middle East and Eastern Europe). However, the increase in per capita income and consumption in some countries remain insufficient for food security and nutrition, and large portions of the population are expected to remain malnourished and food insecure. Income distribution also remains uneven, so that inside developing and emerging economies alike, increases in purchasing power will be different among sub-populations.

With food prices increasing for some commodities, positive income effects can be counteracted by the price effect. In the worst case, affordability issues can even cause food demand to decline in vulnerable populations.

The number and share of undernourished people in the world have decreased over time, long-term. The number of undernourished people declined from 900 million in 2000 to 775 million in 2013, while the relative prevalence (share) of undernourished people declined from 14.7 percent in 2000 to 10.8 percent in 2013.

However, recent data rises concerns that the decade-long decline in undernourishment has reached an end and possibly gone in reverse. The absolute number of undernourished people in the world is estimated to have increased to almost 821 million in 2017. Following decades of improvement, the rate of reduction in the number of undernourished people came to a virtual halt between 2010 and 2015, largely attributed to persistent instability in conflict-ridden regions, adverse climate events in many regions of the world and economic slowdowns that affected more peaceful settings and worsened the food security situation. New evidence shows lower levels of per capita food consumption in some countries, and increased inequality in the ability to access food in the populations of other countries. This trend sends a clear warning that unless efforts are enhanced, the Sustainable Development Goals (SDG) target of hunger eradication will not be achieved by 2030.

In 2017, 515 million people in Asia, more than 256 million in Africa, and more than 39 million in Latin America and the Caribbean were estimated not to have access to sufficient food energy. Although the relative prevalence is highest in Africa, the number of people suffering from undernourishment in Asia is about double the number in Africa. While the share of undernourished people in Asia has been declining, both the absolute number and the population share suffering from undernourishment in Africa has increased since 2013. Eastern, Middle and Sub-Saharan Africa remains the regions with the highest prevalence of undernourishment, affecting an alarming 31.4, 26.1 and 23.2 percent of the population in 2017. Other regions where the prevalence of undernourishment is estimated to affect more than 10 percent of the population in 2017 include Western Africa, Southern Asia, Western Asia and the Caribbean.

For developed and developing countries alike, the composition of consumption also depends on cultural and religious traditions. Nevertheless, some major trends are prevalent on a global scale and are expected to continue as incomes and levels of education rise. The main trends that will influence future food demand are: food safety and health benefits, social concerns, production systems and innovations, sustainability and food origin.

In addition to the increasing health consciousness of many consumers, the trend in healthy eating is often driven by government and societal concerns about the global rise in the proportion of overweight and obese people as well as the increase in obesity-related diseases. Governments can play an important role in promoting healthy eating habits to the public through campaigns, advertisements and targeted programmes in schools and workplaces as well as through preventive health care and making healthy food accessible and affordable, especially for low-income populations. As a consequence, demand for food that is certified by an authorized body or is ecolabelled or organic is expected to increase, while the consumption of fast food may decline in the Western world. If consumers become more health conscious themselves, they will demand more information about the products they consume and will want to be able to trace their movements through the value chain.

Demands for greater corporate social responsibility (CSR) and sustainable practices are a growing trend among consumers. Consumers will demand more transparency from producers and retailers about food products, in terms of their origin as well as their farming/fishing practices. Consumers will pay more attention to resource sustainability, seeking out products farmed or caught in a way that has lower impacts on the environment. They will be more concerned about ethical issues, such as fair wages and livelihood practices, and food miles, among other factors. The reliability and reputation of the producer, brand, ecolabel or ecoguide will increasingly influence consumers' choices of food. In response to these consumer demands as well as to "name and shame" practices in the media and NGO sector, corporations may progressively change their practices to make them more socially responsible.

Consumers' interest in the sustainable production of foods will continue to be an increasing trend, especially in wealthy developed countries. Multiple legislations related to sustainable production and food safety will reinforce the trend. The popularity of sustainable and "socially responsible" products will increase as a result.

Attitudes, traditions and special production methods distinguishing foods in national and international markets are elements that will influence the choice for local foods over imported products among consumers on occasions when product prices are competitive.

With consumers' buying practices shifting, this will in turn influence how food is produced and processed. In some instances, such as the cultivation of organic foods, production systems will revert towards using less synthetic inputs (e.g. reduced use of pesticides). As organic foods become big business, organic methods will continue to expand beyond their traditional, small-scale ambit. The definition of organic will remain driven by government standards for certification, with some countries having more stringent standards than others. In other cases, developments in nanotechnology and genetic modification will stimulate the production of new foods and growing methods. These developments in the food industry will further facilitate the growth in relevant ecolabelling and certification schemes among producers.

6. FISHERIES AND AQUACULTURE PRODUCTION

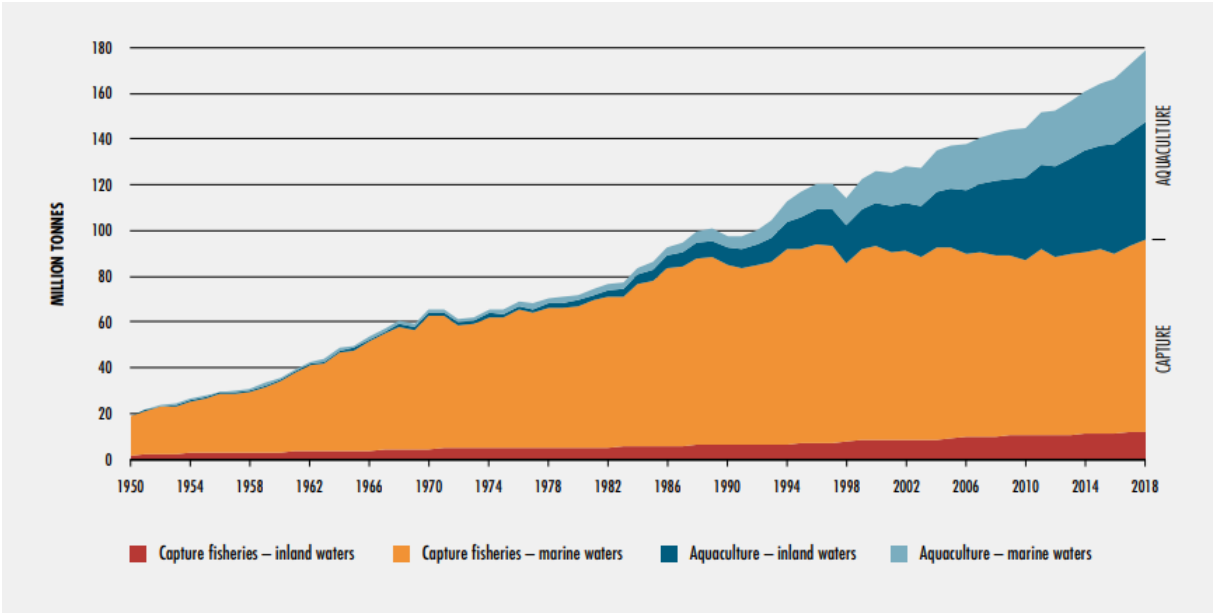
Fisheries and aquaculture production have an important role to play in meeting the demand for food in the world and reducing hunger and poverty in the poorest regions. This chapter describes the evolution of the sector over time and discusses the potential for increased production in fisheries and aquaculture in the future.

6.1 World production of fish from 1950 to the present

Figure 21 shows world fish production of aquaculture and capture fisheries from 1950 to 2018. World fish production has grown dramatically since 1950. Total catches (capture fisheries and aquaculture) were only 20 million tonnes in 1950. In 2018, the fisheries of the world, including aquaculture, produced total harvests in the order of 178.5 million tonnes. Of these totals, aquaculture accounted for 82.1 million tonnes or 46 percent of the total, Capture fisheries accounted for 96.4 million tonnes or 54 percent of the total. These figures exclude aquatic plants.

Catches from capture fisheries were 18.7 million tonnes in 1950. There were significant increases on a yearly basis over the following decades until the mid-1980s when the catches levelled off at about 85-95 million tonnes per annum.

The contribution of aquaculture or fish farming to total production was negligible in 1950. Even in 1970, aquaculture production (excluding aquatic plants) was only about 2.5 million tonnes, or about 4 percent of total seafood production. This increased to 47.1 million tonnes in 1980. Production took off in the 1980s, when aquaculture achieved the high growth rates that the sector continues to sustain today. From 1980 to 2016, the average annual growth rate in output has been 8.2 percent. From 2000 to 2016, the average annual growth rate has been 5.8 percent. From 2016-18, the average annual growth rate was 4 percent (FAO, 2020).



Source: FAO (2020)
Note: Excludes aquatic animals and aquatic plants.

Figure 21. World fish production per year, capture and aquaculture, 1950-2018

Per capita consumption in developing regions and low-income countries is still lower than in developed countries. However, the gap in consumption is slowly narrowing.

Per capita fish consumption increased from 9.9 kg (live weight equivalent) in 1960 to 18.6 kg in 2010. In 2018 the world's total food fish consumption was 152.9 million tonnes live weight equivalent, excluding China 97.7 million tonnes (FAO, 2020). Per capita food fish consumption was 20.3 kg/year; excluding China 16 kg/year. There are, however, substantial differences between low-income food-deficient developing countries and industrialised countries as will be illustrated later**.** In developed countries, the consumption was 24.4 kg per capita in 2018 while it was only 9.3 kg per capita in low-income food-deficit countries. Taking into account the population increase in this period (Chapter 2), it is remarkable that per capita fish consumption has been maintained and even increased in recent years.

The importance of aquaculture, not only as a source for seafood but also for food in general, is also set to continue to increase as will be analysed in the next chapter.

As for employment, 59.5 million people were engaged in the primary sector of capture fisheries and aquaculture in 2018, with 20.5 million people engaged in aquaculture and 39 million people engaged in fisheries (FAO, 2020). In 2018, almost 85 percent of the global population engaged in the fisheries and aquaculture sectors was in Asia, followed by Africa (9.2 percent) and the Americas (4.8 percent). The 20.5 million (34.5 percent of all people employed in the sectors) engaged in aquaculture, concentrated primarily in Asia (95.5 percent) followed by Africa and the Americas (1.9 percent each). In terms of the sex ratio, men dominate both with regard to fisheries and aquaculture. In terms of fish processing, however, the situation is different. For example in Africa, women make up about 58 percent of workers in the post-harvest seafood value chain (FAO, 2020).

6.2 Capture fisheries

According to FAO (2018), fish stocks are classified into two categories: Fished within biologically sustainable levels, which are stocks with abundance at or above the level associated with maximum sustainable yield (MSY) or fished at biologically unsustainable levels, which are stocks less abundant than the level needed to produce MSY. The percentage of stocks fished within biologically sustainable levels is the indicator used to measure progress towards the Sustainable Development Goals (SDGs) target for marine fisheries (target 14.4). Stocks are also characterised as i) overfished: having abundance lower than the level that can produce MSY, ii) maximally sustainably fished: having abundance at or close to the level of MSY, or iii) underfished: abundance above the level corresponding to MSY.

As mentioned above, production from capture fisheries reached a plateau in the mid-1980s. According to FAO (2020), the fraction of fish stocks within biologically sustainable levels decreased from 90 percent in 1974 to 65.8 percent in 2017 (Figure 22). On the other hand, the fraction of stocks fished at biologically unsustainable levels increased from 10 percent in 1974 to 34.2 percent in 2017. These statistics treat all fish stocks equally regardless of their biomass and catch. In terms of landings, 78.7 percent of landings come from biologically sustainable stocks. In 2017, the maximally sustainably fished stocks accounted for 59.6 percent and underfished stocks for 6.2 percent of the total number of assessed stocks.
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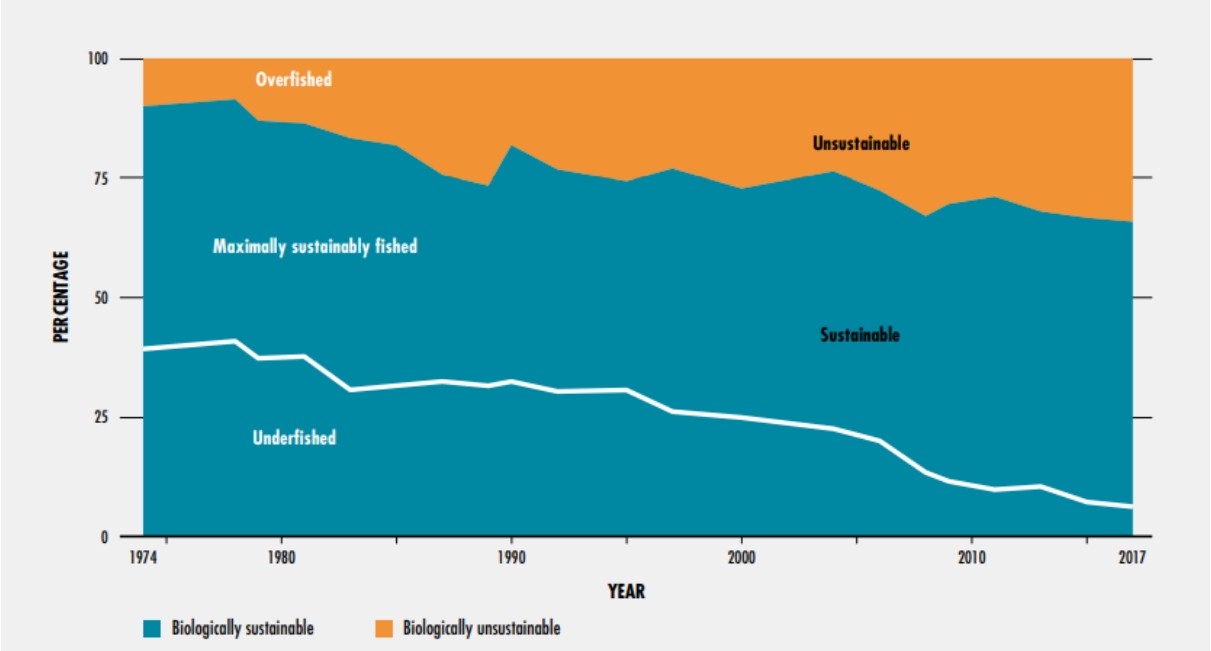


Source: FAO (2020)

Figure 22. Stock status of marine fishery resources, 1975-2017

Although the production of global capture fisheries remains stable (about 90 million tonnes), there have been changes in catches by region, country, fishing areas and species.

When it comes to marine capture production, finfish is seen to dominate with 85 percent of the total; crustaceans and molluscs represent just over 7 percent each (Table 25). In 2018, the three species with the largest landings were anchoveta (7.045 million tonnes), Alaska pollock (3.397 million tonnes) and skipjack tuna (3.161 million tonnes) which combined represented 16 percent of the total. In most years, anchoveta is the most harvested species in the world but with significant variations over time.

Table 25. Marine Capture Production. Major Species and Genera 2004-18. Million tonnes

Species	**Average prod. 2004-13**	**2015**	**2016**	**2017**	**2018**
Anchoveta	7 276	4 310	3 192	3 923	7 045
Alaska pollock	2 897	3 373	3 476	3 489	3 397
Skipjack tuna	2 494	2 822	2 862	2 785	3 161
Atlantic herring	2 162	1 512	1 640	1 816	1 820
Blue whiting	1 182	1 414	1 190	1 559	1 712
European pilchard	1 084	1 176	1 279	1 437	1 608
Pacific chub mackerel	1 483	1 457	1 565	1 514	1 557
Yellowfin tuna	1 239	1 377	1 479	1 513	1 458
Scads nei	1 199	1 041	1 046	1 186	1 336
Atlantic cod	948	1 304	1 329	1 308	1 218
Largehead hairtail	1 326	1 272	1 234	1 221	1 151
Atlantic mackerel	751	1 247	1 141	1 218	1 047
Japanese anchovy	1 347	1 336	1 128	1 060	957
Sardinellas nei	899	1 057	1 106	1 138	887
Others	41 187	41 936	42 343	43 444	43 572
Finfish total	**67 474**	**66 634**	**66 012**	**68 612**	**71 926**
Custraceans total	5 454	6 109	5 979	6 027	5 999
Molluscs total	6 616	7 129	5 728	6 012	5 929
Other animals total	459	636	554	556	532
Total all species	**80 002**	**80 507**	**78 272**	**81 208**	**84 412**

Nei = not elsewhere included.

Source: FAO (2020)

The top fish producers are listed in Table 26. In 2018, the combined catches of the 25 largest producers amounted to 67.8 million tonnes or 80 percent of the total. China ranked as the largest producer with 12.7 million tonnes followed by Peru with 7.15 million tonnes. Peruvian catches vary considerably over time owing to variability in the anchoveta stock. In years with low catches, Peru is surpassed by countries such as Indonesia, Russia, the United States and India. Several Asian fishing countries, in particular China, Indonesia, India and Viet Nam, recorded significant increases in catches over time. The increase in catches in the Russian Federation is also remarkable. The increase is partially due to the government's decision to remove excessive formalities for the documentation of landing operations. Catch projections by the Russian Federation suggest an increase to 6 million tonnes by 2020. Chile and Japan registered decreased catches over time.

Table 26: Global capture production ('000 tonnes): top 25 producers

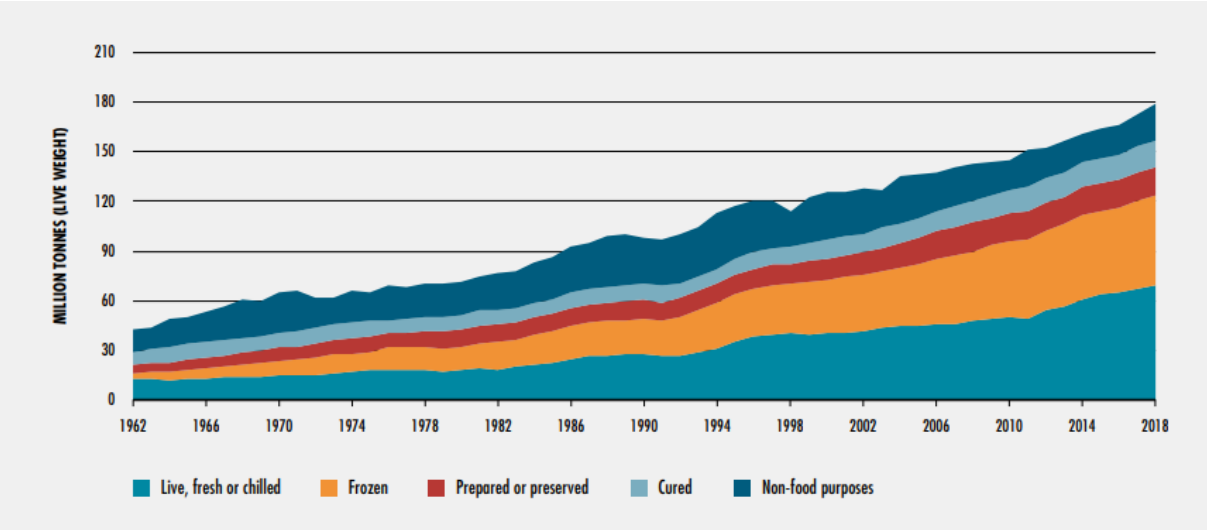
Country or territory	Production (average per year)			Production				Percentage of total, 2018
	1980s	1990s	2000s	2015	2016	2017	2018	
	(million tonnes, live weight)							
China	3.82	9.96	12.43	14.39	13.78	13.19	12.68	15
Peru (total)	4.14	8.10	8.07	4.79	3.77	4.13	7.15	8
Peru (excluding anchoveta)	*2.50*	*2.54*	*0.95*	*1.02*	*0.92*	*0.83*	*0.96*	–
Indonesia	1.74	3.03	4.37	6.22	6.11	6.31	6.71	8
Russian Federation	1.51	4.72	3.20	4.17	4.47	4.59	4.84	6
United States of America	4.53	5.15	4.75	5.02	4.88	5.02	4.72	6
India	1.69	2.60	2.95	3.50	3.71	3.94	3.62	4
Viet Nam	0.53	0.94	1.72	2.71	2.93	3.15	3.19	4
Japan	10.59	6.72	4.41	3.37	3.17	3.18	3.10	4
Norway	2.21	2.43	2.52	2.29	2.03	2.38	2.49	3
Chile (total)	4.52	5.95	4.02	1.79	1.50	1.92	2.12	3
Chile (excluding anchoveta)	*4.00*	*4.45*	*2.75*	*1.25*	*1.16*	*1.29*	*1.27*	–
Philippines	1.32	1.68	2.08	1.95	1.87	1.72	1.89	2
Thailand	2.08	2.70	2.38	1.32	1.34	1.31	1.51	2
Mexico	1.21	1.18	1.31	1.32	1.31	1.46	1.47	2
Malaysia	0.76	1.08	1.31	1.49	1.57	1.47	1.45	2
Morocco	0.46	0.68	0.97	1.35	1.43	1.36	1.36	2
Republic of Korea	2.18	2.25	1.78	1.64	1.35	1.35	1.33	2
Iceland	1.43	1.67	1.66	1.32	1.07	1.18	1.26	1
Myanmar	0.50	0.61	1.10	1.11	1.19	1.27	1.14	1
Mauritania	0.06	0.06	0.19	0.39	0.59	0.78	0.95	1
Spain	1.21	1.13	0.92	0.97	0.91	0.94	0.92	1
Argentina	0.41	0.99	0.94	0.80	0.74	0.81	0.82	1
Taiwan Province of China	0.83	1.05	1.02	0.99	0.75	0.75	0.81	1
Denmark	1.86	1.71	1.05	0.87	0.67	0.90	0.79	1
Canada	1.41	1.09	1.01	0.82	0.84	0.81	0.78	1
Iran (Islamic Republic of)	0.11	0.23	0.31	0.54	0.59	0.69	0.72	1
Total 25 major producers	**51.10**	**67.71**	**66.45**	**65.11**	**62.58**	**64.60**	**67.83**	**80**
Total all other producers	**21.00**	**14.15**	**15.12**	**15.39**	**15.69**	**16.61**	**16.58**	**20**
World total	**72.10**	**81.86**	**81.56**	**80.51**	**78.27**	**81.21**	**84.41**	**100**

Source: FAO (2020)

6.3 Usage

In 2018, about 88 percent (or over 156 million tonnes) of the 179 million tonnes of total fish production was utilised for direct human consumption (Figure 23), while the remaining 12 percent (or about 22 million tonnes) was used for non-food purposes. Of the latter, 80 percent was reduced to fishmeal and fish oil.

The proportion of fish used for direct human consumption has increased significantly from 67 percent in the 1960s. In 2018, live, fresh or chilled fish still represented the largest share of fish utilised for direct human consumption (44 percent), and was often the most preferred and highly priced form of fish. It was followed by frozen (35 percent), prepared and preserved fish (11 percent) and cured (10 percent). Freezing represents the main method of preserving fish for food, accounting for 62 percent of all processed fish for human consumption (i.e., excluding live, fresh or chilled fish).

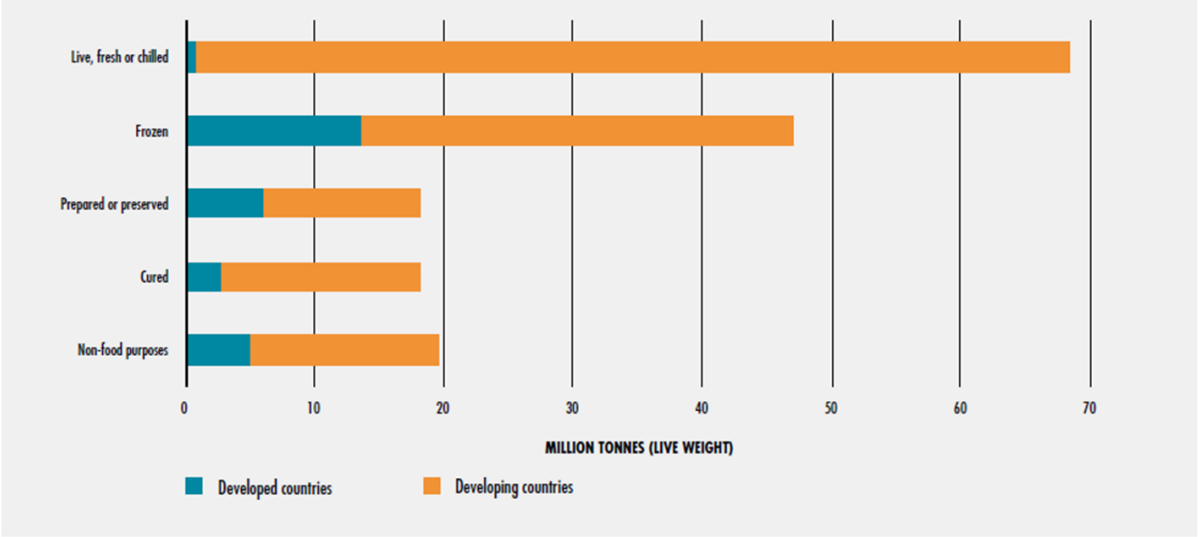


Source: FAO (2020)

Figure 23. Utilisation of world fisheries production (breakdown by quantity), 1962-2018

These general data mask major differences. Fish utilisation and processing methods differ significantly across regions and countries (figure 24). About two-thirds of the fish production used for human consumption is used in frozen and prepared and preserved forms in Europe and North America. In Asia, a large amount of production is sold live or fresh to consumers.

In developed countries, the share of frozen fish for human consumption rose from 27 percent in the 1960s to 58 percent in 2018, while the share of cured forms declined from 25 percent in the 1960s to 12 percent in 2018. In many developing countries, fish processing has been evolving from traditional methods to more advanced value-adding processes. Overall, in developing countries, growth has been seen in the share of production destined for human consumption in frozen form (from 3 percent in the 1960s to 8 percent in the 1980s and 31 percent in 2018) and in prepared or preserved form (from 4 percent in the 1960s to 9 percent in 2018). Fish preserved by salting, fermentation, drying and smoking – particularly customary in Africa and Asia – declined from 29 percent in the 1960s to 10 percent of all fish destined for human consumption in developing countries in 2018. However, in developing countries, fish continues to be mostly utilised in live or fresh form, soon after landing or harvesting from aquaculture, even as that share declined from 62 percent in the 1960s to 51 percent in 2018.



Source: FAO (2020)

Figure 24. Utilisation of world fisheries production: developed versus developing countries, 2018

Table 27a and b describe the production of fishmeal and fish oil from the FAO fish model (Table 27b) and the Marine Ingredients Organisation (IFFO) (Table 22c). In 2016, fishmeal production was about 4.45 million tonnes, increasing to 4.8 million tonnes in 2017 with fish oil production at about 1 million tonnes.

Table 27a. Fishmeal and fish oil production in product weight 2010-16. Million Tonnes

Production	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Fishmeal	4.57	5.57	4.70	4.81	4.25	4.47	4.44
Fish oil	0.93	1.14	0.98	1.00	0.95	0.90	0.79

***Source*:** FAO Fish Model

Table 27b. Fishmeal and fish oil production in product weight 2013-17. Million Tonnes

Production	**2013**	**2014**	**2015**	**2016**	**2017**
Fishmeal	4.95	4.53	4.77	4.47	4.77
Fish oil	0.95	0.96	0.94	0.92	1.00

Source: International Fishmeal and Fish Oil Organisation (IFFO)

Several factors have contributed to the decline in fishmeal production. Fishmeal and fish oil are produced from many different species. However, small pelagic species, anchoveta in particular, are the main raw material for production. In 2010 the El Niño phenomenon caused a significant drop in the catches of anchoveta, which in turn reduced the production of fishmeal and fish oil. There was also an El Nino in 2016 which caused a reduction in anchoveta catches, albeit not as severe as in 2010. Many countries, including all the major producing countries, applied stricter control measures of wild fishery resources (Mittaine, 2012). In particular, management control measures for the anchoveta fishery in Peru and a reduction in fleet capacity caused by the introduction of individual vessel quota systems contributed to the production decline (Aranda, 2009). Increased processing for direct human consumption of fish formerly used for fishmeal was an additional factor behind the downward trend in production.

Another source of raw material for the production of fishmeal is fish processing by-products. The more efficient utilisation of by-products including waste was made possible by improved

processing technologies and a focus on safe and hygienic methods of processing in many countries.

The increase in global aquaculture production has led to a concern that increased demand for feed from a growing aquaculture sector will increase fishing pressure on wild stocks and consequently threaten the sustainability of the associated capture fisheries. This is also known as the "fishmeal trap" (Asche & Bjørndal, 2011).

Increased aquaculture production has the potential to influence wild fish stocks via increased demand for feed. This generally happens when the management system for the species in question is weak. Fishmeal has been a part of the much larger protein meal market, and, in particular, fishmeal is a close substitute for soybean meal. With this market structure, it is the total supply of and demand for protein meals, of which fishmeal makes up only a small part, that determines prices for fishmeal. Moreover, the growth in aquaculture production appears not to have been influenced much by fishmeal prices, and one seems to be able to substitute away from fishmeal as a feed ingredient when prices are high. One is then led to the conclusion that increased demand for fishmeal from aquaculture cannot have any significant impact on fishmeal prices in the long run, and accordingly does not lead to increased fishing pressure.

The use of marine ingredients for aquaculture feed is criticized by some commentators who claim that increased aquaculture production is based on the depletion of capture fishery resources. Although there is no agreement among specialists on this issue, the areas of potential concern are recognized. "It is concluded that future growth of fed aquaculture will be associated with proportionately greater use of land animal and plant proteins, oils and carbohydrates sources, and with a continuing decline in dependence on marine ingredients" (Shepherd, 2013). With aquaculture production increasing while the supply of fishmeal remains limited, fishmeal will be used more and more strategically in the feeding process. All in all, there is little reason to expect that a limited or even declining supply of fishmeal and fish oil in the future will negatively affect the potential for further expansion in aquaculture.

6.4 Aquaculture

Aquaculture can be defined as the human cultivation of organisms in water (Asche & Bjørndal, 2011). The production process in aquaculture is determined by biological, technological, economic and environmental factors. The production process can be closed in the sense that it does not depend on wild stocks to provide fingerlings or fry.

A number of criteria can be used to classify an aquaculture system. From an economic point of view, the most significant criterion is intensity. The most interesting feature in this regard is the degree of control over the production process.

In intensive aquaculture, the production system is closed. Fish are reared in confined areas and the farmer controls production factors such as farm size, stocking and feeding of fish. Traditional aquaculture varies between semi-intensive and extensive. The small ponds used in Chinese aquaculture were traditionally operated on an extensive basis, as the farmer did little to control growth and biomass. While this system is still common, many farms have become semi-intensive as farmers actively feed their fish to enhance production and undertake other productivity enhancing measures such as maintaining higher densities.

Table 28 describes world aquaculture production by main group of species in the period from 1970 to 2016. Finfish is the largest group of species in terms of production with 51.3 million tonnes in 2016, followed by aquatic plants (30.1 million tonnes), molluscs (17.1 million tonnes) and crustaceans (7.9 million tonnes). The contribution of other species groups to aquaculture production is less important.

Table 28: World aquaculture production of food fish by main groups of species (thousand tonnes), 1970-2016

Species groups	1970	1980	1990	2000	2010	2011	2012	2013	2014	2015	2016
Freshwater and Diadromous Fish	1.432	2.584	8.348	19.836	36.613	38.626	42.277	45.027	47.306	48.836	51.345
Aquatic Plants	959	2.641	3.765	9.306	18.992	20.785	23.555	26.863	27.356	29.365	30.139
Molluscs excl. Cephalopods	1.068	1.837	3.609	9.758	14.064	14.372	14.874	15.476	16.047	16.408	17.139
Crustaceans	10	87	755	1.691	5.586	5.979	6.277	6.498	7.047	7.351	7.862
Demersal Marine Fish	5	26	99	403	1.108	1.157	1.225	1.257	1.338	1.462	1.534
Aquatic Animals NEI	6	12	45	156	818	754	839	895	894	911	939
Marine Fish NEI	3	9	59	423	479	574	586	623	685	725	845
Pelagic Marine Fish	43	152	170	151	294	333	366	379	350	360	367
Others	0	0	0	1	63	54	22	34	48	41	38
Cephalopods	0	0	0	0	0	0	0	0	0	0	0

***Source**:* FAO (2018)

Table 29 shows the main species groups and main species in world aquaculture production in the period 2010-18. In 2018, finfish represented about 66 percent of total aquaculture production, while the shares of crustaceans and molluscs were about 11 and 21 percent, respectively. In terms of individual species, grass carp and silver carp were at the top of the list. Production of all species listed increased over the period, although growth rates varied.

As far as modern industrialised aquaculture is concerned, salmon and shrimp/prawn are the leading species. These are also high-value species, so that the value share is considerably higher than the quantity share. Farmed salmon and shrimp/prawn are now sold all over the world.

Table 29: Major Species in Aquaculture 2010, 2014, 2016 and 2018. '000 Tonnes

	2010	2014	2016	2018
Finfish total	**37 745.1**	**47 219.1**	**51 078.0**	**54 279.0**
Grass carp	4 213.1	5 039.8	5 444.5	5 704.0
Silver carp	3 972.0	4 575.4	4 717.0	4 788.5
Nile tilapia	2 657.7	3 758.4	4 165.0	4 525.4
Common carp	3 331.0	3 866.3	4 054.7	4 189.5
Bighead carp	2 496.9	2 957.6	3161.5	3 143.7
Catla	2 526.4	2 269.4	2 509.4	3 041.3
Carassius	2 137.8	2 511.9	2 726.7	2 772.3
Freshwater fish nei	1 355.9	1 983.5	2 582.0	2 545.1
Atlantic salmon	1 437.1	2 348.1	2 247.3	2 435.9
Striped catfish	1 749.4	2 036.8	2 191.7	2 359.5
Roho labeo	1 133.2	1 670.2	1 842.7	2 016.8
Milkfish	808.6	1 041.4	1 194.8	1 327.2
Torpedo-shaped catfishes nei	343.3	867.0	961.7	1 245.3
Tilapias nei	472.5	960.8	972.6	1 030.0
Rainbow trout	752.4	794.9	832.1	848.1
Crustaceans total	**5 478.8**	**6 748.3**	**7 676.1**	**9 386.5**
Whiteleg shrimp	2 648.5	3 595.7	4 126.0	4 966.2
Red swamp crawfish	596.3	659.3	894.7	1 711.3
Chinese mitten crab	572.4	722.7	748.8	757.0
Giant tiger prawn	562.9	701.8	705.9	750.6
Molluscs total	**13 728.3**	**15 707.8**	**16 840.1**	**17 510.9**
Cupped oysters nei	3 570.7	4 181.6	4 690.8	5 171.1
Japanese carpet shell	3 500.2	3 838.6	4 175.8	4 139.2
Scallops nei	1 366.6	1 576.5	1 849.9	1 918.0
Sea mussels nei	871.4	992.9	1 085.4	1 205.1
Marine molluscs nei	556.3	1 035.4	1 118.1	1 056.4
Other animals total	**791.8**	**830.7**	**909.6**	**918.6**

Nei = not elsewhere included.
Source: FAO (2020)

Table 30 lists aquaculture by region and the producers for the period 1995-2018. In 2018, Asia represented 88.69 percent of total production, with 4.63 percent for the Americas, Africa 2.67 percent for Africa, 3.75 percent for Europe and 0.25 percent for Oceania. Despite a great increase in absolute terms, China's share decreased from 65.03 percent in 1995 to 57.93 percent in 2018. Nevertheless, there has been little change in Asia's market share over the period due to the emergence of countries such as India, Indonesia, Viet Nam and Bangladesh as major producers. With the exception of North America and the European Union, most regions and countries exhibit substantial growth in absolute terms over the period.

Table 30: Aquaculture Production by Region and by Major Selected producers 1995-2018. '000 Tonnes

Region/country	1995	2000	2005	2010	2015	2018
Africa	110.2	399.6	646.4	1 285.8	1 777.6	2 195.9
Egypt	71.8	340.1	539.7	919.6	1 174.8	1 561.5
Northern Africa excl. Egypt	4.4	4.8	7.2	10.0	23.8	38.0
Nigeria	16.6	25.7	56.4	200.5	316.7	291.3
Sub-Saharan Africa excl Nigeria	17.4	29.0	43.1	155.6	262.3	305.1
Americas	919.6	1 423.4	2 176.9	2 514.6	3 274.7	3 799.2
Chile	157.1	391.6	723.9	701.1	1 045.8	1 266.1
Rest of Latin America and Caribbean	282.8	447.4	784.5	1 154.5	1 615.5	1 873.6
North America	478.7	584.5	668.5	659.0	613.4	659.6
Asia	21 677.1	28 420.6	39 185.9	51 228.8	64 591.8	72 812.2
China	15 855.7	21 522.1	28 120.7	35 513.4	43 748.2	47 559.1
India	1 658.8	1 942.5	2 967.4	3 785.8	5 260.0	7 066.0
Indonesia	641.1	788.5	1 197.1	2 304.8	4 342.5	5 426.9
Viet Nam	381.1	498.5	1 437.3	2 683.1	3 462.4	4 134.0
Bangladesh	317.1	657.1	882.1	1 308.5	2 060.4	2 405.4
Rest of Asia	2 823.4	3 011.8	4 581.4	5 633.1	5 718.4	6 220.7
Europe[a)]	1 581.4	2 052.6	2 137.3	2 527.0	2 948.6	3 082.6
Norway	277.6	491.3	661.9	1 019.8	1 380.8	1 354.9
European Union members	1 182.6	1 402.5	1 272.4	1 263.3	1 263.7	1 364.4
Rest of Europe	121.2	158.7	203.1	243.9	304.0	363.2
Oceania	94.2	121.5	151.5	187.8	178.5	205.3
World	**24 382.5**	**32 417.7**	**44 298.0**	**57 743.9**	**72 771.3**	**82 095.1**

a) Including Cyprus

Source: FAO (2020)

Productivity growth and technological progress have been important factors underlying production growth in aquaculture. The prices of many farmed products have declined over time. Thus, for production to be profitable, production costs have had to be substantially reduced. The main factor in reducing production costs has been productivity growth through improved technologies and better production practices.

Reduced production costs are primarily due to two factors. First, fish farmers have become more efficient, as they produce a larger quantity with the same amount of inputs. This is normally referred to as productivity growth. Second, improved input factors make the production process less costly. This is evident from the lower quantities of inputs used per unit of output and the lower prices for inputs. Changes in the quality of inputs or their prices can also change the mix of input factors.

Feed is the most vital input factor in the production process, and improvement in feed quality is one of the most important reasons for productivity growth.

In nature, fish are affected by disease, and they are likewise affected in captivity. Moreover, the high densities of fish in captivity substantially increase the risk of diseases spreading. To facilitate industrial production, it must be possible to control diseases.

Systematic breeding, simply described, is choosing the best parents to produce offspring with the most desirable traits. The aim of systematic breeding is to use breeding animals with the best genes as parents of the next generation and at the same time to avoid inbreeding.

Commonly, technological progress can be divided into two parts, depending on how advanced the producers in question are. State-of-the-art producers will exploit the best technology, and can only improve productivity if technology itself improves. However, at any point in time, there will be a number of firms that do not employ state-of-the-art technology. These producers can improve productivity, even if technology is not improving, by catching up with best practices.

Any production process that interacts with the natural environment has the potential to damage the environment around the production site. The environmental issues that arose in intensive salmon and shrimp farming must be considered in relation to the introduction of a new technology that uses the environment as an input. The larger the production at any site and the more intensive the process, the larger the potential for environmental damage. However, having a greater degree of control over the production process in intensive aquaculture also makes it easier to address these issues.

There are two main motivations for the industry to address environmental effects: (i) the effects reduce productivity and therefore profits; and/or (ii) government regulations force the industry to do so. There is some form of environmental regulation in virtually all countries where aquaculture has some prominence, limiting what the industry can and cannot do.

6.5 Global fish exports and imports

The increasing participation of developing countries in fish exports and imports has been one of the defining features of world fish markets for the past decades. The increase in fishery trade was motivated by strong demand from developed countries. On the supply side, the tremendous increase in aquaculture production by developing countries has been very important.

The export value of fish – capture and farmed – has increased rapidly in recent decades, up from almost USD 8 billion in 1976 to USD 148.6 billion in 2014, with a temporary dip to USD 133.2 billion in 2015, increasing to USD 142.8 billion in 2016 and USD 163 billion in 2018, with USD 75 billion and 83 billion from developed and developing countries, respectively. This means the share of developing countries in export value was 54 percent as compared to 46 percent for developed countries. The same year developing countries represented 60 percent of total quantity, and their net fish export revenues (exports minus imports) reached USD 38 billion.

While developed markets still dominate fish imports, the importance of developing countries as consumers as well as producers of fish and fish products has been steadily increasing. In 2018, fish imports by developing countries was 31 percent by value and 49 percent by quantity. As consumer purchasing power increases and preferences evolve, an increasing proportion of production that would previously have been exported to developed markets is now being directed to meet the demand of regional and domestic consumers.

Source: FAO (2020)

Figure 25. World exports and imports of fish trade, developing and developed countries, quantity (million tonnes) and value (USD billions), 1976-2018

The fisheries and aquaculture sectors have demonstrated openness to integration in international trade in the last three decades. Sustained demand, trade liberalisation policies, the globalisation of food systems and technological advancements in the food value chain have resulted in an increased proportion of production being exported.

Fish trade involves a wide range of products and participants. Among the most highly traded fish commodities are shrimps, salmon, tuna and groundfish. High-value species are largely directed towards more prosperous markets, while low-value species such as small pelagics are generally exported to low-income markets.

Table 31 shows the top ten exporters and importers of fishery products from 2000-16. As mentioned above, developing countries play an important role in world fish food exports. China, Viet Nam and Thailand are the leading exporters of fish products among developing countries. It is very interesting to note that India is now the 6th largest fish exporter in the world, while up to 2010 the country was not among the 10 largest exporters. China's exports have expanded considerably since the 1990s, and represented 14.2 percent of total world fish exports in 2016,

with a value of USD 20.3 billion. China, since 2002 has been the largest exporter of fish and fish products, although they represent only 1 percent of its total merchandise trade. After exceptionally rapid gains through the 1990s and 2000s, the average annual increase in the value of Chinese exports of fish and fish products dropped from 14 percent in 2000-08 to 9.1 percent in 2009-17. In 2017, Chinese exports of fish and fish products reached USD 20.5 billion, with an increase of 2 percent relative to 2016 and of 4 percent relative to 2015 (FAO, 2018).

After China, the major exporters in 2016 were Norway, Viet Nam and Thailand. Among developed countries, Norway, the United States of America, Denmark, Canada and Spain are the leading fish exporters. It should, however, be kept in mind that there is a substantial reexport of fish.

Throughout the time period under consideration, the United States has been the largest importer with USD 20.8 million recorded for 2016. Japan's imports peaked at USD 18.4 million in 2012, and has decreased in the following years. In 2016 Japan imported for USD 14.2 million. From 2011 onwards China has been the third largest importer in the world after the United States and Japan. China increased its fish food and fish products imports mostly by outsourcing. China imports raw materials from major regions for further processing and export. The European Union is by far the largest single market for imported fish and fishery products. Among individual countries, Spain, France, Italy, Germany, Sweden and the United Kingdom are large importers.

Table 31: Top ten exporters, top ten importers, for 2000, 2005, 2010-16. Million USD

Exporters	2000	2005	2010	2011	2012	2013	2014	2015	2016
China	3.706	7.674	13.475	17.229	18.445	19.711	21.192	19.924	20.323
Norway	3.550	4.922	8.853	9.484	8.921	10.392	10.831	9.211	10.798
Viet Nam	1.484	2.765	5.123	6.260	6.291	6.901	8.047	6.774	7.344
Thailand	4.384	4.503	7.166	8.160	8.145	7.068	6.657	5.702	5.915
USA	3.119	4.287	4.775	5.901	5.484	5.685	5.851	5.670	5.588
India	1.418	1.598	2.567	3.551	3.417	4.622	5.614	4.883	5.555
Chile	1.858	3.043	3.511	4.631	4.490	5.173	6.048	4.964	5.292
Canada	2.835	3.615	3.875	4.225	4.250	4.391	4.560	4.659	4.947
Denmark	2.766	3.695	4.208	4.507	4.160	4.682	4.778	4.283	4.710
Sweden	476	1.185	2.671	2.865	2.878	3.588	3.885	3.681	4.428

Importers	2000	2005	2010	2011	2012	2013	2014	2015	2016
USA	10.554	12.887	15.641	17.633	17.742	19.174	21.512	20.052	20.763
Japan	15.743	14.729	15.176	17.728	18.356	15.655	15.204	13.752	14.216
China	1.821	4.031	6.343	7.798	7.695	8.363	8.890	8.722	9.055
Spain	3.372	5.649	6.542	7.340	6.413	6.444	7.049	6.503	7.177
France	3.018	4.604	6.010	6.628	6.096	6.571	6.672	5.802	6.241
Italy	2.555	4.250	5.404	6.250	5.537	5.779	6.146	5.579	6.197
Germany	2.282	3.263	4.763	5.565	5.241	5.476	6.095	5.190	5.662
Sweden	712	1.600	3.298	3.637	3.623	4.490	4.788	4.430	5.192
Korea, Republic of	1.412	2.398	3.227	3.976	3.776	3.679	4.310	4.384	4.636
United Kingdom	2.210	3.209	3.748	4.296	4.280	4.541	4.595	4.141	4.257

Source: FAO FishStat (2018)

In 2018, in terms of value, China represented 14 percent of the world export of fish, followed by Norway (7 percent), Viet Nam (5 percent), Thailand, the USA, India and the Netherlands (4 percent each); and Canada and Russia (3 percent each). In terms of imports, the USA accounts for 14 percent of world imports, followed by Japan and China, each with 9 percent, Spain (5 percent), Italy, France, Germany and Republic of Korea (each 4 percent), and Sweden and the Netherlands (3 percent each). The combined share of the EU was 34 percent. Traditionally, the

EU, the USA and Japan dominated world imports with a combined share of 76 percent in 1976. In 2018, this had been reduced to 57 percent (FAO, 2020). This reduced share is, however, due to faster demand growth in many emerging economies. When analysing these figures, it must also be kept in mind that a number of countries import fish for further processing and exports.

6.6 The potential for increased production

According to OECD-FAO (2017), total fish production is expected to increase from 168.3 million tonnes as the average for the base period 2014-16 to reach 193.9 million tonnes by 2026, an increase of 25.6 million tonnes. This outcome is partly affected by the assumed *El Niño* event in 2026. According to these projections, total fish production at the global level is anticipated to grow by just over 1 percent p.a. over the outlook period 2017-26, a substantial reduction when compared to the 2.4 percent p.a. growth rate witnessed over the previous decade. This slowdown is driven by the combined effect of growth rates falling in both capture fisheries and aquaculture.

The observed slowdown in aquaculture growth is expected to continue, falling from 5.3 percent p.a. over the period 2007-16 to 2.3 percent p.a. for 2017-26. Aquaculture production is expected to surpass total capture fisheries production (including that utilised for non-food uses) in 2021, a year when capture production is assumed to be lower as a consequence of *El Niño*, and then continue to increase in absolute terms until the end of the outlook period. Global aquaculture production is anticipated to exceed the 100 million tonnes for the first time in 2025 and to reach 102 million tonnes in 2026.

6.6.1 Climate change

Global climate change policy has been mostly driven by the activities of the industrialized countries, but the most severe consequences are being felt by developing countries as most of them are located in regions already subject to climate extremes (Conway, 2012, p. 286).

Predicting the long-term consequences of climate change is difficult. Cheung et al. (2009) concluded that climate change might lead to a large-scale redistribution of global catch potential, with an average increase of 30-70 percent in high-latitude regions and a drop of up to 40 percent in the tropics. In addition, in the last few years the maximum catch potential has been declining considerably in the southward margins of semi-enclosed seas (a gulf, basin or sea surrounded by two or more coastal states) while increasing in the poleward tips of continental shelf margins.

Climate change and climate variability impacts have already increased uncertainty in the supply of fish from capture fisheries and aquaculture. The priorities and focus of countries with respect to mitigating climate effects, as well as increasing their resilience to these effects, vary according to the number of issues that might affect them. An assessment of risks faced by, and the vulnerability of, an individual region’s fisheries and aquaculture resources is necessary in order to establish proper management techniques. Local programmes for climate change adaptation need to be fully integrated within the United Nations Framework Convention on Climate Change.

Possible impacts of climate change on fisheries and aquaculture have been analysed in a recent report by the FAO (Barange et al., 2018), to be discussed more fully in the next chapter.

6.6.2 Capture fisheries

In the OECD-FAO (2017) report, capture fisheries production is forecast to grow by 5 percent, from about 91 million tonnes to about 95 million tonnes by 2022. The increase is attributed to stock recovery resulting from improved resource management. Among other factors contributing to growth are more efficient use of fishery production through reduced discards, waste and losses, increased production in countries still not subject to production quotas, increased efficiency of small-scale fisheries, improved fishing technologies and decreases in illegal, unreported and unregulated (IUU) fishing.

A key element of sustainable production is waste minimization, taking into account the mandatory landing and usage of bycatch. As reported by Kelleher (2005, p. 6), in the 1992-2001 period, the yearly average discards are estimated to be 7.3 million tonnes, which is lower than previous estimates of 27 million and 20 million tonnes. Bycatch reduction is largely a result of the use of more-selective fishing gear, the introduction of bycatch and discard regulations, improved enforcement of regulatory measures, increased retention of bycatch for human or animal food results from better processing technologies and expanding market opportunities for lower-value catch.

Increased efficiency of the value chain in small-scale fisheries will lead to higher production volumes in the future. With the globalization of the fisheries sector, the ability to adhere to market access requirements becomes a crucial task. Small-scale producers, especially in countries with low domestic consumption rates, need to focus on markets and marketing. This will not only benefit producers and production, but it could also help the country achieve improved food security and nutrition.

Fishing technologies have an impact on fish production and fishing sustainability (FAO, 2012). Most fishing gear in use today, especially in developing countries, were developed when fisheries resources were abundant, energy costs were much lower and less attention was paid to the negative impact of fishing on the ecosystem. Taking into account the scarcity of resources today, low-impact fuel-efficient fishing is highly relevant for production. The impact of fishing gear on the ecosystem largely depends on physical characteristics, the mechanics of its operation, where, when and how the gear is used and the extent of its use. The undeniable fact is that when gear is poorly selected, it leads to an incidental catch of fish and juveniles and the accidental mortality of non-target species and seabirds.

Addressing fisheries overcapacity and IUU fishing through more effective governance is also important for a growth in production. While it is difficult to estimate precisely the total IUU catch, IUU fishing accounts for the major proportion of catches for some species.

6.6.3 Aquaculture

Products from aquaculture will account for a growing share of international trade while continuing to play a key role in food security, with significant production also destined for domestic consumption. Aquaculture is expected to expand in all continents in terms of new areas and species, as well as through the intensification of production and diversification of the product range to better meet consumer needs. The global distribution of aquaculture production is likely to continue to remain imbalanced, with China dominating world production.

In aquaculture in particular, the degree to which technological advances and better management practices directed towards sustainable production are incorporated into business practices will influence future growth. Taking into account the projected increases in fishmeal and fish oil prices, improvements in feed efficiency and greater use of substitutes are essential.

As noted above, based on the OECD-FAO (2017), world aquaculture production[27] is expected to increase by 39 percent from 78.8 million tonnes in 2016 to 109.8 million tonnes by 2030[28]. This corresponds to an average annual growth rate of 2.24 percent, which is considerably less than the growth achieved up to 2016 and also less than what was observed for 2016-18. According to the report, the lower growth rate will mainly be caused by water scarcity, less optimal production location availability and high input costs (fishmeal, fish oil and other feeds). Despite the slower growth rate, aquaculture will remain one of the fastest-growing food producing sectors.

This assumption is somewhat pessimistic. Although the annual growth rate is likely to be reduced, the large reduction that is assumed for the next decade may appear to be rather pessimistic. First, although there may be less optimal production location availability, there is scope for increased production at existing locations and some scope for production in new locations. Second, as for fishmeal, history shows there is great scope for productivity improvements in the use of fish feed as well as substitution of other types of meal. The research currently being undertaken in this area will allow for continued expansion. In addition, numerous farmed species are herbivorous and thus not affected by developments in the market for fishmeal. Third, and importantly, when it comes to technology, there is enormous scope for catching up as well as developing new technologies. This is particularly true for developing countries, which represent the bulk of aquaculture production. Moreover, regulations more favourable to aquaculture development may also lead to increased production in many countries.

For all these reasons, it may be expected that aquaculture production will continue to grow at a fairly rapid rate also in the coming decades. The following chapter analyses various scenarios to this effect.

[27] These figures do not include aquatic plants.
[28] The OECD-FAO (2017) gives projections up to 2026; for this report, projections have been extended to 2030.

7. FUTURE FISH PRODUCTION

As described in this report, aquaculture has expanded over several decades. This is due to factors on the supply as well as the demand side that have resulted in good profitability and allowed production to expand over time. It should also be noted that many demand side variables such as population and income growth in addition to changes in consumer preferences (see Chapter 5) are likely to create a positive business environment for the continued expansion of aquaculture also in the future.

In addition to profitability, many other variables will influence the future development of aquaculture. Regulations of aquaculture, in particular those limiting the development of new sites or negatively affecting the potential for increased production at existing sites, are an obstacle to the development of aquaculture. In most countries an environmental assessment is required to establish a fish farm as aquaculture interacts with the environment (Asche & Bjørndal, 2011). The negative impact of aquaculture on the environment is an externality. Although there are instances where it is in the interest of industry to internalise an externality, it is nevertheless the responsibility of governments to do this in one way or the other. In addition, there may be conflicting uses of an area suitable for aquaculture, be it for farming, recreation, fishing or other purposes. Accordingly, there are many reasons for government regulation of aquaculture. However, in many countries, regulations have become a binding constraint on further development, in some instances including outright bans on aquaculture. As various countries have started implementing aquaculture friendly regulations and market policies, further expansion of aquaculture production is feasible. Moreover, genetic improvements and technological developments, including improvements in inputs in production such as feed, spurred on by the profitability of aquaculture, will also contribute to an increase in production.

In this chapter, we will analyze alternative scenarios for future fish production. This will be done by use of the FAO FISH Model. On the demand side, this model takes into account expected future changes in population and GDP as well as demand and income elasticities. Other demand shifters like the retail prices of different meats are also included. On the supply side, we consider several alternatives for the development in capture fisheries and aquaculture.

Five scenarios that allow for different assumptions with regard to future aquaculture production will be modelled. When it comes to future capture fishery production, however, most of the scenarios will be based on the same assumptions although there will be some differences[29]. We will consider the following scenarios:

I. Average annual aquaculture growth rate of 4 percent
II. Extension of the OECD-FAO (2017) Outlook scenario
III. Reduced growth in China
IV. Average annual aquaculture growth rate of 5 percent
V. Climate change

We start by explaining and justifying the different scenarios.

[29] Actual capture production in 2016 and 2030 forecasted production for the different scenarios is given in the Appendix, Table 10.A1.

7.1 Fish production

7.1.1 Scenario I (the base case): Average annual aquaculture growth rate of 4 percent

The rationale for this scenario is that it is felt that the reduction in the growth rate of aquaculture production in the OECD-FAO (2017) Outlook, which give projections up to 2026, is too severe, as has been discussed in Chapter 6. Aquaculture is still undergoing rapid growth and intensification, and its potential has only recently begun to be realised (see, for example, Belton et al., 2018; Edwards, 2015; Little et al., 2016). Technical progress in genetic improvement, feeding efficiencies and other management practices are well underway and demonstrating potential. Gjedrem et al. (2012) reported more than 100 family-based selection programmes in aquaculture (including 27 for tilapia, 13 for Atlantic salmon and 13 for rainbow trout). Various countries around the globe, including China, currently have ongoing selective breeding programmes for tilapia (Eknath et al., 2007; Gjedrem et al., 2012). Selective breeding programmes have also been initiated for carp and shrimp (Dey et al., 2010, 2013; Hung et al., 2013; Ninh et al., 2013). Overall, feed use efficiency and fish oil efficiency are improving (Little et al., 2016; Sarker et al., 2013; Waite et al., 2014).

As highlighted in Chapter 6, from 1980 to 2016, the average annual growth rate in output has been 8.2 percent. From 2000 to 2016, the average annual growth rate has been 5.8 percent. Despite a lower growth rate, the growth in absolute terms can still be larger in the future as growth is on a larger base.

A recent projection based on the AsiaFish model, a well-regarded country-specific fish sector model, shows that aquaculture in Indonesia, a major producer of farmed fish (Chapter 6), is likely to expand at about 7 percent a year from 2012 to 2030 under the business as usual scenario, which is only slightly below the 7.7 percent growth rate achieved during the period 1960 to 2013 (Tran et al., 2017).

Geographically, the aquaculture sector is already advanced in Asia and is currently going through intensification (see for example, Belton et al., 2018). Aquaculture is also beginning to expand rapidly in various African countries including Nigeria, Uganda, Kenya, Zambia and South Africa (FAO, 2017a). Latin America and the Caribbean have potential for aquaculture growth too (FAO, 2017b).

For this scenario, therefore, more optimistic assumptions about productivity improvements have been made than in the OECD-FAO Outlook and supply elasticities have been revised. The new assumptions have given rise to an average production increase of 4 percent per year. Annual production numbers[30] for this case are presented in Figure 26[31]. This scenario is considered the base case for this analysis.

[30] The scenario imposed an equal upward shift in supply due to overall productivity gains in order to reach the 4 percent average annual growth rate. The imposed shift will not increase production of all these species by the same percentage because of the differences in the output price elasticities as the prices are changing in this scenario. Alternatively, a time profile could have been specified with higher rates initially and then decreasing, but this would have little impact on the results.

[31] It is important to note that non-commercial subsistence fisheries' catches in coastal ecosystems (such as coral reef flats and estuaries) and floodplains are generally neglected in official catch statistics (Dey et al., 2005b; Pauly & Zeller, 2016). This comment applies to all scenarios under consideration.

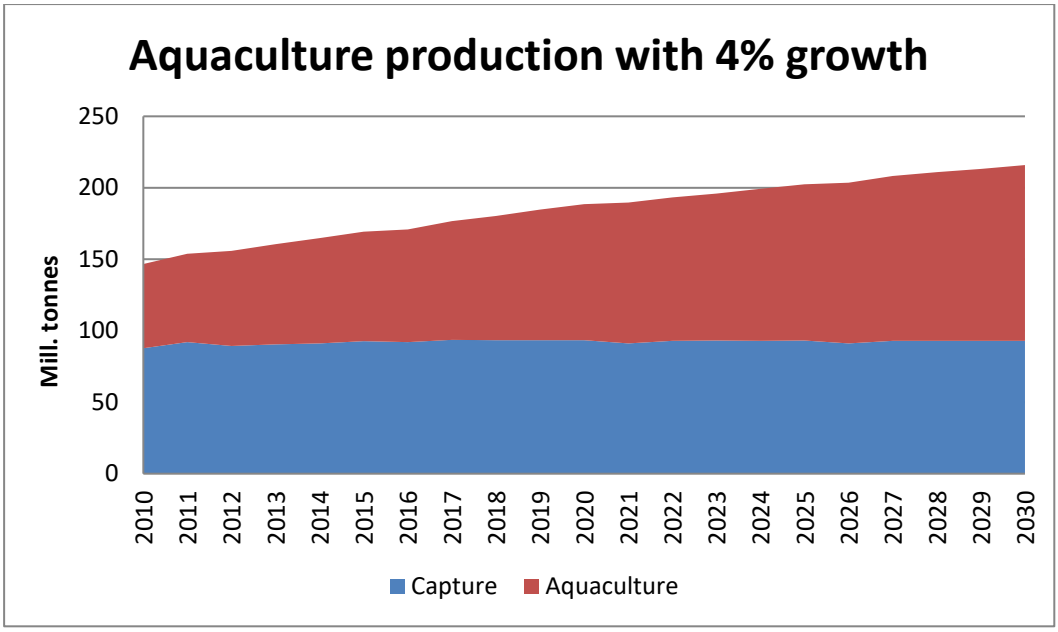


Figure 26. Capture and aquaculture production 2010-30 – Scenario I: 4 percent annual growth. Million tonnes (live weight basis)

Capture production shows little change over time with 92.0 million tonnes in 2016, between 93-94 tonnes annually in most years up to 2030 and with 92.9 million tonnes forecast for 2030. Aquaculture production on the other hand is seen to increase from 78.8 million tonnes in 2016 to 123 million tonnes in 2030 with total fish production in that year at 215.9 million tonnes, with 57 percent originating from aquaculture. Total fish production over this period increases by 26.4 percent.

7.1.2 Scenario II: Extension of the OECD-FAO (2017) Outlook

Estimates based on the OECD-FAO (2017) Outlook are considered next. The Outlook gives projections up to 2026 which in this report have been updated to 2030, based on the same underlying assumptions. This scenario is accordingly called *Extension of the OECD-FAO (2017) Outlook*. Production figures up to 2030 are given in Figure 27. As can be seen, capture production is more or less stable with minor variations from year to year: in 2016, capture production is 92 million tonnes, while it is projected to be 93.7 million tonnes in 2030. These assumptions are similar to scenario I. The lower aquaculture production leads to higher fish prices and, consequently, larger capture production in a few countries for which fishing quotas are not enforced.

Aquaculture production, on the other hand, is increasing, from 78.8 million tonnes in 2016 to 109.8 million tonnes in 2030. Consequently, total fish production increases from 170.8 million tonnes in 2016 to 203.5 million tonnes in 2030 with 46 percent from capture and 54 percent from aquaculture. Total fish production increases by 19.1 percent over the 2016-30 period as compared to 26.5 percent for scenario I.

For the period 2016-30, average annual growth in aquaculture is estimated at 2.4 percent. This is considerably less than what has been experienced in recent decades (cf. Chapter 6) and, as argued previously, the assumption appears rather pessimistic. Moreover, this is considerably lower than in scenario I.

Scenario II is based on the premise that the OECD-FAO Outlook is not considering any significant changes in factors affecting production such as technology, access to new space and regulations. Essentially production conditions are not expected to change much. This is in line with the fact that even if seafood production increases without being constrained by fishmeal production, aquaculture is showing signs of slowing down, see for example, Liu and Sumaila (2008) and Asche et al. (2013). The main difference with scenario I is that scenario I considers improvements in different factors which would lead to a higher increase in production.

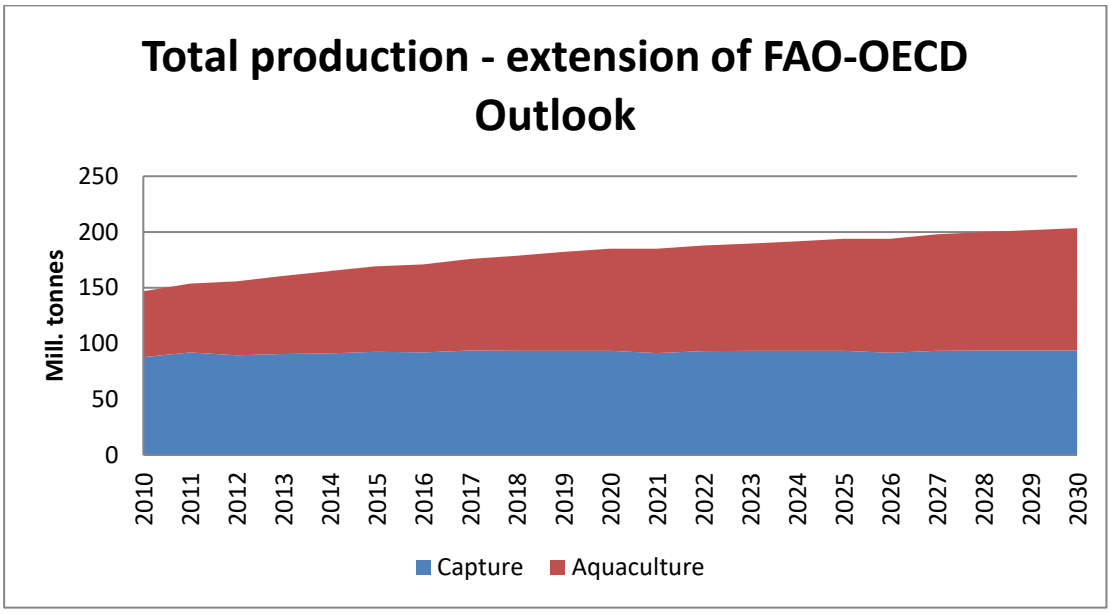


Figure 27. Capture and aquaculture production 2010-30. Scenario II – extension of the OECD-FAO (2017) Outlook. Million tonnes

7.1.3 Scenario III: Reduced growth in China

China is the largest producer of fish in the world. In 2016, its output of aquatic products reached 69 million tonnes, which represents 37 percent of world output.

Many fish stocks are overexploited, so harvests need to be reduced to allow them to recover. In the next 10 years, according to the China Agricultural Outlook (2015-26)[32], the Chinese Government will introduce a range of major reforms, including control of fishing vessels, improvement of the moratorium and the quota systems, including reduced harvests (quotas) for some species so as to improve the sustainability of fisheries. Taking this into consideration, in the next 10 years, capture fishery production is expected to decrease at an average annual rate of 3.6 percent and come down to 15.67 million tonnes in 2017, 12.94 million tonnes in 2020 and 12.06 million tonnes in 2026, that is, a reduction of 3.5 million tonnes over the period. An interesting question is whether these policies will lead to increased production in the long run, (i.e., after 2026 or so[33]).

[32] China Agricultural Outlook (2017-2026). [ERI6202530017]
http://www.chinabookshop.net/china-agricultural-outlook20172026-p-25300.html

[33] The experience in Europe shows that a more rational and environmental friendly fisheries management system over time can lead to increasing harvests. Examples include cod in the North Atlantic and anchovy in North Spain.

As for aquaculture, given the fixed area of ponds, the key to stabilising and enhancing aquaculture capacity is to improve existing fish farming facilities and conditions. During the Outlook period, the Chinese government will pay attention to developing ecologically sound and healthy aquaculture production that relies on technological innovations and the preservation of resources and the environment. Aquaculture will go through a process of restructuring and transformation. On one hand, the area for aquaculture will be regulated downward. However, while the total area of aquaculture may decrease, the areas of pond aquaculture will basically be maintained at the current level. On the other hand, varieties of aquaculture will move towards varieties of low consumption, low emission and high efficiency. Also, in aquaculture, improved management is likely to lead to increased production in the long run, in the same way as for fisheries. Production might also move towards meeting the demands of the growing Chinese middle class and to target production of more expensive and profitable species than the traditional carps. While this might lower production, it will raise profits per unit pond area.

Aquaculture output was expected to reach 52.52 million tonnes in 2017, 53.91 million tonnes in 2020 and 58.03 million tonnes in 2026. This represents an increase of 6.47 million tonnes over 2016, with an average annual growth rate of 1.2 percent, considerably lower than the average annual growth rate of 5.2 percent over the past 10 years. It will be interesting to see if production expands more beyond the Outlook period.

The total output of aquatic products is expected to be 68.19 million tonnes in 2017, declining to 66.85 million tonnes in 2020, then increasing to 70.08 million tonnes in 2026, just one million tonnes more than in 2016. During the Outlook period, the average annual growth rate of output will be 0.2 percent, significantly lower than the 4.2 percent of the previous 10 years. In 2026, aquaculture is expected to represent 82.8 percent of total output, 8.1 percentage points higher than in 2016.

Annual production figures for this scenario are presented in Figures 28 and 29 for capture fisheries and aquaculture, respectively, with comparison to the extension of scenario II OECD-FAO Outlook. Since the China scenario generates higher prices, most endogenous variables of the FAO FISH model are affected, in particular aquaculture production in other countries, which are larger than under scenario II.

Prices may rise in the first years of the period under consideration, i.e., the period of contraction, but will decrease in the future; however, this is uncertain. Price transmission is not perfect and we do not know what other producing and exporting countries will do. Chinese exporters could face losses due to competition from other countries and bargaining power from traders in importing countries. These losses may be recovered when production of higher quality fish increases in the future. Although these trends are the most likely ones, the extent to which they take place depends on many issues, such as substitution by other species and sources. In this context, market share and bargaining power are crucial aspects.

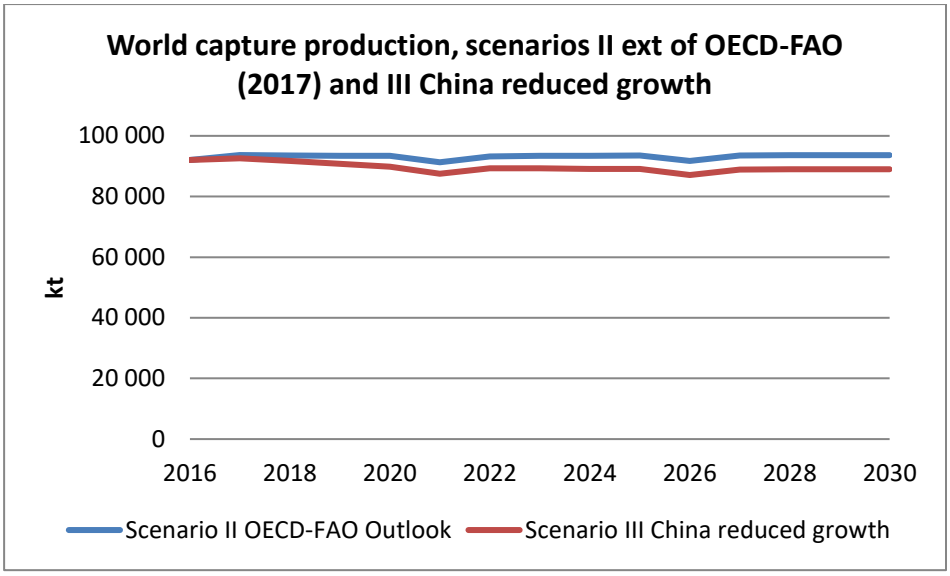


Figure 28. Capture fishery production under scenario II extension of OECD-FAO Outlook scenario and scenario III China reduced growth 2016-30. Million tonnes

In scenario III, world capture fishery production is reduced from 92 million tonnes in 2016 to 89.2 million tonnes in 2030, although recovery can be expected in the longer term. The reduction is mainly due to a decline in catches in Asia (China) over this period from 50.1 to 45.8 million tonnes. This decline is to some degree compensated by slightly increased catches in other regions caused by the higher prices so that the net decline over the period is 2.8 million tonnes. An interesting question we cannot address is whether this increase from other countries is sustainable in the long run.

While aquaculture production in scenario II is expected to increase from 78.8 million tonnes in 2016 to 109.8 million tonnes in 2030, representing a growth rate of 2.4 percent, in scenario III it increases to 105.9 million tonnes in 2030. This represents an average annual growth rate of 2.13 percent, that is, less than in scenario II. Note that the higher prices generated by the lower production in China compared to scenario II has led other countries to increase their aquaculture production. According to the FAO FISH model they were able to replace 51 percent of the decrease in China's aquaculture production between scenario II and III or 4.1 million tonnes of that 8.0 million tonnes difference.

According to the FAO FISH model, the positive net export position of China is expected to gradually disappear by 2023 but to return to 1.6 million tonnes by 2030, which is considerably less than the 4.8 million tonnes recorded in 2016.

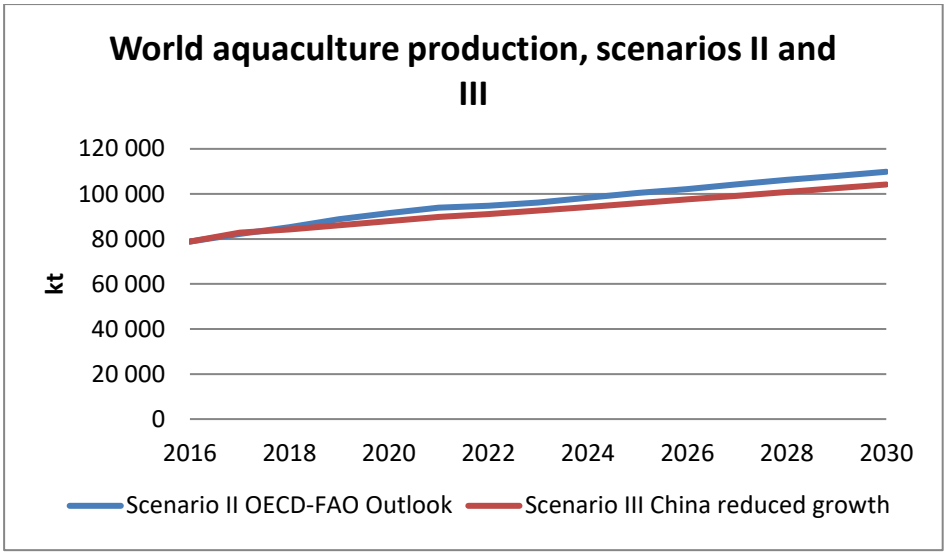


Figure 29. Aquaculture production under scenario II extension of (OECD-FAO 2017) Outlook and scenario III China reduced growth 2016-30. Million tonnes

7.1.4 Scenario IV (the optimistic case): A 5 percent average annual aquaculture growth rate

This scenario will be justified on the basis of more favourable regulations and the introduction of improved technologies that will allow for a larger increase in production than in the baseline scenario I, although with capture fish production as in scenario I. Nevertheless, it should be noted that the 5 percent annual growth rate (like for the 4 percent scenario) is not equal for each year, but is 5 percent on average in order to keep the same overall dynamics? Achieving this is assumed to be done by overall productivity improvements as well as improved feed efficiency[34].

As discussed above there are environmental and other constraints on aquaculture development; however, several countries are working to solve or at least mitigate some of these constraints and invest in aquaculture activities and the marine sector in general (e.g. Blue Growth).

As there appear to be constraints on expansion in some areas, there has been greater interest in the development of new technologies. These include:

a. Open ocean aquaculture, which might become important by the second part of the 2020s[35]. Even if some of these technologies will only replace existing coastal production, they will add a new dimension to aquaculture, and result in an environment where regulations should not become as limiting as in coastal areas.
b. Production technologies are still limiting in the case of most marine fish species, but that restriction should relax as time passes, and therefore, in the second half of the 2020s, production of marine fish should evolve more rapidly than at present. China also sees growth in marine aquaculture (Cao et al., 2017).

[34] Comments in footnote 30 above apply here as well.
[35] This type of aquaculture is currently banned in some countries with a large potential for production such as the US. This is an example of how regulations negatively affect aquaculture growth.

c. Implementation of commercial integrated multi-tropic aquaculture (IMTA) in coastal areas of China is promising. Despite challenges, implementing commercial IMTA can improve the overall sustainability of aquaculture in the coastal zone (Wartenberg et al., 2017). Nevertheless, it appears that IMTA has never reached an interesting level anywhere in the world, and chances are that it will remain being a 'desideratum' in the foreseeable future, without any significant effect on production levels.
d. More than proportional growth should also be expected in recirculating aquaculture systems (RAS) all over the world.
e. Aquaculture-assisted fisheries should increase their influence in total production, as new seeding projects gain acceptance in many parts of the world[36].
f. Adoption of community-based fish culture in floodplains will further improve fish production. WorldFish established a new approach, known as community-based fish culture, where fish are cultured communally during the flood season, but the same land is cultivated individually for rice during the dry season (Dey et al., 2005a). The innovations of the community-based approach to fish culture in floodplains have been widely used in Bangladesh as well as in other countries of Asia (Dey et al., 2013; Haque & Dey, 2017) and have huge potential.

It is important to note that some of these technologies have not yet proved to be economically feasible. Nevertheless, there is substantial investment in many parts of the world. Even if some of the new technologies may not be put to widespread use, the R&D involved is likely to have a beneficial impact and spillover effect also on existing technologies[37].

It is expected that some of these "new" technologies such as RAS will become economically efficient (or reduce their current risks) in the coming years. The sharing of know-how or just copying success stories should result in the fast dispersion of these technologies. Moreover, it is very difficult for a company or country to protect innovations or improvements in production technologies. Companies may be willing to export their technologies to other companies or through having their own plants abroad (which may also lead to risk reduction).

Let us also look at potential expansion from a geographical perspective. In many countries, better control of environmental problems and diseases needs to be introduced as is the case with China. Once improved regulations have been put in place, this should have a positive impact on farmed production growth and expansion. China is an interesting case in this regard. As outlined above, the Chinese Government is going to implement policies and regulations, which will allow the sustainable development and expansion of existing aquaculture. This will over time result in increased capacity and growth of production. If there is evidence of success in China, and such policies are also implemented in other countries, such as India or Brazil, there will be a significant increase in worldwide production. However, this increase will only happen if the other countries also adjust their policies and regulations.

[36] Galicia, with more than three decades of a hatchery-based fishery, is an example where this kind of system has resulted in great social benefits.
[37] Due to constraints on the expansion of salmon farming in countries such as Norway and Chile, there are now investments in land-based farming of salmon. Although it is too soon to tell whether full cycle land-based salmon production will be profitable, at least one important change in the mode of production can be observed. It is becoming common to produce smolts of up to one kg before release into the sea. This means that the sea phase is greatly reduced, possibly to only six months, which will reduce environmental problems and may allow for an increase in production (Bjørndal & Tusvik, 2020).

The growth potential for aquaculture in Asia outside of China varies by country. According to official statistics, Japanese aquaculture production decreased more than 10 percent in volume from 2006 to 2016. With limitation of sea-areas and a decreasing work force in aquaculture, the production decrease in Japan is likely to continue. Other industrial economies such as Korea and Taiwan Province of China may follow a similar decreasing trend due to the shift of the work force from aquaculture to other industrial sectors, as well as to saturated area coverage in aquaculture fields for the next decades.

By contrast, further expansion of aquaculture production is expected in other countries such as Indonesia or Myanmar. The growth rate for such countries, however, may slow down for the next decades due to the lack of recruitment of a new work force in the aquaculture sector. In Indonesia, for instance, fish farmers numbered 3,351,000 and 3,344,000 in the years 2010 and 2014, respectively (page 34 of FAO-SOFIA 2016). The price increase in artificial feeding could be another limiting factor for growth in aquaculture production. However, recent trends to replace fishmeal and oil with agricultural ingredients might help levelling future prices.

Technological developments for aquaculture are expected in many Asian countries. They include improvements in artificial feeds, development of breeds, and the use of information technology (IT) and artificial intelligence (AI) for improved production management[38]. Such technologies could offset the decreasing work forces and other constraints for future aquaculture. However, their exact impact on production increase is largely unknown at this stage.

The growth rate of Asian aquaculture (including China) during 2001-15 was 6 percent[39]. It is likely that the future growth in this region would not exceed this rate of increase.

Assuming that the future world will be more globalised, the new production technologies, along with farmed products, will be traded more intensively than in the past. Production technologies could become more similar globally, and the differences in production efficiencies by country would be more or less levelled off. It is reasonable to assume that the future growth in this region would not significantly differ from the world average. All this suggests that scenario IV assumptions are plausible.

When it comes to Latin America, Brazil and Mexico are large importers of seafood and both countries have excellent possibilities for increasing their farmed output. Brazil has the possibility to become a top-ten producer of aquaculture products in the coming decade. The main problem to be solved is that of improved governance.

Chile, which has faced substantial challenges for a number of years, should undertake a serious reorganisation of its salmon farming industry. If this is done, salmon production could grow substantially, and Chile might increase its share in world markets, particularly during the 2020s. However, they have major climate change related issues to do with parasites and disease and also growing friction between the fisheries and aquaculture sectors that is slowing investment and production growth. Additionally, it is also expected that special attention will be given to small-scale family-oriented aquaculture production, which will largely target the domestic market. Chile needs to solve the above-mentioned issues and modify regulations so as to

[38] Aquaculture is seen as a candidate for use of AI. Perhaps robots too may reduce the need for labour on fish farms.
[39] Page 6 of FAO Aquaculture Newsletter No 56, April 2017.

recover productivity and increase production. Governance issues are at the centre of future prospects.

Countries such as Argentina, currently insignificant in terms of aquaculture production, might increase their farmed output if local authorities support aquaculture, as currently seems to be the case. Peru should also show a more than proportional increase in aquaculture output in the coming decade, subject to a more direct governmental influence on these matters.

The case of China assumes that changes in the regulations are expected to result in more efficient and sustainable aquaculture, which is very important. Many countries have the potential to expand their production if they undertake the required changes in their regulations. The conclusion is that a significant increase in aquaculture production will occur if countries implement policies and regulations favouring the development of aquaculture. For example, rapid growth of aquaculture in Asia (and more recently in Africa) has been driven overwhelmingly by market friendly government policies, encouraging investments by commercially oriented farmers and supporting sustainable intensification and increasingly sophisticated technologies (Brummett et al., 2011; Hernandez et al., 2017; Belton et al., 2017; Kaminski et al., 2017; Henriksson et al., 2018). Sustainable intensification and market-based governance followed in Asia and some African counties are likely to further enhance aquaculture growth.

The main issue in the EU is spatial planning and availability, including conflicts due to alternative uses of water resources. Any increase in production, under current conditions, will come from new successful technologies. This is well documented in some of the STECF reports on the economic performance of aquaculture as well in some specific EU projects (see e.g. Ertöra & Ortega-Cerdà, 2015; STECF, 2016). Norway has a great potential for increased production using both traditional and new production technologies. However, for this to take place, environmental problems need to be brought under control (Bjørndal & Tusvik, 2019).

Annual world production numbers for this case are presented in Figure 30. Capture production shows little change over time at 92 million tonnes in 2016, between 93-94 tonnes annually in most years up to 2030, and at 92.9 million tonnes in 2030. Aquaculture production on the other hand is seen to increase from 78.8 million tonnes in 2016 to 134 million tonnes in 2030 with total fish production in that year of 226.9 million tonnes, with 59.2 percent originating from aquaculture. Total fish production over this period increases by 32.8 percent.

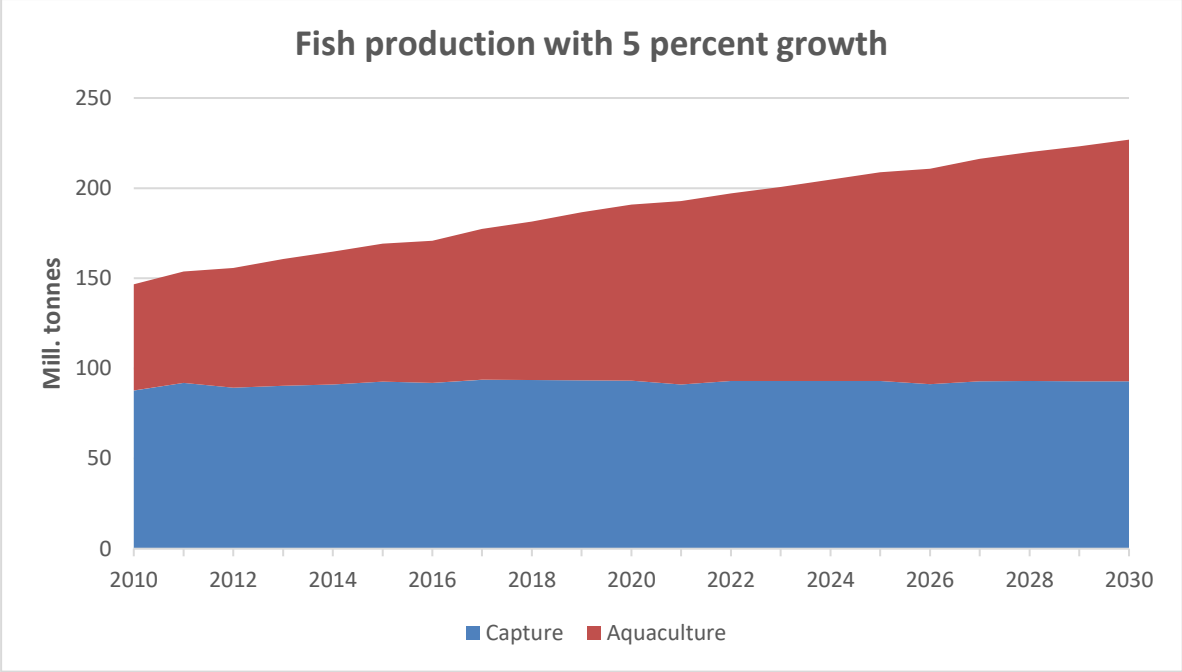


Figure 30. Aquaculture and capture fish production under scenario IV 2010-30. Million tonnes

7.1.5 Scenario V: Climate change

Global climate change policy has been mostly driven by the activities of the industrialised countries, but the most severe consequences are being felt by developing countries as most of them are located in regions already subject to climate extremes (Conway, 2012, p. 286).

Predicting the long-term consequences of climate change is difficult. Cheung et al. (2009) concluded that climate change might lead to a large-scale redistribution of global catch potential, with an average increase of 30-70 percent in high-latitude regions and a drop of up to 40 percent in the tropics. In addition, in the last few years the maximum catch potential has been declining considerably in the southward margins of semi-enclosed seas (a gulf, basin or sea surrounded by two or more coastal states) while increasing in the poleward tips of continental shelf margins.

Climate change and climate variability impacts have already increased uncertainty in the supply of fish from capture fisheries and aquaculture. The priorities and focus of countries with respect to mitigating climate effects, as well as increasing their resilience to these effects, vary according to the number of issues that might affect them. An assessment of risks faced by, and the vulnerability of, an individual region's fisheries and aquaculture resources is necessary in order to establish proper management techniques. Local programmes for climate change adaptation need to be fully integrated within the United Nations Framework Convention on Climate Change.

Possible impacts of climate change on fisheries and aquaculture have been analysed in a recent report by the FAO (Barange et al., 2018). It may, however, be suggested that in many ways the report poses more questions than answers so that the Climate change scenario to be analysed is simply one out of numerous possibilities.

According to the FAO report, ocean capacity to produce fish will diminish in practically all scenarios, except for the one with the most modest CO2 growth rate. Primary production can hardly be projected with reasonable degrees of certainty, particularly in areas with important upwelling in the Pacific and Atlantic, and therefore, future capture fish production of many important species is uncertain. In general, we may expect some warm water species to move to colder areas and perhaps a decline in cold water species. However, in terms of aggregate fish supply, it is uncertain what the net effect will be.

Marine fish displacement due to environmental changes such as water temperatures, oxygen, primary production, changes in ocean currents and the like are also envisaged, but again, are difficult to predict. Changes in pH in oceanic environments will become more noticeable, and will have some negative effects, particularly on molluscs, but this too is difficult to estimate with any reasonable accuracy. Ocean acidification may notably reduce the overall production of a number of commercially important mollusc species. It is important to see if international efforts can mitigate (or change) some of these trends.

Sea level rises will affect both coastal fishermen and aquaculture production. More competition on fresh water resources, alternative uses, environmental degradation and the like, should also negatively affect production prospects, but again, to an unknown extent.

Moreover, it is likely that local small-scale capture fisheries and aquaculture production will be affected, and social problems in coastal communities will need governmental intervention in most countries.

On the other hand, in general terms, potential capture fishery decline due to climate change may turn into an opportunity for aquaculture, even though aquaculture may also be negatively impacted by climate change. Here, technological developments in farmed production should make a difference. Technological improvements related to open ocean and recirculation production systems will likely open more opportunities for medium to large scale enterprises, rather than for small scale producers.

Acidification of the oceans, changes in water temperatures both inland and in the marine environment, pollution and social conflicts will affect the future deployment of the aquaculture industry, probably limiting production in fresh water, and moving coastal aquaculture farther offshore. In as far as these issues are adequately addressed by institutions such as the FAO, technological development should help to mitigate some of the potential decreases in coastal and freshwater environments. Nevertheless, there could be a period with reduced production lasting several years. In the long run, the likelihood is that marine aquaculture will increase its importance in total farmed production, while the degree of the importance and the rate of increase significantly varies according to the species and areas. Another variable of potential importance is increased storminess. Some sites may prove no longer sufficiently sheltered or require more robust and expensive systems, affecting profitability.

Disease is another issue to be aware of. The incidence and severity of disease are both expected to increase in overall terms, although it is difficult to make any estimates of likely impacts.

If changes are drastic or rapid so that species cannot adapt, or this becomes too costly, the situation may be different. This may imply that production becomes too costly because: a) their growth rates are lower under the new conditions, b) the quality of the fish is reduced (i.e., lower price), or c) the technological costs are too high (e.g. to cool the water), etc. This may lead to

changes in the traditional species farmed by a country which in turn will produce other species that will become more efficient to cultivate in the new environment. This in turn will depend on the introduction of policies and regulations to aim at controlling climate change impacts of production technologies.

When it comes to aquaculture, vulnerability and adaptation options are studied in the FAO report. Vulnerability of aquaculture (V) is expressed as a function of exposure (E) to climate change and sensitivity (S) to climate change (f(E, S)), while better adaptive capacity (AC) can mitigate the negative effects of exposure and sensitivity. This approach is applied to evaluate vulnerability in freshwater, brackish water and marine aquaculture for a number of countries. This will be the point of departure for our analysis of the consequences of climate change for aquaculture.

Initial scenarios on impacts of climate change on fisheries and aquaculture were developed primarily using the climate change scales reported in Barange et. al. (2018). These scales were used to compute shifts in seafood supply from the three sources, i.e., marine capture, inland capture and aquaculture. Climate impacts are modelled as percentage change in supply against the baseline level for every year, where the baseline is represented by scenario I. In the absence of data for a country/region, a suitable proxy region/country was chosen; for example, for countries other than Australia and New Zealand in Oceania, data on Indonesia were used as approximations of marine capture fisheries production. The shift in supply is assumed to be gradual over the 2017 to 2030 period.

The following general assumptions have been made:

1. For marine fisheries, countries/regions in higher latitudes and in the Southern Ocean are projected to witness increased catch (or to show lower levels of adverse impact). Therefore, countries such as Canada, Russia, Norway and Chile would see larger catch/production over time. Tropical countries would in general witness decreased catch. Major underlying causes for the changes in marine fisheries productivity are: change in plankton productivity; direct effect of warming on fish physiology and loss of habitat.
2. For inland capture fisheries, it is assumed that the majority of countries would face declining production due to factors such as anthropogenic stress, changes in precipitation, changes in air/water temperatures, flooding etc.
3. For aquaculture, all species farmed in a given country are assumed to be impacted to the same degree. Adverse impact of climate change is assumed to lead to reduced production efficiency and other factors causing reduced production efficiency. The reduction is assumed to be partly due to farms going out of business due to bankruptcy. This in turn is assumed to have implications for factor demand, particularly of fishmeal and fish oil.
4. The world economy in general, in particular income, will not vary because of the changing fisheries and aquaculture productions. This is because major industries (other than fisheries, aquaculture and agriculture) in the world in general are not affected as a total and the underlying assumptions regarding demand for fisheries and aquaculture products are not subject to modifications.

Assumptions for different countries and regions are presented in the Appendix (Table A7.3).

Production over the 2015-30 for scenario V is given in Figure 31. Capture production declines from 92 million tonnes in 2016 to 85.5 million tonnes in 2030, a decline of 7.1 percent. Aquaculture production, on the other hand, increases from 78.8 million tonnes in 2016 to 96.72

million tonnes in 2030, an increase of 22.7 percent. Total fish production increases from 170.8 million tonnes in 2016 to 182.2 million tonnes in 2030, an increase of only 6.7 percent.

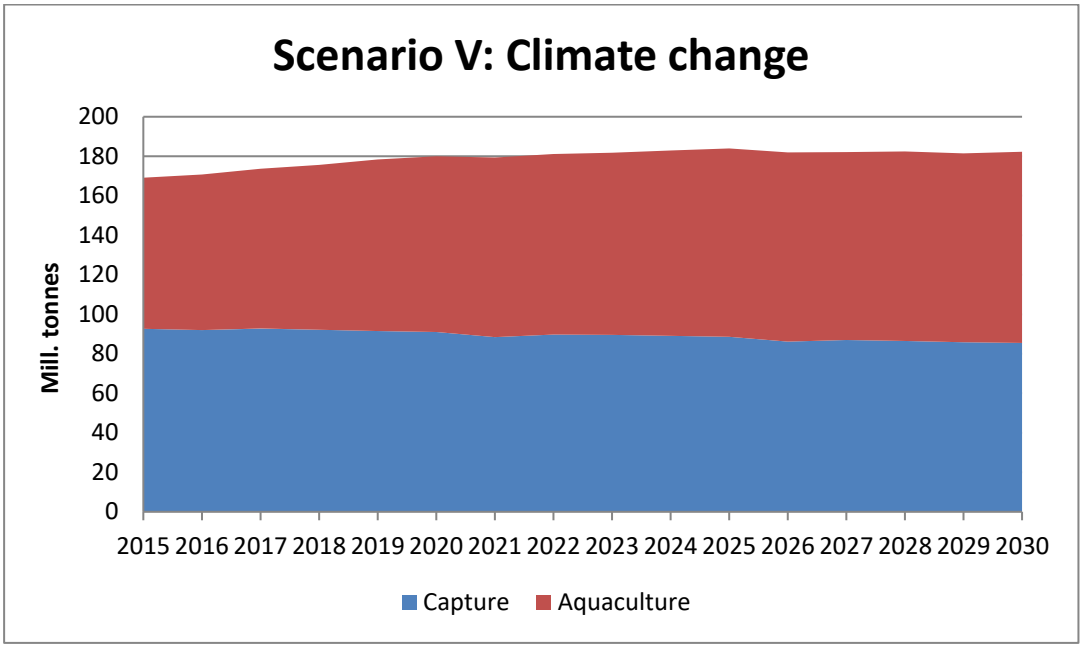


Figure 31. Capture and aquaculture production 2015-30 - Scenario V: Climate change. Million tonnes

7.1.6 Regional composition

Next, we will look more closely at the regional composition of forecasted production. Table 32 gives a regional breakdown of aquaculture production in 2016 (actual) and 2030 (projected), under the five scenarios considered. In scenario I, world aquaculture production increases 56.1 percent to 123 million tonnes by 2030, in scenario II production increases 39.3 percent from 2016 to 109.8 million tonnes in 2030, in the China reduced growth scenario III production increases by 34.4 percent to 105.9 million tonnes by 2030, in scenario IV production in 2030 reaches 134 million tonnes, an increase of 70.0 percent whereas in scenario V, 2030 production is estimated at 96.7 million tonnes, a 22.7 percent increase over 2016. In other words, the climate change scenario involves the lowest increase in production of all alternatives considered.

Asia is dominant when it comes to aquaculture production with a share of 89.4 percent of the total in 2016. In the baseline scenario I, 4 percent annual growth, the share of Asia is reduced by 0.4 percentage points by 2030, with minor increases in the shares of Europe and the Americas. In scenario II, there is a minor increase in the share of Asia by 2030 and slight decreases in the shares of Europe, the Americas and Oceania. The share of Africa increases slightly in 2030 under both scenarios, while in scenario IV it is virtually unchanged.

In the China reduced growth scenario III, the share of Asia in world aquaculture production is reduced to 87.5 percent. For the other continents production in 2030 is very similar to that of scenario I. In scenarios I, II and III, average annual growth in aquaculture production in Asia is 3.03 percent, 2.45 percent and 2.05 percent, respectively.

In scenario IV, Asia represents 88.2 percent of the total in 2030, slightly less than in the baseline. The shares of Europe, America and Africa are 4.3, 4.8 and 2.5 percent, respectively.

In Scenario V, the share of Asia in 2030 is reduced to 87.2 percent. This is because the increase in Asia over the 2015-30 period (23.3 percent) is lower than the overall increase in production (26.3 percent). On the other hand, climate change has a positive impact in the Oceania, the Americas and Europe.

Table 32. 2016 and 2030 aquaculture production for scenarios I-V. '000 tonnes

Region	2016 prod. (percent)	2030 prod. Sc. I baseline: 4% annual increase	Increase 2016-30 percent	2030 prod. Sc. II: Ext. OECD-FAO Outlook	Increase 2016-30 percent	2030 prod. Sc. III: China scenario	Increase 2016-30 percent	2030 prod. Sc. IV: Optimistic	Increase 2016-30 percent	2030 prod. Sc. V: Climate change	Change 2016-30 percent
World	78 826	123 013	56.1	109 833	39.3	105 937	34.4	134 001	70.0	96 723	22.7
Europe	3 007 (3.8)	4 954	64.7	3 980	32.4	4 613	53.4	5 742	91.0	4 516	50.2
Americas	3 310 (4.2)	5 542	67.4	4 637	40.1	5 320	60.7	6 422	94.0	5 080	53.5
Asia	70 489 (89.4)	109 233	55.0	98 229	39.4	92 715 (87.5%)	31.5	118 176	66.2	84 345	19.7
Africa	1 813 (2.3)	2 980	64.4	2 728	50.5	2 978	64.3	3 303	82.2	2 471	36.3
Oceania	189 (0.2)	296	56.6	251	32.8	303	60.3	350	85.2	303	60.3
Orphands	8 (-)	8 (-)		8 (-)		8 (-)		8 (-)		8 (-)	

Expectations regarding Africa point to significant growth in aquaculture in the coming years. However, these results contradict that: although the increases for scenarios I-IV are fairly substantial compared to 2016, both in absolute and relative terms, at the world level Africa will remain a minor producer. Changes in regulations, infrastructure and technology updates are required for aquaculture in Africa to expand more. On the other hand, the influence of climate change is expected to hit the low latitudes most both in terms of changes in temperature, storminess, etc. and lack of resilience. This will negatively affect Africa. For Europe, there are no expectations of significant growth in future aquaculture production. It is most likely that new species will grow at the expense of already existing ones.

Asia, in general, may reach a maximum point, if it is not yet reached with the current technologies. However, if our expectations in scenario III are correct, we may expect some increase in the long term, due to the introduction of new technology and management improvements. On the other hand, note that depending on the likelihood that other countries will replace the gap left by China's contraction, the share may decrease, remain stable or even grow in the long term.

While world capture production is essentially the same in scenarios I, II and IV but with some decline in scenario III, climate change will have an impact on capture fishery production as shown in Figure 31: total production is forecasted to decline from 92.0 million tonnes in 2016 to 85.5 million tonnes in 2030, a decrease of 7.1 percent. Table 33 illustrates the regional differences in this regard. While all regions show declining catches, except Europe, where there is a slight increase and the Americas, where production is unchanged, Asia is most affected by climate change and will observe a reduction in catches of about 6 million tonnes or 11.8 percent. Asia is also losing "market share", as its share in total production declines from 55.2 percent in

2016 to 52.4 percent in 2030. On the other hand, the "market shares" of Europe and the Americas increase somewhat, whereas those of Africa and Oceania remain unchanged.

Table 33. 2016 and 2030 capture fishery production scenario V Climate change. '000 tonnes

Region	2016 Production (percent)	2030 Production (percent)	Increase 2016-30 Percent
World	92 016	85 490	-7.1
Europe	13 989 (15.2)	14 257 (16.7)	1.9
Americas	16 724 (18.2)	16 717 (19.6)	0.04
Asia	50 794 (55.2)	44 812 (52.4)	-11.8
Africa	8 845 (9.6)	8 109 (9.5)	-8.3
Oceania	1 371 (1.5%)	1 295 (1.5)	-5.5
Orphans	294 (0.3)	300 (0.4)	2.0

7.2 Fish prices

The model is also used to generate future prices for the different scenarios, in particular, the prices of traded fish products, capture fish and aquaculture fish. The *price of traded fish products* is the price of all traded products coming from capture and aquaculture. It should be noted that this price is influenced by the cost of the secondary sector (processing) since products traded are not all live or whole: much trade is done after a first transformation. For this reason, the price of traded products is always higher than the *prices of capture and aquaculture fish,* which are primary sector or first-hand prices, i.e., prices paid to fishermen and fish farmers. Note that the price of capture fish used for reduction is excluded from the price estimations.

The FAO FISH model that incorporates supply and demand side variables is used to solve for the equilibrium prices. It is the traded product price which acts as the world market clearing variable in the model of the aggregate fish market. It should also be noted that, unless otherwise stated, the prices presented are *nominal* prices, which means they will need to be deflated in order to calculate real prices[40]. The prices can be considered *quantitative future price indices,* as they are aggregated prices for traded products as well as for capture and aquaculture fish.

The fish model that simulates future price developments deals with the fact that consumer and producer prices are not the same and they not necessarily fluctuate with the same amplitude because consumer prices include, in addition to the cost of raw materials, also the costs of other inputs including labour, machinery and energy. The link between the two prices thus depends on the share of other input costs in total costs. Empirical studies indicate that the cost share of other inputs is higher in developed than in developing countries, an indication of a larger degree of processing as well as higher input costs, for example, for labour. In a price transmission equation those shares determine the elasticity between the producer and the consumer price. The size of the elasticities affects the impact on the producer price of a shock such as an

[40] In the supply functions, nominal prices are divided by a deflator to transform them to real prices. This is because supply depends on real, not nominal, prices.

increase in production. The higher the elasticity, the smaller the decline required in the product price to allow the consumption of the added production in the case of a positive increase in output. In the initial model for the OECD-FAO Outlook (2017), the elasticities were on average 0.27 for developed countries and 0.4 for developing countries, and these are the assumptions maintained for scenario II. However, based on initial simulations of other scenarios, the model showed severe producer price declines following an increase in aquaculture production. As it was felt that these declines were too severe, it was decided to increase these elasticities. Accordingly, they were increased to 0.55 and 0.8 for developed and developing countries respectively, in scenarios I and III-V.

In the case of the world capture price, this is determined by three explanatory variables. The most important in this regard is the traded product price, which acts as the world market clearing variable in the model of the aggregate fish market: the higher the clearing price, the higher the capture price. The second one is the share of total production that comes from capture; the lower it is, the higher is the price of capture given the clearing price. The third one is the price of crude oil as an indicator of the cost of fishing: a higher cost of fuel will reduce fishing effort in unregulated fisheries and thus reduce catches leading to an increase in price (the impact of this variable is small given the large number of regulated fisheries around the world).

The world aquaculture price is simply a ratio of the value divided by production where the value is the product of the aquaculture price and production in each country. When the share of aquaculture production of a given country increases, the price of aquaculture falls relative to the domestic product traded price of that country. Again, like for the capture price, the most important variable in this equation is the market clearing fish price.

As noted above, prices presented are all in nominal US dollars. The (anticipated) US GDP deflator up to 2030 is given in Appendix, Table 7.A2 and will be used to calculate real prices. Over the 2016-30 period, the US GDP deflator is forecast to increase by 34.4 percent.

7.2.1 Fish price traded products

Figure 32 gives nominal world prices for traded fish products from 2010 to 2030, with 2016 the last actual observation at USD 2,860.60/tonne. The two "growth" scenarios, I and IV, both show declining prices over time, to USD 2,549.30/tonne – a 10.9 percent decline – in 2030 for scenario I, while the scenario IV price declines 24.3 percent to USD 2,166.00/tonne. The extension of the OECD-FAO scenario shows a modest price increase (9.5 percent), the China scenario a larger price increase (28.1 percent), while the climate change scenario sees a price increase of 52.3 percent to USD 4,357/tonne.

Table 3 gives the 2030 nominal price as well as the percentage change over the period 2016-30. When considering these changes, it must be borne in mind that the inflation for this period is assumed to be 34.4 percent. In real terms, scenario V implies an increase in real price of almost 18 percent. Scenario III implies a small reduction in real price, while the others show larger reductions, in particular scenario IV, which involves a reduction in real price of more than 50 percent.

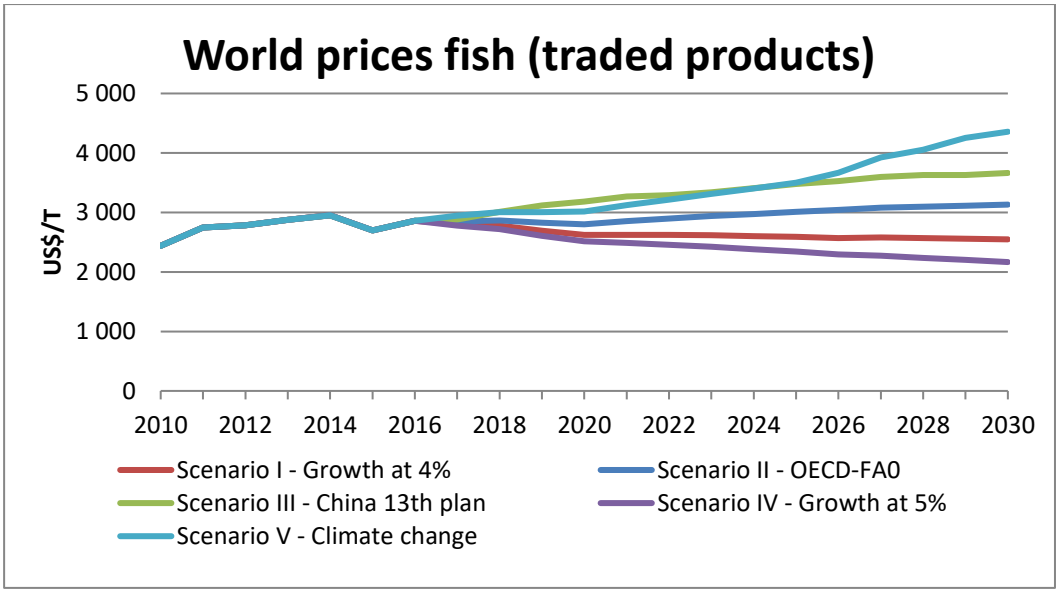


Figure 32. Nominal world prices fish (traded products) scenario I-V USD/tonne 2010-30

Table 34. Nominal world prices traded products 2030 (USD) and price change 2016-30 (percent)[a)]

Scenario	2030 nominal price	Change 2016-30 nominal price
I	2.549.3	-10.9%
II	3.132.0	9.5%
III	3.663.8	28.1%
IV	2,166.0	-24.3%
V	4,357.0	52.3%

a) The 2016 price was USD 2860.6/tonne.

7.2.2 Capture and aquaculture prices

Price forecasts (nominal) for the baseline scenario I with 4 percent annual increase are given in Figure 33. First, it can be observed that the price index for aquaculture is higher than that for capture fish. This is because of the species composition, that is, more of higher valued species in aquaculture[41]. It is, however, also influenced by which species enter into trade. Both prices show a declining trend over time. Aquaculture prices show a decline from USD 2,050.7/tonne in 2016 to US 1,906/tonne in 2030, a reduction of 7.1 percent. Capture prices remain virtually unchanged with an increase from USD 1,575/tonne in 2016 to USD 1,580/tonne in 2030. However, it must be noted that the expected inflation in the period 2016-30 is 34.4 percent, so that there is a reduction in real prices for both aquaculture and capture. It can also be seen that the price dispersion diminishes over time, largely due to the fact that the share of aquaculture in total production is increasing.

[41] It can be noted that, even for the same species, in some instances farmed product is more expensive than capture. See e.g. Norman-Lopez and Asche (2008) and Rodriguez et al. (2013).

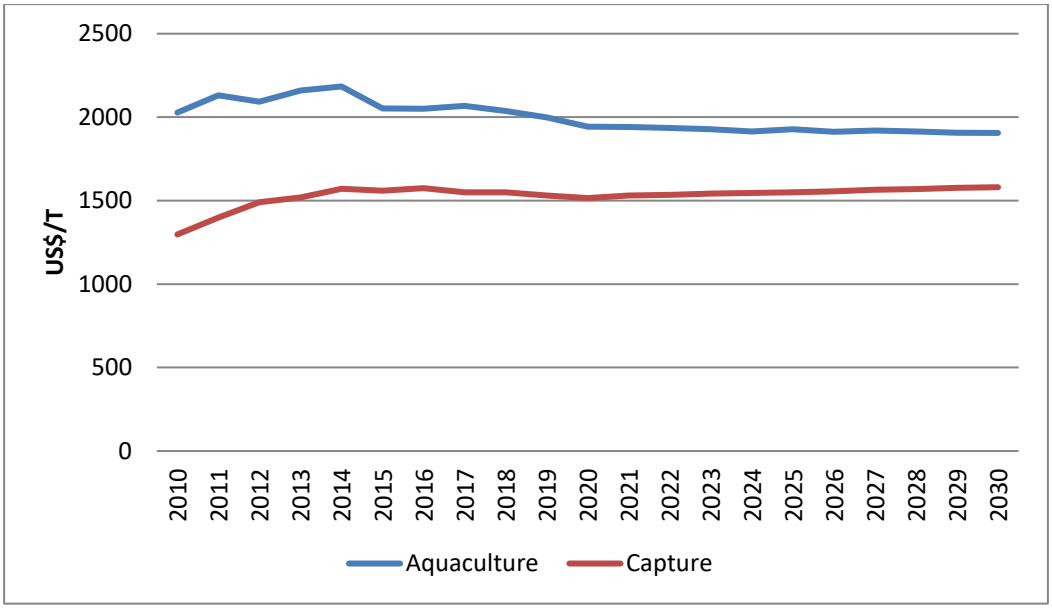


Figure 33. Average annual nominal prices aquaculture and capture 2010-30 for scenario I (4 percent annual aquaculture growth scenario). USD/tonne

The price reduction for farmed fish is so substantial that one might think that many producers will go out of business (as will be seen also for some other scenarios). However, in the scenario imposed on the model it is assumed that productivity improvements will be sufficiently strong to enable the increase in production despite the reduction in price that the increased output will generate.

When we look at development in prices over time, the price dispersion diminishes - lower absolute and relative differences in prices between aquaculture and farmed species. Because aquaculture production is increasing (and in particular, more so than for capture fisheries), aquaculture product prices will decrease more than those of capture fisheries[42]. Thus, partial market integration between wild fisheries and aquaculture products may be assumed. Changes in the composition of aquaculture production may lead to this decrease in the price differentials as well since lower value species like tilapia are gaining market share.

Price series (nominal) for scenario II, extension of the OECD-FAO Outlook, are given in Figure 34. Both price indices show increasing trends over time; however, while the price differential decreased over time for scenario I, this is much less so for scenario II. For farmed fish, the price increases from USD 2,050.7/tonne in 2016 to USD 2,380/tonne in 2030, an increase of 16.1 percent over the period. For capture fish, the price increases from USD 1,575/tonne in 2016 to USD 1,793/tonne in 2030, a 13.9 percent increase over the period. In real terms, both prices are falling, like all the agricultural product prices included in the OECD-FAO Agricultural Outlook. Given the growing importance of aquaculture in the world fish market it is not surprising to have a closer link between the fishery and the agriculture markets because supply is more and more affected by the price of feeds generated in agriculture.

[42] Ideally the fish market would be more disaggregated between capture and aquaculture. If so, capture and aquaculture would be substitutes in the demand functions, probably with significant cross price elasticities. Unfortunately, the trade data does not allow a split between capture and aquaculture so that modelling must be at the aggregate level.

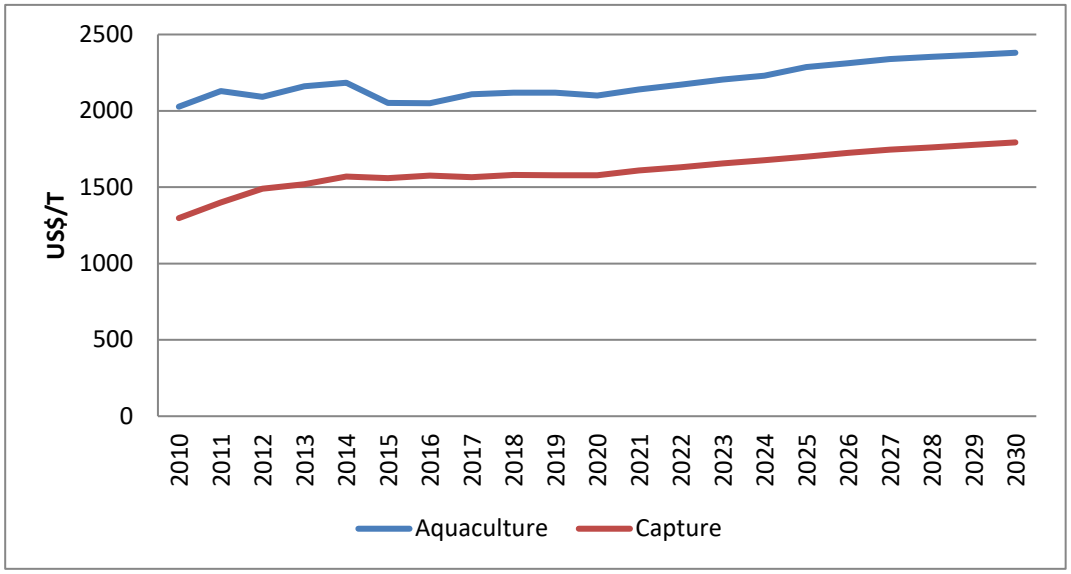


Figure 34. Average annual nominal prices aquaculture and capture 2010-30 for scenario II ext. of OECD-FAO (2017) Outlook. USD/tonne

As for scenario III (Figure 35), the nominal price of capture fish rises from USD 1,575/tonne in 2016 to USD 1,991/tonne in 2030, a rise of 26.4 percent. For aquaculture, the nominal price increases from USD 2,050.7/tonne in 2016 to USD 2,741/tonne in 2030, a surge of 33.7 percent.

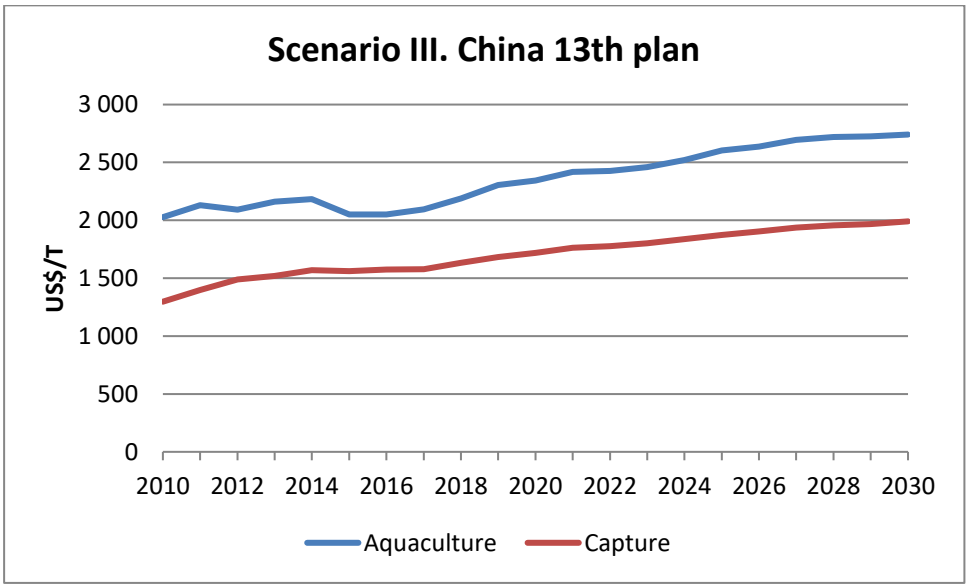


Figure 35. Average annual nominal prices aquaculture and capture 2010-30 for scenario III China 13th plan. USD/tonne

In scenario IV (Figure 36), the nominal price of capture fish declines from USD 1,575/tonne in 2016 to USD 1,428.8/tonne in 2030, a reduction of 9.3 percent. For aquaculture, the nominal price declines from USD 2,050.7/tonne in 2016 to USD 1,608/tonne in 2030, a decline of 21.6 percent.

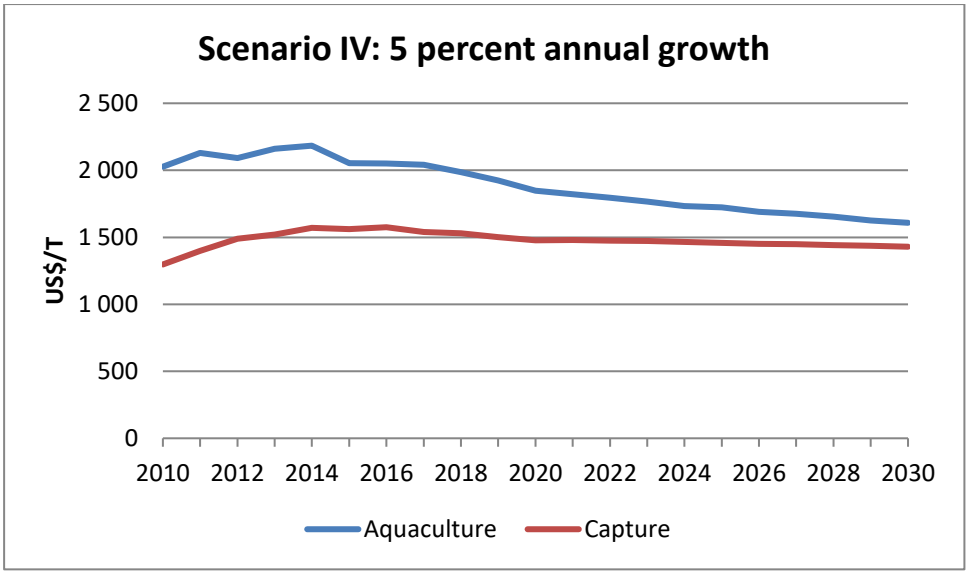


Figure 36. Average annual nominal prices aquaculture and capture 2010-30 for scenario III China 13th plan. USD/tonne

Price developments (nominal) over time for scenario V are presented in Figure 37. For capture fish, the price rises from USD 1,575/tonne in 2016 to USD 2,225.6/tonne in 2030, a rise of 41.3 percent. For aquaculture, the price increases from USD 2,050.7/tonne in 2016 to USD 3,400.7/tonne in 2030, a surge of 65.8 percent.

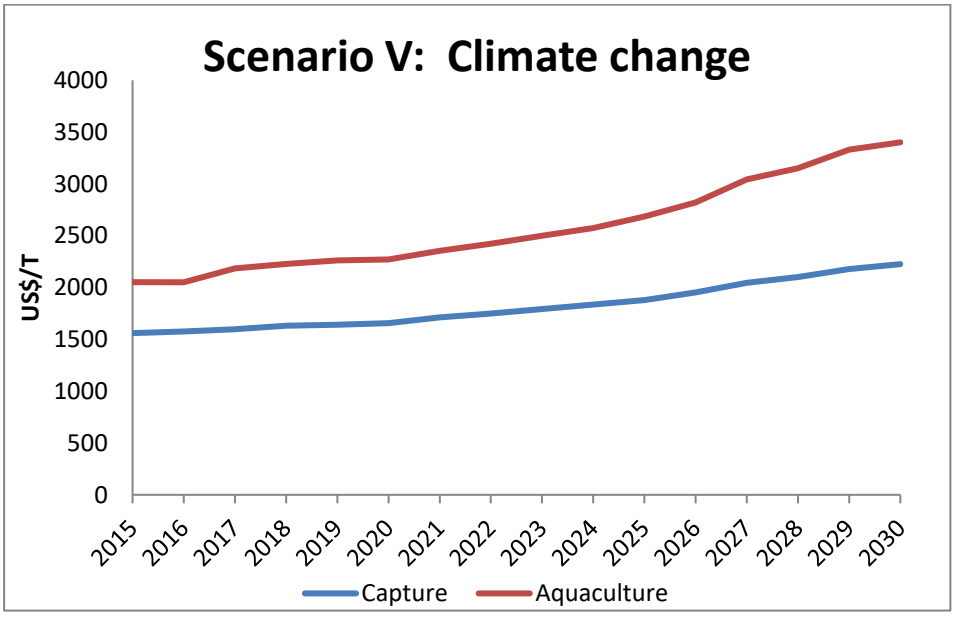


Figure 37. Average annual nominal prices aquaculture and capture 2010-30 for scenario V Climate change. USD/tonne

Figure 38 presents nominal annual prices for capture fish for all scenarios, while Table 34 gives nominal price for 2030 and percentage change in price over the 2016-30 period. It is noticeable that there is a fairly wide dispersion in nominal prices in 2030. The extremes are given by scenarios V (USD 3,400.7/tonne) and IV (USD 1,429.00/tonne).

In the baseline (scenario I), capture prices increase from USD 1,575/tonne in 2016 to USD 1,580 in 2030, an increase of 0.3 percent. In the extension of the OECD-FAO Outlook case, prices increase to USD 1,793/tonne in 2030, an increase of 13.9 percent. In scenario III (China scenario), the price increases to USD 1,991/tonne in 2030, 26.4 percent higher than in 2016. In scenario IV, the optimistic case, the price declines to USD 1,429/tonne, a reduction of 9.3 percent. In scenario V, climate change, the 2030 price ends up at USD 2,225.6/tonne, a 41.3 percent increase over 2015.

When it is borne in mind that the inflation for the period 2016-30 is assumed to be 34.4 percent, it is noticeable that only scenario V implies an increase in real price of slightly less than 7 percent. The other scenarios give decreases in real price varying from 8 percent for scenario III to 44 percent for scenario IV.

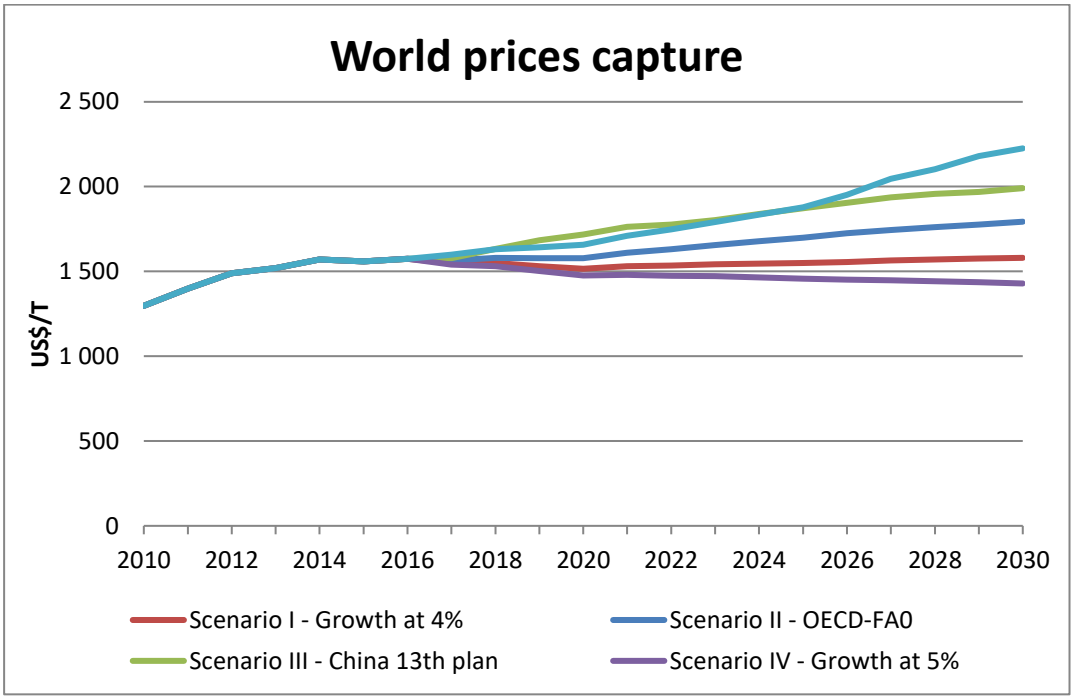


Figure 38. Average annual nominal world prices capture fish scenarios I-V, 2010-30. USD/tonne

Table 34. Nominal world capture price 2030 (USD) and change 2016-30 (percent). Capture: 2016 price USD 1,575/tonne

Scenario	2030 price	Percent increase 2016-30
I	1580.2	0.3
II	1793.3	13.9
III	1991.0	26.4
IV	1428.8	-9.3
V	2,225.6	41.3

For aquaculture products (Figure 39 and Table 35), there is again wide dispersion in 2030 nominal prices between scenario V (USD 3,400.7/tonne) and IV (USD 1,608.2/tonne).

In scenario I, the price decreases from USD 2,050.7/tonne in 2016 to USD 1,906/tonne in 2030, a reduction of 7.1 percent. In scenario II, extension of OECD-FAO (2017), however, the price increases to USD 2,380/tonne in 2030, an increase of 16.1 percent, while in scenario III the increase in the same period is 33.7 percent to USD 2,741/tonne. In scenario IV, the price declines to USD 1,608/tonne, a reduction of 21.6 percent. For scenario V, there is a 65.8 percent price increase from 2016-30, with the price ending up at USD 3,400.7/tonne.

It is again noted that the USA GDP deflator increases by 34.4 percent over that period. Thus, when it comes to the development in the real price, scenario V would imply an increase of more than 30 percent over the 2016-30 period while for scenario III the real price would be more or less unchanged. The three other scenarios imply a reduction in real price, particularly so for scenario V with a reduction of more than 55 percent.

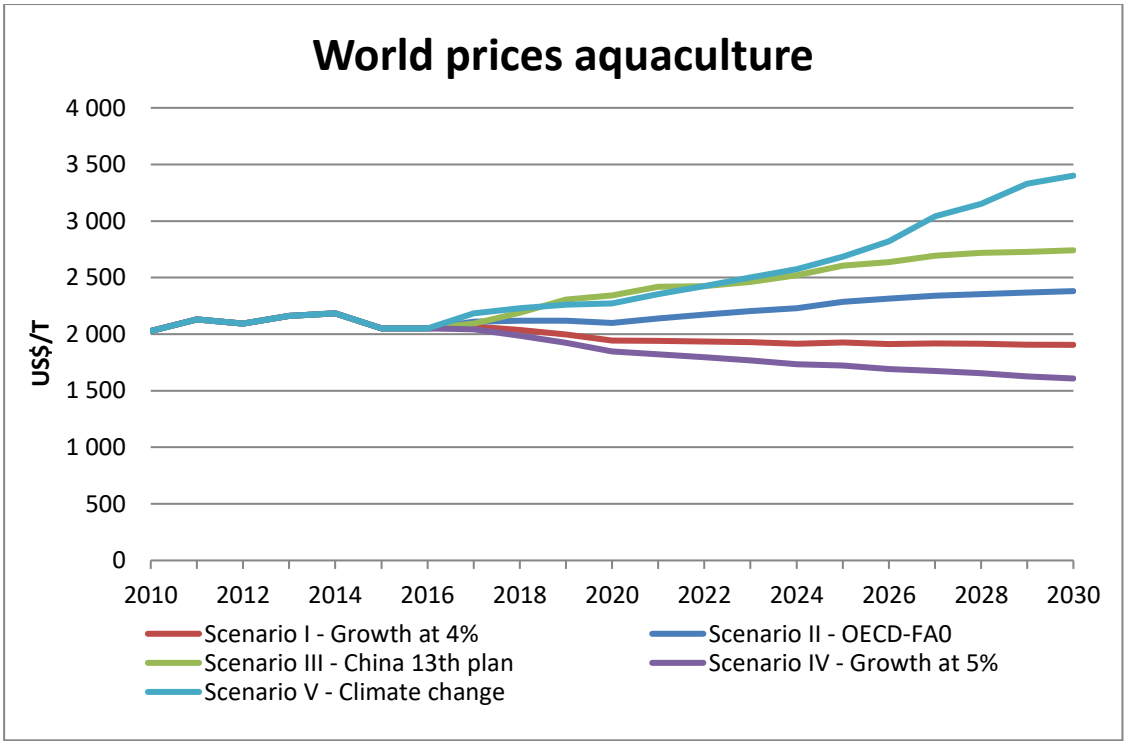


Figure 39. Average annual nominal world prices aquaculture scenarios I-V, 2010-30. USD/tonne

Table 35. Nominal world aquaculture price 2030 (USD) and change 2016-30 (percent). Aquaculture: 2016 price USD 2,050.7/tonne

Scenario	2030 price	Percent increase 2016-30
I	1905.5	-7.1
II	2380.3	16.1
III	2741.0	33.7
IV	1608.2	-21.6
V	3,400.7	65.8

7.2.3 Summary – fish prices

It is important to notice the development in prices over time. Scenario V climate change and scenario IV 5 percent annual growth appear to be the "extremes". With climate change there is an increase in the real capture price of about 7 percent while it is more than 30 percent for aquaculture. With 5 percent annual growth, on the other hand, the real price of capture fish declines by more than 40 percent and that of aquaculture more than 50 percent. The intermediate scenarios are in between, with the China scenario showing constant real price for aquaculture and a smaller reduction in the real price of capture fish.

The substantial price declines for scenario IV may appear unrealistic. Nevertheless, it must be borne in mind that it is assumed that aquaculture will remain profitable as a consequence of efficiency improvements.

It is important to note that what happens in China will have a great impact on markets for both capture and farmed fish. As capture production in other regions of the world are roughly similar in scenarios I, III and IV, much of this impact has to do with the net trade surplus of China. The projected impacts on price in scenario III may happen if, and only if, other countries do not replace the supply gap left by China, which will happen by only about 50 percent in this model. Past experience indicates that as soon as a gap opens up in a market, a new supplier will fill it and produce at a competitive price. Thus, the consequences indicated are likely to be on the high side.

Climate change is also shown to have a potentially very important impact on both capture and aquaculture markets. In this scenario, aquaculture expansion is limited while there is also a reduction in capture fish production. The lower aquaculture production numbers compared to the other scenarios were *imposed* on the model, no matter how high the price would be. For example, for a country showing no change in aquaculture production compared to the other scenarios, climate change is still assumed to have a negative effect since that country would otherwise have produced more under these higher prices. In this particular case the negative effect of climate change is assumed to be exactly equal to the positive effect generated by the higher price. It must nevertheless be pointed out that only one hypothetical scenario has been considered.

Overall, the results presented here confirm those of Lem, Bjørndal and Lappo (2014), namely, future prices of capture as well as farmed fish will be driven by the development in aquaculture production. Several recent studies have shown that nominal prices of many freshwater aquaculture species in Asia have remained fairly constant even with increasing demand (see, for example, Belton et al., 2017; Belton et al., 2018).

7.3 Fishmeal and fish oil production and price

Annual world fishmeal and fish oil production up to 2030 is presented in Figures 40 and 41, respectively. El Niños events are modelled to occur in 2021 and 2026. Except for El Niño years, world production of fishmeal and fish oil is expected to remain fairly stable in all scenarios. All five scenarios show very similar patterns with regard to yearly changes and growth rates.

The highest production in 2030 is 5,131 million tonnes in scenario IV, the lowest is 4,553 million tonnes in scenario V; other scenarios are fairly close to IV.

Alternative sources of protein and lipids are developing fast. Nutreco, for example, now markets a completely fishmeal and fish oil free diet for salmon[43]. Also, over time a higher proportion of output will come from fish processing co-products and novel sources such as marine algae although digestibility may diminish when using that type of meal[44].

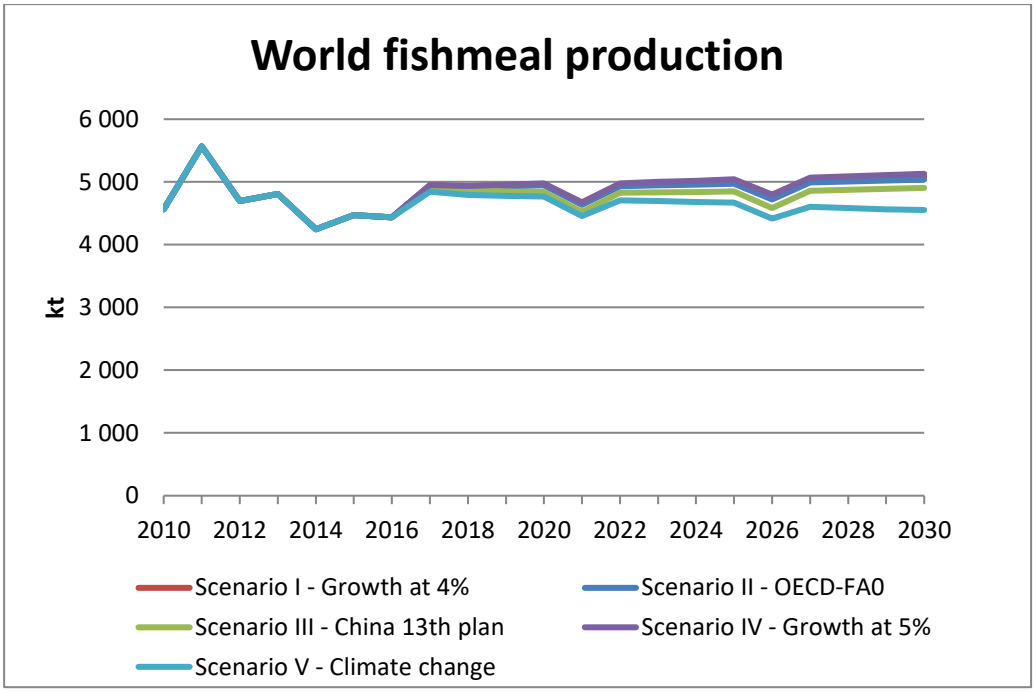


Figure 40. Annual world fishmeal production 2010-30 for scenarios I-V. '000 tonnes

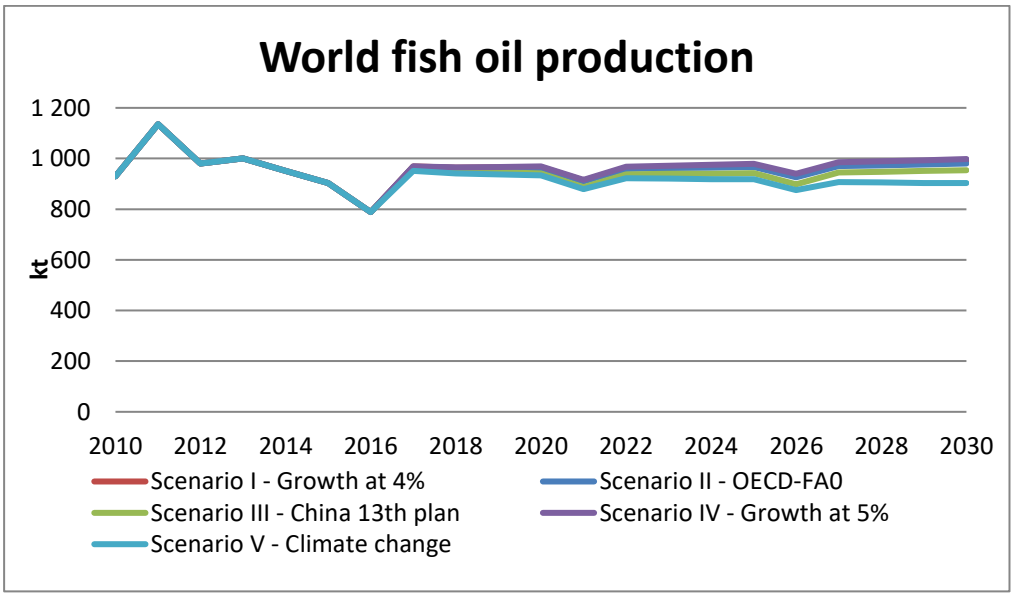


Figure 41. Annual world fish oil production 2010-30 for scenarios I-V. '000 tonnes

[43] The EU discard ban may also have an impact on supplies for fishmeal production.
[44] In 2016, fishmeal production from fish processing co-products amounted to 1.192 million tonnes. In the OECD-FAO scenario it is expected to increase to 1.49 million tonnes, so that the share in total fishmeal production increases from 24.1 to 29.6 percent in 2030. There are only slight differences between the various scenarios.

Developments in fishmeal and fish oil prices under the four scenarios are presented in Figure 42 and 43, respectively. Price trends are the same in all scenarios, with peaks in the El Niño years 2021 and 2026. The 2016 fishmeal price[45] was USD 1,501/tonne. Under scenario I, the price increases to USD 1,601 in 2030 (6.7 percent), in scenario II, the extended OECD-FAO case, it increases to USD 1,636 (9 percent) in scenario III to USD 1,732 (15.4 percent), in scenario IV it ends up at USD 1,590, 5.9 percent higher than the 2016 level, while in scenario V the 2030 price is USD 2080.6/tonnes, an increase of 38.6 percent compared to 2016. With a price increase of 34.4 percent, the real price increases by about 4 percent in scenario V while it declines in all other scenarios.

With regard to the fishmeal prices, it should also be noted that a higher proportion of output will come from fish processing co-products. This will result in a product with higher ash content and eventually lower protein and digestibility. Both factors call for a differentiated price regarding fish meal produced from whole fish, however, in the model fishmeal is treated as a homogeneous product.

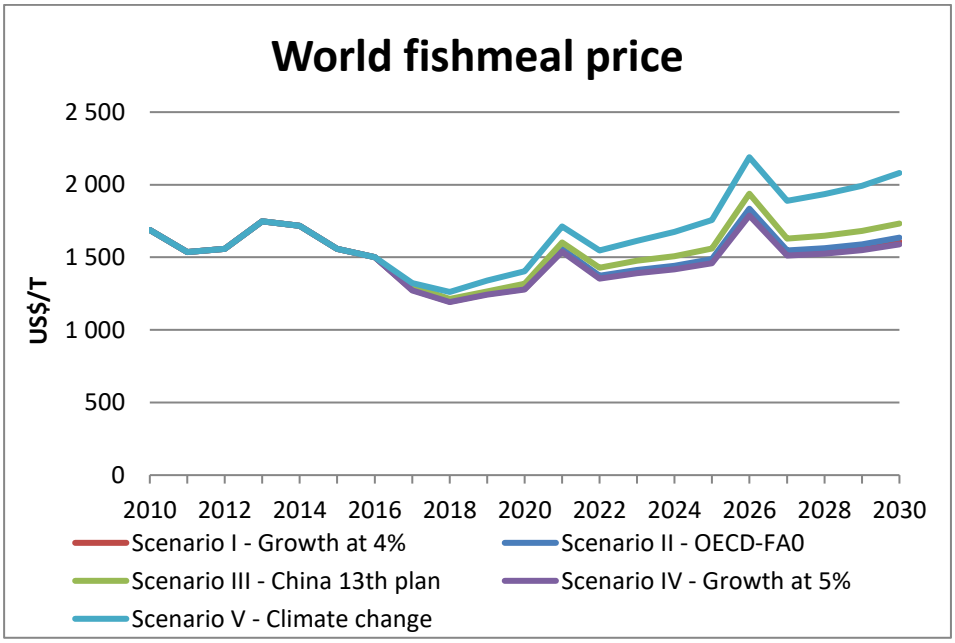


Figure 42. Annual fishmeal price 2010-30 for scenarios I-V. USD/tonne

The lower fish prices in scenarios I and IV, with 4 and 5 percent annual aquaculture growth respectively, compared to the other scenarios, increases the margin for reduction[46], leading to a small increase in reduction and world production of fishmeal and fish oil. In the model, this opportunity cost is directly determined by the price of fish. Since the price of fish falls much more than the price of fishmeal and fish oil, the margin increases, leading to a small increase in reduction and world production of fishmeal and fish oil.

[45] The 2015 fishmeal production was relatively low and the price correspondingly high, which must be considered when these comparisons are made.

[46] This margin is given by ((price of fishmeal*fishmeal yield + fish oil price*fish oil yield)/(opportunity cost of using captured fish)). Thus, if the price of captured fish increases, this margin will decline.

Nevertheless, one may question why fishmeal and fish oil prices are falling slightly and are lower compared to the other scenarios, considering the great increase in world aquaculture production?

In the model, the species using the most fishmeal in their feed ration, such as salmon and shrimp, have the highest supply elasticities. Scenarios I and IV impose equal annual upward shifts of 4 and 5 percent in supply, respectively, due to overall productivity gains in order to reach the 4 and 5 percent average annual growth rates. The imposed shift will not increase production of all these species by the same percentage because of differences in the output price elasticities since the prices in this scenario are changing. The increase in supply reduces world and national prices, which affect differently species specific? supply functions due to the difference in elasticities. In fact, it is even possible that some species in some countries, such as shrimps in China and Thailand, show reduced production in spite of the imposed upward shift in supply.

So basically, the reduction in some of these aquaculture products is sufficient to reduce the overall demand for fishmeal, and since there is a small increase in production due to the large decline in the opportunity cost of using fish for reduction, the model shows a small decline in the price of fishmeal and fish oil[47].

Furthermore, higher incomes globally and increasing consumption of processed and filleted fish products are creating a greater supply of fish processing co-products to be used in fish meal production, which also contributes to higher production of fish meal and oil in this scenario. The reverse argument is also true. With smaller aquaculture production in China, which is dominated by species using small amounts of fishmeal and oil, the increase in world price is transmitted to all other countries, which respond with higher aquaculture production of the species they produce, which typically use more fishmeal and oil than in China[48]. Even though world aquaculture production is smaller in scenario III, the species composition and the adjustment in fishmeal and oil production is sufficient to generate the highest price for these products among all scenarios except climate change.

The 2016 fish oil price was USD 1,700. In scenario I, it ends up at USD 1,936/tonne, a 13.9 percent increase, in scenario II, it increases by 7.8 percent to USD 1,833/tonne, in scenario III, the 2030 price is 2,145/tonne, a 26.2 percent increase over 2016, in scenario IV, the 2030 price is USD 2,016, 18.6 percent higher than in 2015, whereas in scenario V it ends up at USD 2,572.6/tonne, an increase of 51.3 percent. Thus, the real price increases in scenario V, while it declines in all other scenarios.

[47] An interesting question, which can only be analysed with a disaggregated fish market model, is the following: Can an increase in production of aquaculture species using no or very small amounts of fishmeal due to productivity gains sufficiently reduce price and production of species using a large amount of fishmeal to generate an overall decline in fishmeal demand and price? If we believe that the cross-price elasticities are sufficiently strong to force the same price changes (which is certainly not the case) for all aquaculture species, then the answer is yes, according to this scenario.

[48] This may not be the case for South East Asia and other tilapia or catfish producing regions (Africa, Latin America) as these are species that make little use of fish meal and fish oil so that to the degree they replace production in China, the fishmeal and fish oil markets will have little impact.

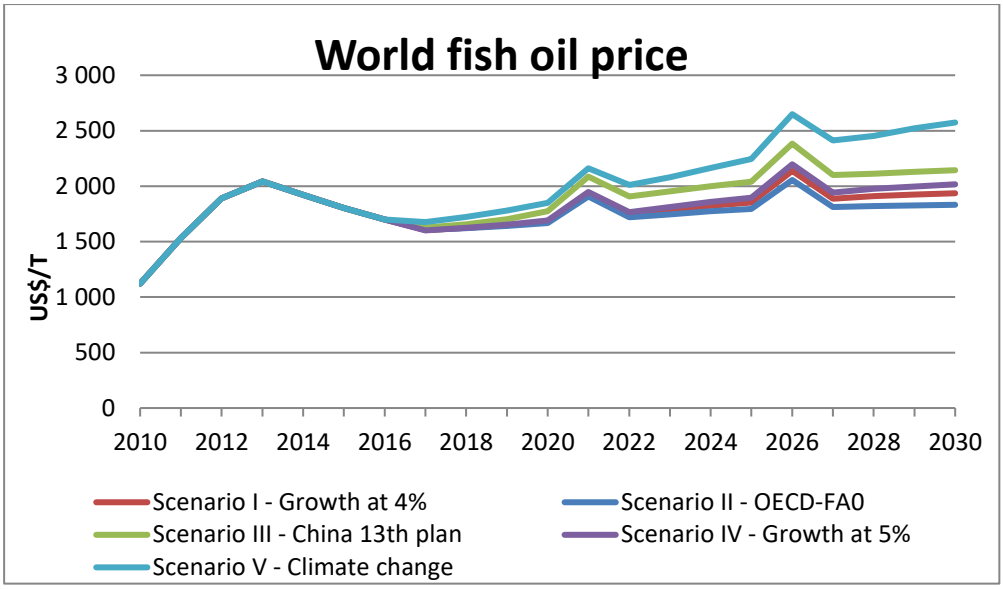


Figure 43. Annual fish oil price 2010-30 for scenarios I-IV. USD/tonne

7.4 Summary and discussion

This analysis has provided interesting and important results with regard to the future contribution of capture fisheries and aquaculture to future food security. A number of scenarios for future growth in aquaculture, with annual growth in the 2016-30 varying between 2.4 percent and 5 percent, have been presented. Moreover, it has been argued that with further developments in R&D and easing of regulations in some countries, an annual growth rate of 4 percent, or possibly even 5 percent, appears realistic.

One surprising result is that, for the optimistic scenario IV, the real price of capture fish declines by more than 40 percent and that of aquaculture by more than 50 percent over the 2016-30 period. As the prices are largely driven by the development in aquaculture, one may ask how this is possible. The scenario imposed on the FAO FISH model assumes there will be enough productivity improvements to allow this production increase to take place as well as aquaculture to remain profitable despite the large reduction in price. This scenario is a good example of the danger of producing extreme shocks to a model that has some imbedded assumptions which may not remain true in these extreme situations. Only about 12 percent of capture production is endogenous in the model with a relatively low supply elasticity estimated over a period with no extended low prices. The other 88 percent are exogenous and assumed to be controlled by binding fishing quotas. The imbedded assumption in the model about that part of capture production is there is no quota under-fill which would clearly be the case in this scenario with much lower prices. With a larger decline in capture production the reduction in the market clearing price would be much less pronounced. Introducing supply functions for that part of capture production with an if-then-else statement to prevent over-quota fishing is an area for future research.

Another area for future research is the discovery of the saturation point for fish consumption of the different countries represented in the model given their level of meat consumption. As highlighted in Chapter 6, world per capita fish consumption has been maintained and has even slightly increased in recent years, despite fairly large population growth. Actual consumption

in 2016 at the world level and for various regions is given in Table 36 with forecasted numbers for 2030.

At the world level, per capita consumption will increase for all scenarios except that related to climate change. Naturally, the increase is largest in scenario IV, with 5 percent annual aquaculture growth, leading to a per capita consumption of 24.78 kg in 2030, an increase of 21 percent over 2016. The climate change scenario, on the other hand, implies a 3.4 percent reduction to 19.85 kg.

Table 36. Fish consumption kg/per capita, actual 2016 and projected 2030 for scenarios I-V

	Actual	Sc. I: Growth 4%	Sc. II: Ext. of OECD-FAO	Sc. III: China	Sc. IV: Growth 5%	Sc. V: Climate change
	2016	2030	2030	2030	2030	2030
World	20.46	23.54	22.05	20.92	24.78	19.85
Americas	14.82	16.90	16.28	15.96	17.40	16.09
Asia	24.44	29.48	27.31	25.58	31.30	24.06
Europe	21.845	25.04	24.26	23.71	25.67	23.19
Africa	9.63	9.74	9.33	9.11	10.09	8.40
Oceania	26.84	31.77	31.18	30.91	32.25	26.29
World fish price traded products	2,860.6	2,549.3	3,132.0	3,663.8	2,166.0	4,357.0

It is noticeable that per capita consumption in the Americas and Europe increases in all scenarios, even in that related to climate change. The per capita consumption in Asia and Oceania declines in the climate change scenario, but increases in all others.

Africa, on the other hand, is different. Per capita consumption increases marginally in scenario I, but with 4.8 percent in scenario IV. The other scenarios show a decline in consumption, which is particularly strong for climate change, with a 12.7 percent reduction by 2030. In other words, the detrimental impact of climate change could be particularly hard in Africa, which has the lowest consumption at the outset and is in need of expanded production.

8. POLICY IMPLICATIONS

This analysis has provided interesting and important results with regard to the future contribution of capture fisheries and aquaculture to future food security. A number of scenarios for future growth in aquaculture, with annual growth in the 2016-30 varying between 2.4 percent and 5 percent, have been presented. Moreover, it has been argued that with further developments in R&D and easing of regulations in some countries, an annual growth rate of 4 percent, or possibly even 5 percent, appears realistic. The results give rise to numerous policy implications.

One surprising result is that, for the optimistic scenario V, the real price of capture fish declines by more than 40 percent and that of aquaculture more than 50 percent over the 2016-30 period. As the prices are largely driven by the development in aquaculture, one may ask how this is possible. The FAO FISH model assumes there will be productivity improvements that will allow production of increase as well as aquaculture to remain profitable despite the large reduction in price. This result may appear counterintuitive, also taken into consideration that there will be fairly large positive shifts in demand in this period due to variables such as population and income growth and changes in consumer preferences. This will be an area for future research.

As highlighted in Chapter 6, world per capita fish consumption has been maintained and has even slightly increased in recent years, despite fairly large population growth. As for the future scenarios presented in Chapter 7, different projections were provided for per capita consumption in 2030. The most dramatic case, that of climate change, involves reduced average consumption at the world level and reduced consumption in all regions of the world except the richest ones – the Americas and Europe. The China scenario involves only a slight increase in consumption at the world level and all regions, except Africa. Nevertheless, there is some uncertainty regarding this scenario due to the extent our countries will move in to fill the "gap" due to reduced production in China. Scenarios I, II and IV, all exhibiting various rates of future growth in aquaculture, involved various degrees of increased per capita consumption at the world level. The richer regions of the world, in particular the Americas, Europe and Oceania, all fare well under most scenarios.

Africa, on the other hand, is different. Per capita consumption increases marginally in scenario I, but with 4.8 percent in scenario IV. The other scenarios show a decline in consumption, which is particularly strong for climate change, with a 12.7 percent reduction by 2030. In other words, the detrimental impact of climate change could be particularly hard in Africa, which has the lowest consumption at the outset and is in need of expanded production.

It is noticeable that per capita consumption in the Americas and Europe increases in all scenarios, even in that related to climate change. The per capita consumption in Asia and Oceania declines in the climate change scenario, but increases in all others.

The reduction in prices in many of the scenarios may come as a surprise to many observers. This highlights the importance of future productivity growth in aquaculture so that cost of production can come down as production expands and production can remain profitable. Furthermore, to achieve productivity growth and increase production, countries need to devote resources to R&D so as to achieve technological development. This relates to "new" or not fully developed technologies as well as productivity growth for existing technologies.

It is very important to invest in research that increases aquaculture yield and profitability. Genetic improvement of species like salmon, carp and tilapia have able to increase aquaculture yield and reduce the production cost per unit of fish produced. Though adoption of these genetically improved fish strains reduces fish prices, it increases farm profitability (see, for example, Dey 2005, Dey et al., 2010 & Dey et al., 2013a). One key issue here is the easy access to quality fish seeds of these improved strains to all farmers, which is particularly important in developing countries.

Feed costs account for 30-70 percent of total production costs in aquaculture, and improving feed efficiency is key to reducing production costs in aquaculture. Though much work has been done on nutritional and husbandry approaches to improve feed efficiency, it is still an important researchable issue particularly in developing countries. Genetic improvement could play an important role in improving feed efficiency (de Verdal et al., 2017). Farmer profitability is often reduced as the result of losses due to disease, costs associated with the treatment of moribund fish, and decreased growth during convalescence. In various developing countries, few fish farmers and hatchery managers have even a basic education in fish health management and biosecurity practices. Additionally, many developing countries have no effective health certification programmes or diagnostic laboratories to support rural farmers with checking the health status of their stocks. As a result, fish farmers are unable to stock pathogen free fish nor diagnose and effectively treat disease episodes when they arise, and thereby unable to reduce losses due to fish disease.

Though environmental concerned associated with intensive aquaculture system is mostly limited in developed countries (Knapp & Robino, 2016), there are some cases in which poorly managed aquaculture has led to negative environmental consequences (see, for example, Troell et al., 2014). Moreover, rising use of wild fish in aquafeeds has the potential to increase their price and increase cost of aquaculture production. It is, therefore, important that government policies provide adequate incentives for resource efficiency, environmental protection, and sustainable intensification of aquaculture (broadly defined as “producing more using less”). A recent study conducted in Bangladesh shows that simple changes in fish farming technology and management practices can make intensive forms of aquaculture more sustainable (Henriksson et al., 2018).

In many parts of the world regulations represent an effective constraint on the development of aquaculture, as discussed in Chapter 7. van Senten et al. (2017, 2018 and 2019) and Engle et al. (2019) have found that the regulatory system has increased cost of aquaculture in the United States; for salmonid, mean farm regulatory cost were estimated at $150,506 /farm (Engle et al., 2019). Smaller scale farms are being negatively affected to a disproportionally greater extent than larger scale farms. For aquaculture to reach its potential, it is important that enabling regulations are introduced although it is, of course, important that environmental considerations are maintained.

For capture fisheries it is important that management is improved so as to enhance the economic benefits from this sector (World Bank, 2017). Various natural resource management strategies (NRMs), such as marine protected areas have shown positive impacts in some counties, expanding the stock and catch of fish (see, for example, Dey et al., 2016 & Rosegrant et al., 2016). However, current efforts on various NRM strategies are too small to have any meaningful impact to reverse the declining trends of coastal fisheries catch. Therefore, the positive effects of NRM strategies should be supported and communities encouraged.

In many developing countries, fish caught offshore cannot be marketed due to the absence of transport/storage and facilities/marketing chains. Improvement in storage and transportation facilities and onshore processing of oceanic species (such as tuna) will augment the domestic supply of fish. Better marketing and processing infrastructure are necessary for both inland and marine capture fisheries. Some of these facilities can be used for farmed fish as well.

Inland fisheries are important due to their significant contribution to food security and livelihood for the rural poor (Golden et al., 2016 and 2017). Establishment of community organisations for managing common property resources are important, particularly for countries with large inland fisheries reservoirs and seasonally flood lands (Dey et al., 2013b). We must also ensure improvements in fisheries management and marine conservation schemes that will facilitate equitable delivery of seafood to nutritionally vulnerable populations.

As highlighted in this report, fish is very much a traded commodity. To handle the increased volumes, an efficient marketing system, including supply chains, is very much in order. Much research and development assistance in the fisheries and aquaculture sector have been directed toward supporting engagement in global value chains. There is a need for investment in infrastructure to facilitate domestic and regional value chains as potential markets for producers, which will also improve nutrition for low-income rural and urban consumers (Béné et al., 2010).

Furthermore, trade barriers, including non-tariff trade barriers, need to come down. Though traditional barriers to trade such as tariffs and quantitative restrictions are reduced following the World Trade Organisation agreement, many developing countries are concerned about regulatory barriers such as quality and composition standards, and labelling requirements.

The analysis of economic aspects of future food security included one scenario analyzing the impacts of climate change on fisheries and aquaculture as based on the recent FAO report by Barange et al. (2018). The case study in question was seen to have profound impacts on production and prices, however, it was stressed that this represented only one out of many future scenarios. Nevertheless, this points to the importance of analyzing the impacts of climate change also from an economic perspective.

Recent literature on entrepreneurship in agricultural value chains advocates more contextualized understanding of entrepreneurship in order to better harness the opportunities from entrepreneurship (Bush et al., 2019). There is a need to elucidate practical ways to increase women's engagement in and returns from seafood value chains.

Africa in general, and Sub-Saharan Africa in particular, is the region that is seen to be most challenging in terms of the future: several scenarios imply a reduction in per capita fish consumption over time while two show a somewhat modest increase in consumption up to 2030. This result is a consequence of large population growth combined with a limited increase in production: even if relative growth rates may be high, absolute growth remains modest as the base is quite limited. In addition to this, due to lower incomes than in other parts of the world, the region is less able to import fish from other reasons than is the case in other regions.

The implication of this is that policies to promote aquaculture development in Africa are needed. This includes technology generation and dissemination, development of infrastructure (roads, facilities, supply chains, land tenure etc.) as well as training. There must be further

investments in the sector, which requires both entrepreneurship development and access to finance.

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APPENDIX

Table 7.A1. World capture production 2016 and 2030

Region	2016 production	2030 production
Scenario I	92 016	93 216
Scenario II	92 016	93 659
Scenario III	92 016	89 008
Scenario IV	92 016	92 903
Scenario V	92 016	84 490

Table 7.A2. The US GDP deflator 2010-30. 2010 = 100

Year	GDP deflator 2010 = 100[a)]	GDP deflator 2016 = 100
2010	1	
2011	1.021	
2012	1.039	
2013	1.056	
2014	1.075	
2015	1.087	
2016	1.101	1.000
2017	1.121	
2018	1.148	
2019	1.174	
2020	1.199	
2021	1.225	
2022	1.251	
2023	1.278	
2024	1.305	
2025	1.332	
2026	1.361	
2027	1.390	
2028	1.419	
2029	1.449	
2030	1.480	

a) ***Source***: OECD Economic Outlook Report

Table 7A3. Country/region-wise assumed shifts in supply curve (as percent change in yield) in marine capture, inland capture, and aquaculture sectors

	Marine capture	Inland capture	Aquaculture
China	-10	-10	-25
Canada	10	0	0
Mexico	-10	-10	0
USA	-10	-5	-10
EU-N (European Union 28)	-20	-5	-5
EU-W (Western Europe, other)	-10	-5	-5
Norway	10	-5	-10
Russia	20	0	-10
Africa (sub-Saharan Africa, least developed)	-20	-5	-5
Ghana	-20	-5	0
Nigeria	-20	-5	-10
Egypt		-5	-25
Bangladesh	-10	-5	-25
India	-10	-5	-15
Pakistan	-10	-25	-10
Malaysia	-10	-5	-15
Thailand	-10	-5	-25
Indonesia	-20	-5	-25
Philippines	-10	-5	-20
Japan	-10	-5	0
Korea	0	-5	0
Iran	-10	-20	-10
Turkey		-25	-10
Asia (Asia, other)	-10	-5	-15
Asia (Asia, least developed)	-10	-5	-15
Columbia	-10	0	-5
Chile	10	-5	-10
Peru	-10	-5	-10
Brazil	-10	-5	-10
South American countries	-10	0	-10
Australia	-10	20	0
New Zealand	-10	20	0

Note: These shifts are to be understood as relative to the assumptions in the baseline scenario I. An example will illustrate this. Consider China aquaculture, -25 percent. In the baseline annual growth is 4 percent. With climate change this will be reduced by 25 percent to 3 percent in 2030. The reduction will take place gradually over time, from 4 percent in 2017 to 3 percent in 2030.

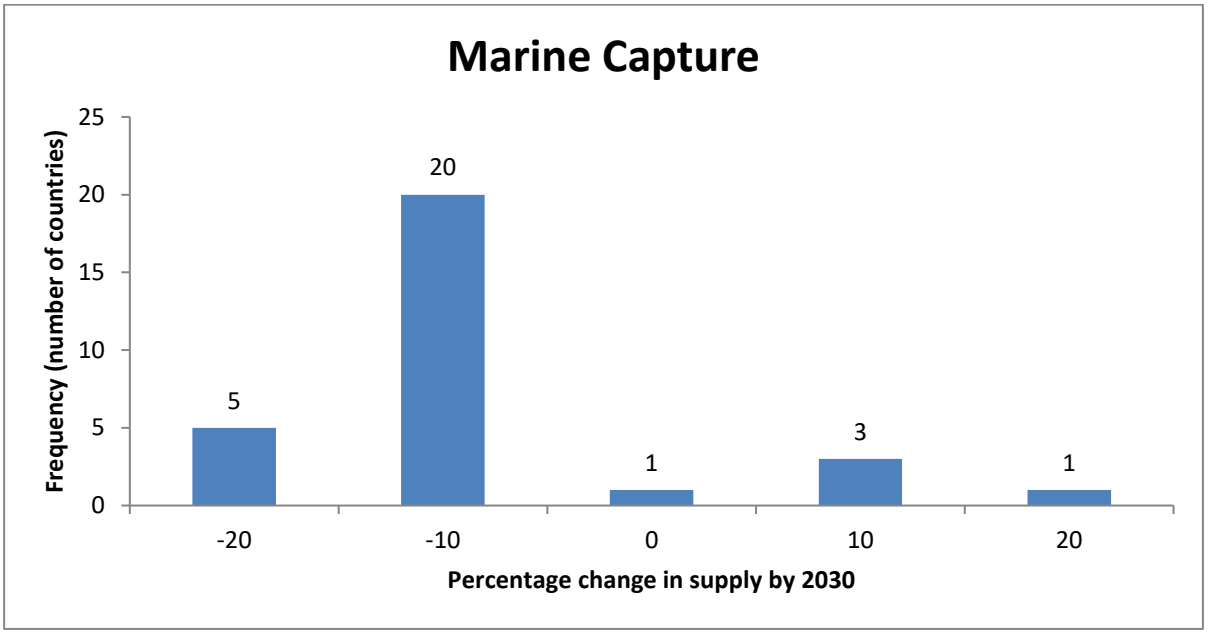

Figure A7. 1. Frequency distribution of country-level percentage change in marine capture fisheries supply

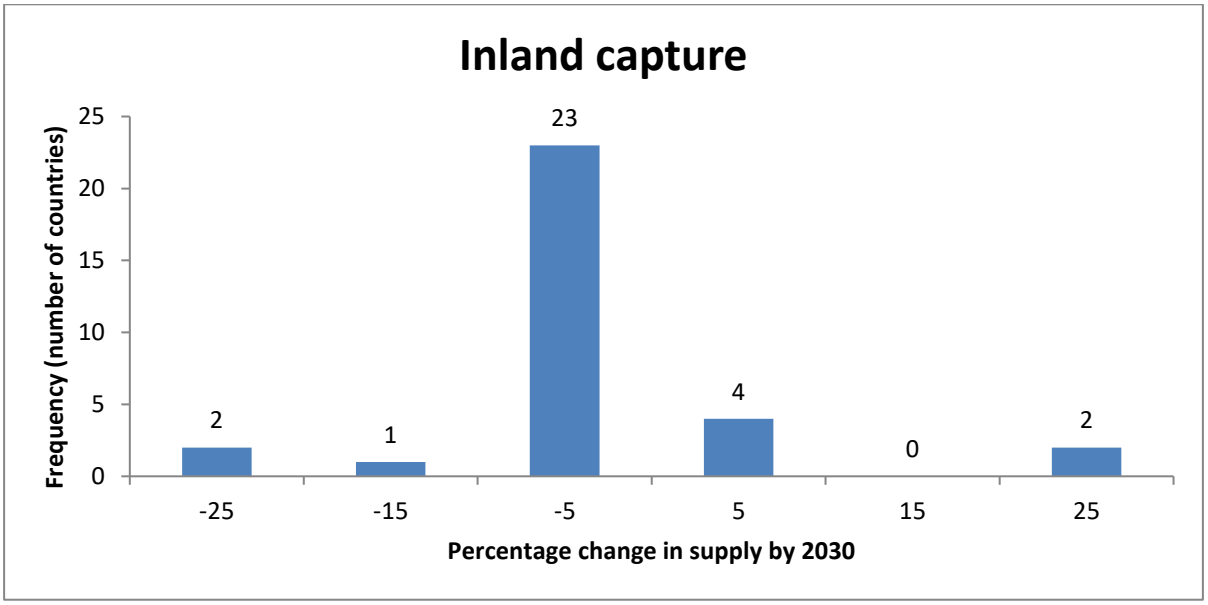

Figure A7. 2. Frequency distribution of country-level percentage change in inland capture fisheries supply

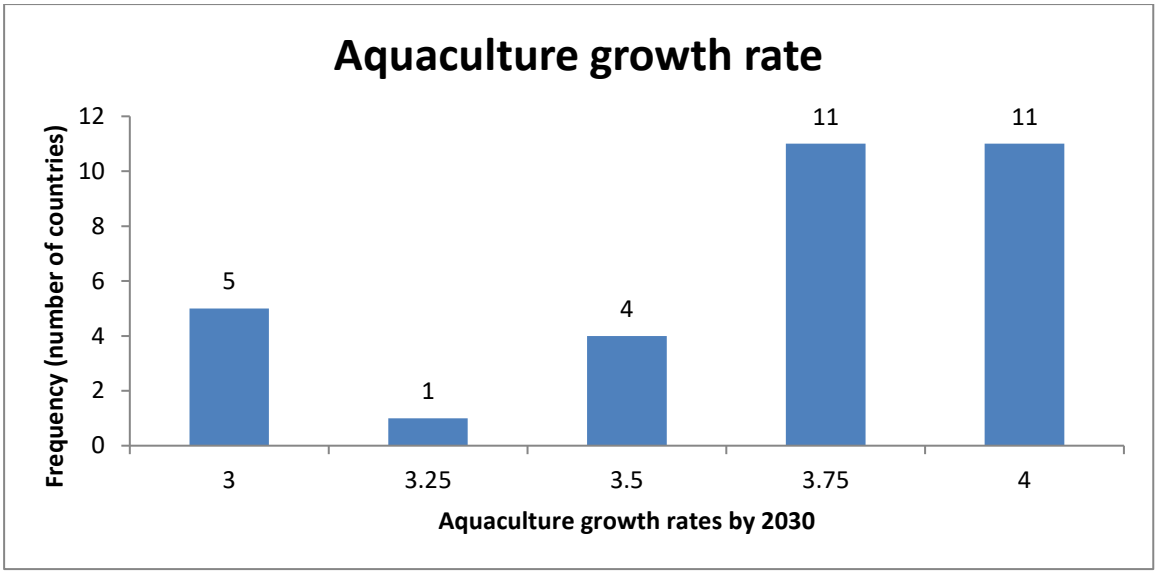

Figure A7. 3. Frequency distribution of country-level percentage change in aquaculture growth rate

There is much concern about future food supply and demand on the basis of expected population growth as well as due to the large number of people still suffering from undernourishment. At the same time there are limits to the potential for expanded production from fisheries, aquaculture and agriculture. What is often overlooked in many studies is the economic impact of changes in supply and demand for example due to changes in food prices, household income and consumer preferences. This analysis takes an economic approach in analysing supply of and demand for food up to 2030, with a particular emphasis on fisheries and aquaculture.

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