2 Trends and patterns in antibiotic use and antimicrobial resistance

This chapter presents trends and patterns in antibiotic consumption and antimicrobial resistance (AMR) from a One Health perspective for up to 52 countries including OECD countries, OECD accession and selected partner countries, Group of 20 (G20) countries and European Union (EU) and European Economic Area (EEA) member states. The chapter looks at historical data, presenting projections on AMR proportions for up to 2035 for 12 priority antibiotic-bacterium combinations and lines of antimicrobial treatment. Finally, it analyses the latest evidence to shed some light on the impact of the COVID-19 pandemic on AMR.

Key findings

- Between 2000 and 2019, on average across OECD countries, sales of all classes of antibiotics increased slightly from 21.4 to 21.8 defined daily doses (DDD) per 1 000 inhabitants per day. The levels and trends across individual countries were very heterogeneous. In more recent years, between 2016 and 2019, there have been reductions in total antibiotic consumption in most European countries. In G20 countries, the average trend shows a convergence, over the last two decades, towards OECD levels of antibiotic use, indicating significant increases in countries like Brazil, China, India, Indonesia and Saudi Arabia.
- In line with recent trends in Europe and should total antibiotic consumption continue to evolve along the same lines as in the period 2000-15, it is projected that consumption will decrease between 2015 and 2035 by 3% in the OECD. However, consumption of the highest priority and third-line antibiotics, like carbapenems, is projected to increase, albeit from currently low levels. The impact of COVID-19 remains unclear and antibiotic consumption may not follow along with the previous trends due to the pandemic.
- Over the last two decades, on average across OECD countries, sales of all classes of antimicrobials used in chicken, cattle and pig systems, adjusted for total production and importation of meat products, are estimated to have halved, with most of the decrease taking place from around 2014 in the OECD and 2010 in the EU/EEA member states. Reductions in antimicrobial consumption in animals per animal biomass have been driven by both reductions in total antimicrobial consumption and increases in food animal biomass.
- If downward trends in OECD and EU/EEA persist in the future, these regions could see further reductions in antimicrobial consumption in food animals per animal biomass. Consumption could decrease an estimated 10% in the OECD and 12% in the EU/EEA by 2035 compared to 2020 while stabilising in the G20 at 2020 levels.
- It is estimated that, in 2019, resistance proportions, averaged across 12 priority antibiotic-bacterium combinations, were 20% in OECD countries, 22% in the EU/EEA and 30% in the G20. Average resistance proportions, across all 12 antibiotic-bacterium combinations, in 2019, differed considerably: Denmark and Norway had the lowest estimated average resistance proportions, almost 6%, while in Greece and Türkiye, more than 44% of infections were estimated to be due to resistant bacteria. India had estimated average resistance proportions in excess of 55%. For some antibiotic-bacterium combinations, over 95% of infections were from resistant bacteria in the countries with the highest resistance proportions.
- Based on new historical data on resistance proportions and correlates of AMR, it is projected that between 2019 and 2035, resistance proportions, averaged across 12 priority antibiotic-bacterium combinations, will remain mostly flat if current trends in resistance, and correlates of resistance, continue into the future and no other policy actions are taken beyond the ones currently in place. A stabilisation of average resistance proportions at 2019 levels is also projected for EU/EEA countries and G20 countries. These estimates should be interpreted with caution, given the fundamental uncertainty surrounding the impact of the COVID-19 pandemic.
- Despite a projected overall stabilisation of resistance proportions, for certain countries (e.g. Greece, India, Türkiye) and antibiotic-bacterium pairs, resistance is projected to remain dangerously high. Furthermore, it is projected that the range between the countries with the most resistance and those with less resistance will slightly widen in 2035, indicating countries on the higher end of the range (e.g. Greece and Türkiye) need to do more to reverse current trends, or they will continue to face persistently high resistance. And more can be done. In the context of limited new antibiotics reaching the market, older antibiotics may be a useful resource

yet older antibiotics are often not available in countries. Also, studies have shown that increases in vaccination coverage for influenza are associated with declines in antibiotic prescribing but average vaccination rates in the OECD have actually dropped between 2008 and 2018.

- Finally, gaps in the collection and reporting of comprehensive, internationally comparable, standardised data on antimicrobial consumption and resistance make it more difficult to understand the AMR challenge, its consequences, evolution and whether actions to tackle the challenge are effective. Modelling is helpful but it is not a substitute for comprehensive high-quality surveillance and should not detract from efforts to expand and improve surveillance networks, especially from a One Health perspective.

Introduction

In recent years, there have been multiple calls to action to stem the rise of superbugs. These calls have pointed to the catastrophic impact of AMR and its present as well as future health and economic burden. The threat of a post-antibiotic world has driven multiple policy initiatives, from actions seeking to curtail the use of antimicrobials for the growth promotion of food animals, to antibiotic stewardship in human health, to infection and prevention control. An influential driver for action was provided by the publication, in 2016, of the widely cited Review on Antimicrobial Resistance, which projected that 10 million lives would be lost every year due to AMR infections by 2050 (Review on Antimicrobial Resistance, 2016[1]). Beyond the health burden, there could be serious economic costs by 2050, estimated at 3.8% of annual gross domestic product (GDP), USD 1.2 trillion annually in additional healthcare spending and 28 million more people in extreme poverty (World Bank, 2017[2]).

The OECD *Stemming the Superbug Tide* report (2018[3]) highlighted the huge benefits of early and comprehensive action to tackle AMR. The report also pointed out that, under a business-as-usual scenario in which no policy changes were made, resistance proportions, averaged across 8 priority antibiotic-bacterium combinations, could increase by 1 percentage point between 2015 and 2030 (OECD, 2018[3]). Not only did there seem to be a slowing down of the growth rate of resistance proportions for the period 2015-30 compared to the period 2005-15 but also there was very broad heterogeneity in the estimated trends, from significant increases to decreases in resistance proportions, depending on the country-antibiotic-bacterium combination. One of the key contributions of the report was to highlight that AMR was not a public health threat that all countries could tackle in the same way by focusing on one or two antibiotic-bacterium combinations. Rather the challenge was multifaceted, spanning numerous antibiotic-bacterium combinations, with levels and trends of antimicrobial use and resistance widely disparate across countries and antibiotic-bacterium combinations, and very different drivers of resistance across countries.

As new data have become available, it is timely to assess progress in curtailing the threat of inappropriate antimicrobial consumption, and the emergence and spread of AMR. This chapter starts by discussing recent developments in international data collection on antimicrobial use and resistance and presents new trends in antimicrobial use and concentrations in humans, animals and the environment. Next, it shows new data and estimates of historical and future resistance proportions for 12 priority antibiotic-bacterium combinations. Naturally, it is impossible to address the topic of AMR without mentioning another infectious disease with serious health and economic costs: COVID-19. As discussed below, the impact of COVID-19 on AMR remains to be seen for a number of reasons, yet it is clear that the pandemic has had both positive and negative effects on the emergence and spread of drug-resistant pathogens. As time passes, the net effects should become clearer, though there is a risk that important data may not have been collected as attention turned to the health emergency.

A One Health approach to global surveillance is slowly developing

In May 2016, the final report and recommendations of the Review on Antimicrobial Resistance called for global surveillance of antimicrobial consumption and resistance, both in humans and animals, specifically along three strands (Review on Antimicrobial Resistance, 2016[1]): i) on consumption in both animals and humans; ii) on resistance proportions of bug-drug combinations as well as their health effects on humans; and iii) on molecular biological data of the types of resistant bacteria and the genetic reasons for their resistance. Less than one year before, in October 2015, the World Health Organization (WHO) established the Global Antimicrobial Resistance and Use Surveillance System (GLASS) as the first global system to collect official national AMR data for selected bacterial pathogens causing common infections in humans (WHO, 2020[4]). As of April 2020, 92 countries, territories and areas were enrolled in GLASS: 91 in the AMR surveillance module (GLASS-AMR) and 9 in the antimicrobial consumption surveillance module (GLASS-AMC), which was launched in 2019 (WHO, 2020[4]).

Enrolment data from December 2020[1] show that 21 OECD countries, 16 G20 countries and 19 EU/EEA countries are enrolled in GLASS-AMR. Indeed, according to Wellcome (2020[5]), relative enrolment in GLASS of low-income countries (42%) and lower-middle-income countries (47%) is higher than relative enrolment of high-income countries (3%) and upper-middle-income countries (27%). Despite close collaboration between GLASS and AMR regional networks, among them the European Antimicrobial Resistance Surveillance Network (EARS-Net), only 19 of the 29 EARS-Net countries[2] are enrolled in GLASS-AMR. Similarly, 29 EU/EEA countries are enrolled in the European Surveillance of Antimicrobial Consumption Network (ESAC-Net),[3] yet only 9 countries globally were enrolled in GLASS-AMC in April 2020.

While there has been undeniable progress, gaps remain in the scope and quality of the data provided to GLASS. In 2019 alone, GLASS received data on specimens from 2 365 972 infected patients, 5 551 hospitals and 56 808 outpatient clinics (WHO, 2020[4]). However, experts are concerned by the highly variable quality of the data, including in the numbers of pathogens screened for and submitted isolates, but also the selection of priority pathogens and potential hospital bias in sampling (Wellcome, 2020[5]). There are undoubtedly important challenges to establishing international AMR surveillance networks, including factors related to the communities involved, the hospitals and clinics, the laboratories and the aggregation and reporting of data from different stakeholders (OECD, 2018[3]). Other constraints are due to national policies and agendas, difficult logistics, lack of resources and problems of data management (WHO, 2020[4]).

One overarching challenge is that AMR is actually an umbrella term that includes many different types of drug resistance. Resistance is typically reported in terms of classes of microorganisms and antimicrobial agents (e.g. third-generation cephalosporin-resistant *Enterobacterales*) but in the laboratory, resistance is defined and measured at the level of a specific microorganism (e.g. *Klebsiella pneumoniae [K. pneumoniae]*) and a specific antimicrobial drug (e.g. ceftriaxone, which is a third-generation cephalosporin). Collecting and aggregating international data on resistance across multiple antibiotic-bacterium combinations is thus not straightforward. Even in the most advanced countries, coverage is uneven. For example, in Europe, just 23 out of 37 countries had a surveillance system for reporting carbapenem-resistant *Acinetobacter baumannii (A. baumannii)*, 15 had national recommendations or guidelines for its control and 8 countries had a national plan for its containment (Lötsch et al., 2020[6]). In another example, in Canada, only eight hospitals from six of ten provinces are able to provide resistance data for clinically relevant bacteria (e.g. *Staphylococcus aureus [S. aureus]*) for the period 2007-16 (Lagacé-Wiens et al., 2019[7]).

In the animal sector, there is yet no global framework for the comparable collection, analysis and dissemination of AMR data in animals. In Europe, the European Food Safety Authority (EFSA) co-ordinates mandatory active monitoring of AMR in bacteria (e.g. *Salmonella*, *Campylobacter* and *Escherichia coli [E. coli]*) from healthy food-producing animals and food derived from those animals (Mader et al., 2021[8]). Mader and colleagues (2021[8]) from the EU Joint Action on Antimicrobial Resistance and Healthcare-Associated Infections (EU-JAMRAI) have recently proposed creating EARS-Vet to monitor antimicrobial consumption and resistance in animals, in the same way that EARS-Net and ESAC-Net monitor consumption and resistance in humans. This would go a long way towards reducing the heterogeneity in current monitoring efforts (Schrijver et al., 2018[9]).

With respect to consumption in animals, the World Organisation for Animal Health (WOAH), supported by the United Nations (UN) Food and Agriculture Organization (FAO) and the WHO within the tripartite collaboration, launched in October 2015 a global database on antimicrobial agents intended for use in animals. In its fourth and latest round of data collection, 153 countries participated in the questionnaire, 118 provided quantitative data, 111 of which for only 1 year between 2016 and 2018 (OIE, 2020[10]). At this stage, the WOAH is still reporting data at the regional level, as it continues to assess data validity and robustness. Unlike GLASS, European participation in the WOAH database is largely aligned with participation in the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) project, which collects information on how antimicrobial medicines are used in animals across the EU. The ESVAC project was started by the European Medicines Agency in January 2010, and while participation is voluntary, it has increased since 2010 from 9 to 31 countries. From 2024, EU Regulation 2019/6 has made it mandatory for EU countries to provide antimicrobial use data by animal species (Mader et al., 2021[8]).

There are no formal standardised global efforts to measure antimicrobial concentrations or antimicrobial-resistant bacteria and genes in the environment, specifically in plants and crops, as well as soil and water systems. In the EU, since 2015, member states should monitor surface waters for potential water pollutants included in a watch list, as part of the Water Framework Directive (OECD, 2019[11]). The watch list, which is reviewed every two years and is now in its 3rd version, includes amoxicillin, ciprofloxacin, sulfamethoxazole, and trimethoprim (Gomez Cortes et al., 2020[12]). Three macrolide antibiotics (erythromycin, clarithromycin, azithromycin) that featured in the 1st and 2nd watch list were dropped in 2019, as monitoring is not supposed to exceed four years. In a recent technical brief on the role that water, sanitation and hygiene (WASH) play in the emergence and spread of AMR, the WOAH, FAO and WHO proposed that surveillance in wastewater be incorporated into national surveillance activities and that surveillance mechanisms and regulatory authorities for wastewater aspects of AMR should be strengthened (OIE/FAO/WHO, 2020[13]).

Modelling can help fill gaps but it is not a substitute for surveillance

In the absence of comprehensive, internationally comparable, standardised data on antimicrobial consumption and resistance, researchers have turned to various types of modelling to fill surveillance gaps and inform decision and policy making. Different modelling approaches have been used to estimate global trends for antimicrobial consumption in humans (Klein et al., 2018[14]), AMR in humans (Cravo Oliveira Hashiguchi et al., 2019[15]; Oldenkamp et al., 2021[16]; Hendriksen et al., 2019[17]), antimicrobial consumption in animals (Tiseo et al., 2020[18]; Schar et al., 2020[19]), and AMR in animals (Van Boeckel et al., 2019[20]). Another set of studies used expert elicitation methods to derive estimates on AMR in humans (Colson et al., 2019[21]) and attribution of foodborne diseases to specific foods (Hoffmann et al., 2017[22]).

Either explicitly (in statistical modelling) or implicitly (in expert elicitation), modelling methods are essentially making use of posited or empirical associations between variables for which there are ample historical data (e.g. indicators of economic development, experts' own observations in the field) and antimicrobial consumption and resistance, for which data are scarcer, to fill gaps in surveillance (Box 2.1). Modelling can be useful when data are unavailable or are difficult to compare without manipulation. However, modelling is not a substitute for comprehensive high-quality surveillance and should not detract from efforts to expand and improve surveillance networks. Data-driven models of AMR have limited explanatory power (OECD, 2018[3]) and the relationships the models are based on may be changing over time, or be simply biased by the lack of data on certain bug-drug pairs, countries, species or all of these.

Box 2.1. Modelling methodology used to estimate antimicrobial consumption and resistance

Updates to methodology and new sources of data aligned with a One Health approach

As in the OECD (2018[3]) report titled *Stemming the Superbug Tide: Just a Few Dollars More*, historical and future antimicrobial consumption and resistance were estimated using a combination of statistical techniques making use of as much publicly available, internationally comparable, data as possible, while explicitly incorporating uncertainty in the underlying data, models and assumptions. As before, missing data were imputed using best guesses from theoretically hypothesised and empirically-tested relationships with correlates (Harbarth and Samore, 2005[23]; Byarugaba, 2004[24]; Chatterjee et al., 2018[25]; Holmes et al., 2016[26]). The methodology was updated to reflect best practices in predictive modelling, like the use of cross-validation to select most predictive models (Kuhn and Johnson, 2013[27]) and newly available data and estimates were included, especially new sources relevant from a One Health perspective.

Historical data on antimicrobial consumption and resistance in humans were collected from the Center for Disease Dynamics, Economics & Policy's ResistanceMap, as in the previous report (OECD, 2018[3]). These data were complemented with historical time series for a wide range of indicators (from health and sanitation to agricultural and livestock production) collected from databases of the World Bank, the WHO, the FAO, the European Centre for Disease Prevention and Control (ECDC), the UN World Population Prospects (UN WPP), the UN Development Programme Human Development Database (UNDP-HDD), the United States Department of Agriculture (USDA), the Institute for Health Metrics and Evaluation (IHME) and the OECD's databases. Forecasts for economic growth (USDA), population (UN WPP), health spending (IHME) and antimicrobial consumption in animals (Tiseo et al., 2020[18]; EMA, 2020[28]) were also collected. Whenever multiple sources of data on the same indicator were available, the source with the most comprehensive geographical and temporal coverage was chosen.

Besides the eight antibiotic-bacterium combinations (third-generation cephalosporin-resistant *E. coli*, fluoroquinolones-resistant *E. coli*, penicillin-resistant *Streptococcus pneumoniae (S. pneumoniae)*, methicillin-resistant *S. aureus* (MRSA), carbapenem-resistant *K. pneumoniae*, third-generation cephalosporin-resistant *K. pneumoniae*, carbapenem-resistant *Pseudomonas aeruginosa (P. aeruginosa)*, and vancomycin-resistant *Enterococcus faecalis* (*E. faecalis)* and *Enterococcus faecium (E. faecium*) included in *Stemming the Superbug Tide* (OECD, 2018[3]), carbapenem-resistant *A. baumannii* and fluoroquinolones-resistant *A. baumannii* were also included. Complete estimates of resistance proportions were produced for 51 OECD (including partner countries) and G20 countries from 2000 to 2035, with uncertainty intervals.

The modelling framework is broadly the same as that used in *Stemming the Superbug Tide* (2018[3]), with multiple imputations of missing historical values using a large dataset of covariates (and priors whenever feasible), forecasting of antibiotic consumption in humans using exponential smoothing, forecasting of resistance proportions using an ensemble of three equally weighted models (a mixed-effects linear regression, exponential smoothing with an additive damped trend and a random forest), and incorporation of uncertainty from imputation of missing values, model selection and specification, and some model parameters. As before, the forecasts do not incorporate any potential future policy action or intervention. Methodological updates have focused on the parameterisation of the random forest, optimising hyperparameters using cross-validation (Kuhn and Johnson, 2013[27]) as well as a more exhaustive search of specifications for the mixed-effects linear regression.

There are limited data collected during COVID-19 to inform the trends shown in this report

Most publicly available and internationally comparable datasets available today do not include numbers for 2020 or 2021. As such, it is not yet possible to quantitatively assess the impact of COVID-19 on both antibiotic consumption and AMR at an international level. While the WHO is confident that GLASS will provide important insights once the pandemic subsides (Hsu, 2020[29]), there is also concern from experts that COVID-19 may be undermining surveillance, monitoring and evaluation efforts. Interviews conducted by Wellcome (2020[5]) show that, as attention turned almost exclusively to COVID-19, hospital surveillance activities, like the Global Point Prevalence Survey, have been "almost completely abandoned", while many five-year national action plans that were now entering the evaluation and updating phase may risk being deprioritised.

To project resistance proportions for the next 13 years in this context is naturally very challenging. If the pre-pandemic patterns observed resume in the short term, then the estimates presented here are well-founded. If, on the other hand, COVID-19 constitutes a paradigm shift with a longer-term impact, then any projection of resistance proportions today will be subject to substantial fundamental uncertainty. As new data become available in the next months and years, it will become clearer what impact COVID-19 will have and estimates can be updated to reflect the most up-to-date information.

Note: See Hashiguchi et al. (2019[30]), "Resistance proportions for eight priority antibiotic-bacterium combinations in OECD, EU/EEA and G20 countries 2000 to 2030: a modelling study", https://doi.org/10.2807/1560-7917.ES.2019.24.20.1800445. ResistanceMap aggregates data from international surveillance networks like the EARS-Net, the Central Asian and Eastern European Surveillance of Antimicrobial Resistance (CAESAR), GLASS and others, which in turn aggregate data from national surveillance networks.
Source: OECD (2018[3]), *Stemming the Superbug Tide: Just A Few Dollars More*, https://doi.org/10.1787/9789264307599-en; Harbarth, S. and M. Samore (2005[23]), "Antimicrobial resistance determinants and future control", https://doi.org/10.3201/eid1106.050167; Byarugaba, D. (2004[24]), "Antimicrobial resistance in developing countries and responsible risk factors", https://doi.org/10.1016/J.IJANTIMICAG.2004.02.015; Chatterjee, A. et al. (2018[25]), "Quantifying drivers of antibiotic resistance in humans: A systematic review", https://doi.org/10.1016/S1473-3099(18)30296-2; Holmes, A. et al. (2016[26]), "Understanding the mechanisms and drivers of antimicrobial resistance", https://doi.org/10.1016/S0140-6736(15)00473-0; Kuhn, M. and K. Johnson (2013[27]), *Applied Predictive Modelling*; https://doi.org/10.1007/978-1-4614-6849-3; Tiseo, K. et al. (2020[18]), "Global trends in antimicrobial use in food animals from 2017 to 2030", https://doi.org/10.3390/antibiotics9120918; EMA (2020[28]), *Sales of Veterinary Antimicrobial Agents in 31 European Countries in 2018: Trends from 2010 to 2018, Tenth ESVAC Report*, European Medicines Agency, European Surveillance of Veterinary Antimicrobial Consumption; Hsu, J. (2020[29]), "How COVID-19 is accelerating the threat of antimicrobial resistance", https://doi.org/10.1136/bmj.m1983; Wellcome (2020[5]), *The Global Response to AMR: Momentum, Success, and Critical Gaps*, https://wellcome.org/sites/default/files/wellcome-global-response-amr-report.pdf.

Trends in antibiotic consumption, sales and concentrations

Antibiotics play a crucial role in modern medicine. Since their discovery, they have not only been instrumental in the treatment of infections but have also made possible the development and everyday use of invasive surgical procedures and complex medical interventions, from organ transplantations to treatment of cancers to care of premature neonates (Cecchini and Lee, 2017[31]). There is no doubt that antibiotics have significantly improved population health.

While they are often called "miracle drugs", antibiotics are not infallible. The use of antibiotics exerts selective pressure on microorganisms and invariably leads to AMR, as pathogens develop or acquire mechanisms that allow them to survive and reproduce in environments where antibiotics are present. Historically, it can take only a few years following the discovery of a new antibiotic for bacteria to develop resistance against that antibiotic (OECD, 2018[3]). The more antibiotics are used, the less effective they become. It is vital that antimicrobials be used wisely. When antimicrobials are inappropriately used, there is likely to be very little clinical value for the patient or animal being treated, despite the negative consequence of the emergence of resistance. The benefits of using antibiotics need to be compared with the costs of drug resistance (Cecchini, Langer and Slawomirski, 2015[32]). Many antimicrobials are used in human and veterinary medicine as well as to control plant diseases. While other chemicals promote resistance (e.g. metals, fungicides and biocides), the discussion below focuses on antibiotics.

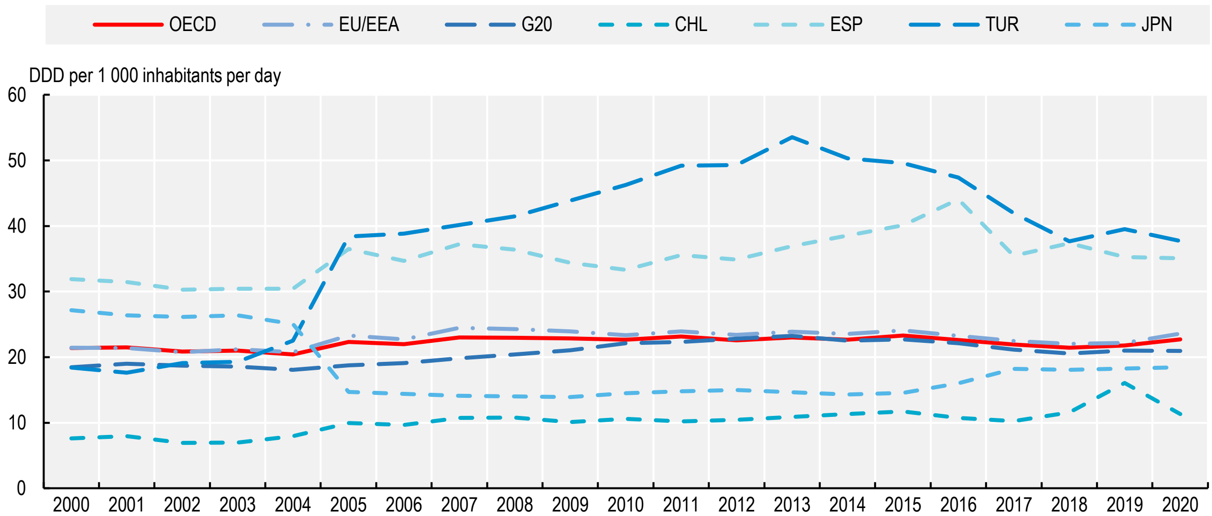
Antibiotic consumption in humans

> *Global consumption of antibiotics has increased in the last 20 years, with consumption rates in the G20 converging towards mostly stable rates in the OECD*

In the last 20 years, on average across OECD countries, sales[4] of all classes of antibiotics monitored through ResistanceMap/IQVIA increased by 1.9%, from 21.4 DDD[5] per 1 000 inhabitants per day in 2000 to an estimated 21.8 in 2019 (Figure 2.1). The levels and trends across individual countries were very heterogeneous. Spain was one of the OECD countries with the highest total consumption, with rates increasing by an estimated 10.6% over the last two decades from 31.9 to 35.3 DDD per 1 000 inhabitants. In Chile, consumption rose an estimated 111% but from much lower starting rates of 7.6 and 16.1 DDD per 1 000 Chileans per day in 2000 and 2019 respectively. Total consumption in Türkiye rose an estimated 115% from 18.4 to 39.5 DDD per 1 000 inhabitants per day, making it the OECD country with the highest growth rate in the last 20 years. Conversely, consumption decreased the most in Japan, dropping an estimated 32.9% from 27.2 to 18.2 DDD per 1 000 inhabitants per day.

Figure 2.1. Average total antibiotic sales in the human sector in the OECD have been largely stable

All antibiotic sales, in DDD per 1 000 inhabitants per day, 2000-19*



Note: *Original data go as far as 2015; estimates for 2016-19 derived through multiple imputations (data from OECD.Stat on consumption used as priors). Averages for different country groups are unweighted. See Note 4 for more details on IQVIA MIDAS database.
Source: OECD analysis of OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

StatLink https://stat.link/4qca1t

Average trends across the EU/EEA mirror those in the OECD. While the data are not strictly comparable, the patterns are well aligned with the latest *Annual Epidemiological Report 2019* published by the European Centre for Disease Prevention and Control (ECDC) (2020[34]), which shows a statistically significant decrease in total consumption (community and hospital sector) of antibacterials for systemic use in the EU/EEA overall, between 2010 and 2019. In G20 countries, the average trend shows a convergence, over the last two decades, towards OECD and EU/EEA levels of total antibiotic consumption, indicating significant increases in non-OECD, non-EU and G20 countries like Brazil, China, India, Indonesia and Saudi Arabia. These five G20 countries, along with Peru and Türkiye, exhibit the highest growth rates in total antibiotic consumption.

Globally, total antibiotic consumption rose by 39% between 2000 and 2015, from 11.3 to 15.7 DDD per 1 000 individuals per day, with low- and middle-income countries (LMICs) topping growth rates (Klein et al., 2018[14]). In LMICs, between 2000 and 2015, total antibiotic consumption increased by 77%, from 7.6 to 13.5 DDD per 1 000 inhabitants per day (Klein et al., 2018[14]). For comparison, in the OECD, over the same period (2000-15), total consumption grew on average across countries by 9% from 21.4 to 23.3 DDD per 1 000 inhabitants per day. While total consumption rates remain much lower in LMICs, there has been a clear convergence over the last two decades.

Most antibiotic consumption in humans takes place in the community. On average across 25 EU/EEA countries, 90% of all DDDs are consumed in the community (country range in 2020: 81-94%) (OECD et al., 2022[35]), while the remaining takes place in the hospital sector. In the United States, most antibiotic expenditure and consumption are associated with the outpatient setting. Similar patterns are observed in Mexico.

Overall antibiotic consumption in humans dropped during the first year of the COVID-19 pandemic in EU/EEA countries and Australia

According to the latest data from the ECDC, in 2020, the mean total consumption of antibiotics in humans in the EU/EEA dropped by 17.6% compared to the year before (OECD et al., 2022[35]). Between 2019 and 2020, there was a decrease of 3.5 DDD per 1 000 inhabitants per day. A majority of countries reported decreases in antibiotic consumption for both the community and the hospital sector and generally larger decreases in the community than in the hospital sector. In the community, the decrease between 2019 and 2020 was proportionally larger in countries with high antibiotic consumption than in countries with low antibiotic consumption. In Australia, the number of antibiotic prescriptions decreased by 40% from 2.3 million in March 2020 to 1.4 million in April 2020, with DDD per 1 000 inhabitants per day falling 39% between April and December 2020 compared with the same period in 2019 (ACSQHC, 2021[36]). In the United States, between March and October 2020, close to four in five patients hospitalised with COVID-19 received an antibiotic (CDC, 2022[37]). However, as in other countries, overall antibiotic use in hospitals, outpatient settings and nursing homes was lower in 2021 than in 2019 (CDC, 2022[37]). There are limited data on the consumption of antibiotics in humans during the pandemic in other OECD countries. There is concern that, in some countries, the pandemic may have led to higher – if perhaps temporary – consumption of antibiotics as a means to treat COVID-19, an approach that is not clinically effective.

Interventions to limit the health impact of the COVID-19 pandemic are likely to be behind changes in antibiotic consumption in humans observed in 2022

Reductions in total antibiotic consumption in humans in EU/EEA countries in 2020 could be related to actions taken by governments and populations to curb the COVID-19 pandemic, including (OECD et al., 2022[35]):

- Changes in infectious disease epidemiology, with particularly prominent decreases in groups of antibiotics prescribed for respiratory infections and to the youngest age groups.
- Non-pharmaceutical interventions intended to limit SARS-CoV-2 (coronavirus disease, COVID-19) spread, including restrictions on movement, physical distancing, respiratory etiquette, hand hygiene and travel restriction. These interventions likely had an impact on the transmission and prevalence of other infectious diseases and may have led to fewer antibiotics being dispensed. In the United States, an analysis of a dataset covering 92% of all retail prescriptions of antibiotics, found that from January to May 2020, the number of patients dispensed antibiotics decreased from 20.3 to 9.9 million (King et al., 2020[38]). Over 6 million fewer outpatients were dispensed antibiotics from retail pharmacies than would be expected based on the same timeframe in previous years (King et al., 2020[38]).
- Lower use of primary care services, due to lockdowns and reprioritisation of healthcare resources, which could have led to a decrease in inappropriate prescribing for milder and self-limiting infection.

Across the EU/EEA, hospitals have been hit hard by COVID-19. As demand for intensive care beds increased rapidly, the number of admissions for elective surgery or chronic care decreased. These changes are not captured by the indicator “DDD per 1 000 inhabitants per day”. If the total number of hospitalised patients decreased substantially in 2020 because of the COVID-19 pandemic, the apparent decrease in hospital antibiotic consumption expressed in “DDD per 1 000 inhabitants per day” could actually become an increase, if expressed in “DDD per 100 bed-days” (OECD et al., 2022[35]). Primary care data from the United Kingdom indicate higher rates of prescribing per patient: when taking into account the drop in the number of medical appointments, the number of antibiotic prescriptions was 7% higher than expected (Armitage and Nellums, 2020[39]). As such, changes in hospital consumption between 2019 and 2020 should be interpreted with caution until further data and analyses are available. Moreover, it is still unclear whether reduced community antibiotic consumption was sustained in 2021 and what implications recent trends in consumption may have on AMR. In the United States, the overall antibiotic use was lower in August 2021 compared to 2019, though the use of some antibiotics such as azithromycin and ceftriaxone increased (CDC, 2022[40]).

In Australia, in April 2020, changes to the Pharmaceutical Benefits Scheme (PBS) reduced the number of repeat prescriptions permissible (typically from one to zero) for the five most dispensed antibiotics in the country, with the objective of reducing inappropriate prescribing (ACSQHC, 2021[36]). It is likely that these changes are behind some of the reductions in antibiotic use observed in 2020. However, the use of some antibiotics that were not subject to this policy change also fell, which suggests that other factors such as the prevalence of respiratory illnesses and reduced health-seeking behaviour could have also contributed to the fall in antibiotic consumption in humans.

Consumption of highest priority antibiotics in humans has been increasing relatively faster than total consumption, both globally and in OECD countries

In 2017, the WHO introduced the Access, Watch, Reserve (AWaRe) classification of antibiotics in its Essential Medicines List, as a tool for improving the use of antibiotics at the local, national and global levels, with the ultimate goal of reducing antimicrobial resistance (WHO, 2019[41]). The tool classifies 180 antibiotics. Access antibiotics are mostly first-line and second-line therapies with lower resistance potential than other antibiotics. Watch antibiotics have higher AMR potential and should be prioritised in stewardship and monitoring efforts. Watch antibiotics include most of the highest priority agents in the WHO list of Critically Important Antimicrobials for Human Medicine (2019[42]). Reserve antibiotics include antibiotics of last resort and should be saved for treatment of confirmed or suspected infections due to multidrug-resistant organisms.

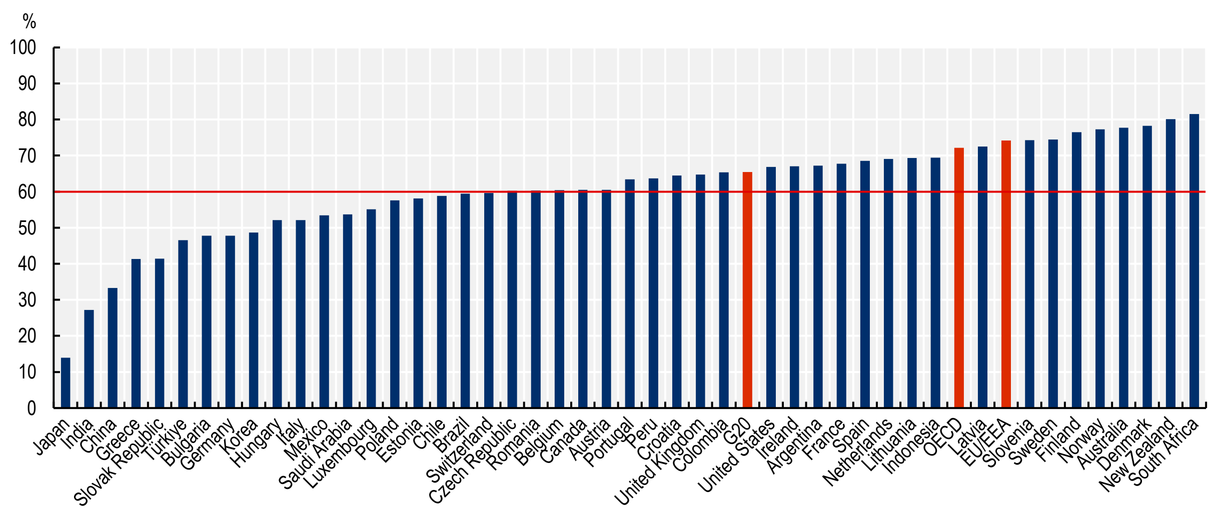
Globally, the consumption of last-resort antibiotics, such as carbapenems and colistin, has been increasing (Klein et al., 2018[14]). Carbapenems are a last-line group of antimicrobials used mainly in hospitals to treat patients with confirmed or suspected serious infections (ECDC, 2020[34]). They act as the last line of defence against multidrug-resistant bacteria. While much of the global growth in last-resort antibiotics has been in low- and middle-income countries (LMICs), growth has not been restricted to LMICs. In relative terms consumption of carbapenems has increased faster than total consumption in OECD, EU/EEA and G20 countries in the last 20 years. As stated, total consumption rose 9% in the OECD between 2000 and 2015, while consumption of carbapenems grew 71% over the same period, albeit from very low levels of consumption. These trends are aligned with data from ECDC (2020[34]) showing that between 2010 and 2019, several European countries exhibited a statistically significant increasing trend in the consumption of last-line groups of antimicrobials. In the EU/EEA, consumption of last-line antibiotics in humans, such as carbapenems and polymyxins (mainly colistin), increased between 2011 and 2020, by 10% and 67% respectively (OECD et al., 2022[35]). These antibiotics are the last line of defence against multidrug-resistant bacteria.

Klein and colleagues (2021[43]) have used ResistanceMap/IQVIA data on a large array of antibiotic agents to understand how the consumption of antibiotics in AWaRe groups has evolved between 2000 and 2015. In 76 countries, the median per capita consumption of Access antibiotics increased by 26% (from 8.4 to 10.6 DDD per 1 000 inhabitants per day), while consumption of Watch antibiotics increased by 91% (from 3.3 to 6.3 DDD per 1 000 inhabitants per day). In high-income countries, consumption of Access antibiotics increased by 15% while consumption of Watch antibiotics grew by 28%. The WHO has proposed that countries should aim for Access antibiotics to make up at least 60% of total national consumption by 2023, a target that the WHO believes would result in better use of antibiotics, reduced costs and increased access (WHO, 2019[41]). In 2015, there were 14 OECD countries that did not meet this target (Figure 2.2). Large economies outside the OECD, like Brazil, China and India were among the countries not meeting the WHO target in 2015. In Japan, some antibiotics are not included in the WHO AWaRe classification, somewhat limiting comparability. In recent years (data not shown), Japan has increased the share of all antibiotics that are Access antibiotics. Since 2015, some countries – particularly OECD countries such as Switzerland – have made important strides on this indicator and now meet the at least 60% target.

A growing consumption of Watch antibiotics, relative to Access antibiotics, could be due to a number of reasons. Klein and colleagues (2021[43]) suggest six, mostly focusing on trends in LMICs. In higher-income countries, drivers could include the promotion of certain antibiotics, over-the-counter sales of antibiotics without a prescription (still allowed in Europe for certain medications like eye drops), diagnostic uncertainty and empirical antibiotic use, and higher rates of AMR infections which require second-line and last-resort antibiotics (Klein et al., 2021[43]; Paget et al., 2017[44]).

Figure 2.2. Consumption of Access antibiotics as a share of total consumption in humans in 2015

The WHO has set a national-level target that 60% of all antibiotic consumption be for Access antibiotics by 2023



Note: No estimates were available for Costa Rica, Cyprus, Iceland, Israel and Malta. Averages for different country groups are unweighted. See Note 4 for more details on IQVIA MIDAS database.
Source: OECD compilation of estimates in Klein, E. et al. (2021[43]), "Assessment of WHO antibiotic consumption and access targets in 76 countries, 2000-15: An analysis of pharmaceutical sales data", https://doi.org/10.1016/S1473-3099(20)30332-7 and IQVIA data provided by Canada.

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Despite overall reductions in 2020, the relative use of broad-spectrum antibiotics in humans increased and variability across EU/EEA countries suggests reductions are possible

On average across the EU/EEA, in 2020, consumption of broad-spectrum antibiotics in the community was 3.5 times higher than the consumption of narrow-spectrum antibiotics, which should typically be the first-line therapy.[6] Between 2011 and 2020, an increasing trend was observed in this ratio for the EU/EEA overall, indicating a shift towards broad-spectrum antibiotics to treat infections in the community (OECD et al., 2022[35]). In the hospital sector, the proportion of broad-spectrum antibiotic consumption[7] also exhibits an increasing trend overall for the EU/EEA between 2011 and 2020, with only one country (Slovenia) with a decreasing trend.

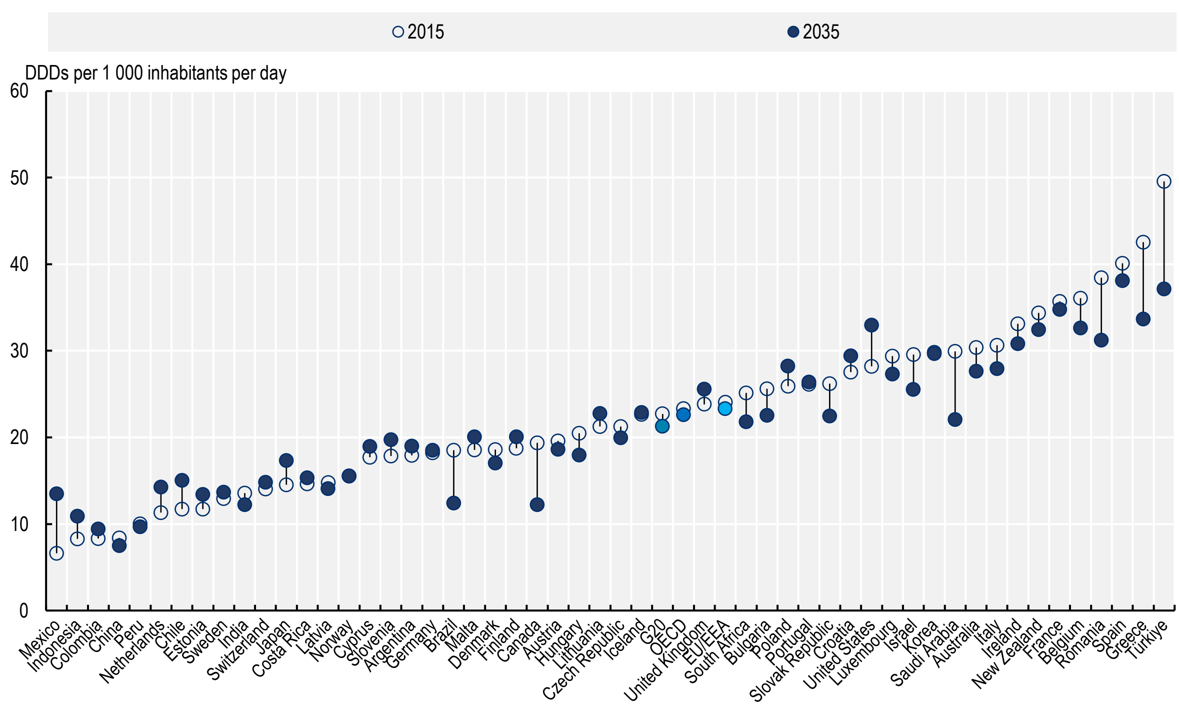
Antibiotic use in humans could decrease slightly in the OECD if trends persist

Should total antibiotic consumption continue to evolve along the same lines as in the period 2000-15, then it is estimated that consumption will decrease between 2015 and 2035 by 3% in the OECD from 23.3 to 22.6 DDD per 1 000 inhabitants per day respectively (Figure 2.3). Countries in the EU/EEA could see average total consumption decrease by 3.3% from 24.1 to 23.3 DDD per 1 000 inhabitants per day, while average total consumption in G20 countries could drop by 6.2% from 22.7 to 21.3 DDD per 1 000 inhabitants per day. Colombia, India and Mexico could see the largest increases in total antibiotic consumption, while Finland, Germany and Luxembourg could exhibit the most significant drops by 2035.

These projections are substantially lower than previous estimates of up to 200% growth in global antibiotic consumption by 2030 (Klein et al., 2018[14]). Reasons for the differences between the two sets of projections are likely to be multiple including, for example, due to a different methodology. However, the most significant factor behind the differences is likely to be the reduction in total antibiotic consumption experienced in most European countries between 2016 and 2019 (ECDC, 2020[45]), which was not captured in the work by Klein and colleagues (2018[14]) but was included as priors in the multiple imputations of missing values in this analysis.

Figure 2.3. If trends persist, total antibiotic consumption in humans in the OECD could decrease

Total antibiotic consumption in 2015 and 2035* in DDD per 1 000 inhabitants per day



Note: * Original data go as far as 2015; estimates for 2016-20 were derived through a combination of multiple imputations (data from OECD.Stat on consumption used as priors) and exponential smoothing with a damped trend. Averages for different country groups are unweighted.
Source: OECD analysis of OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php and IQVIA data provided by Canada.

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A recent challenge that might warrant more attention in the near future is the shortage of medicines, especially antibiotics. In a 2019 survey of 39 European countries, 95% of participating pharmacists indicated that the shortage of medicines was a major problem in their hospital (EAHP, 2019[46]). Antimicrobial agents were the leading cause of shortages in medicines from as far back as 2014. In 2019, around 63% of participating pharmacists indicated that they experienced shortages in antimicrobial agents, 5% more pharmacists than in 2014 indicating the situation is not improving (EAHP, 2019[46]). Antibiotic shortages can lead to delays or inappropriate substitutions.

Older "forgotten" antibiotics are not widely available, despite the potential benefit

With AMR increasingly becoming a global threat and with the approval of antibiotics having dropped significantly (OECD et al., 2017[47]), the European Society of Clinical Microbiology and Infectious Diseases (ESCMID) Study Group for Antibiotic Policies (ESGAP) set out in 2011 to investigate if potentially useful older antibiotics were being marketed in Europe, Australia, Canada and the United States (Pulcini et al., 2012[48]). Since 2000, only five new classes of antibiotics have been put on the market and none of these targets gramme-negative bacteria, which pose the biggest resistance threat (OECD et al., 2017[47]). In this context, older antibiotics may be a useful resource, until new antibiotics reach the market. Yet, despite many of these older antibiotics being categorised as Access antibiotics in WHO AWaRe, they are often not available in countries, either because they were never introduced in the first place or they were withdrawn at some stage (Pulcini et al., 2012[48]).

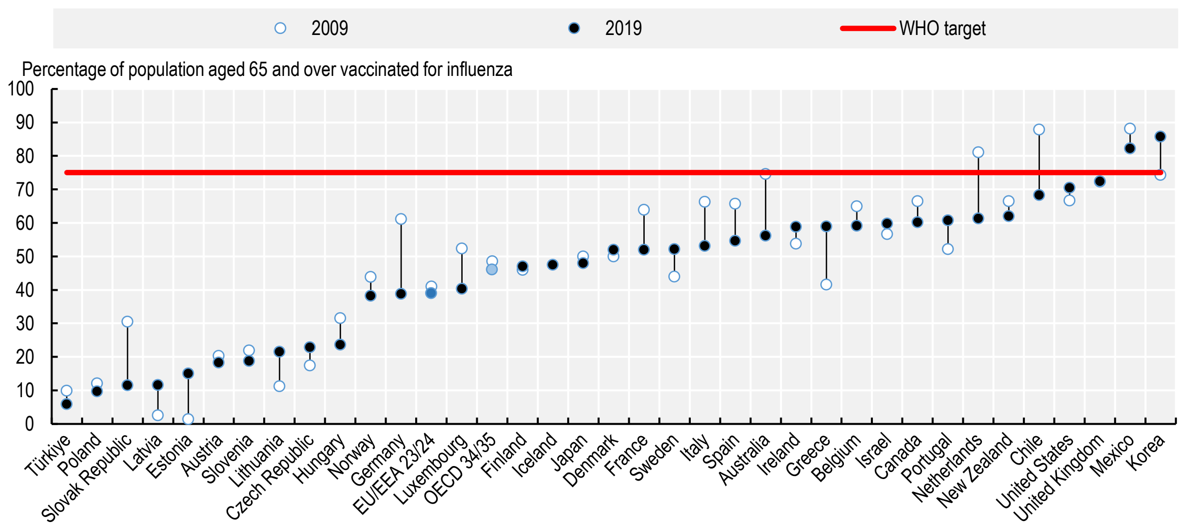
The 2011 ESGAP study showed that 22 out of 33 older but potentially useful antibiotics were marketed in fewer than 20 of the 38 included countries (including European countries, Australia, Canada and the United States, Canada and Australia). More than half of countries (20 out of 38) made only about 66% of forgotten antibiotics (22 out of 33) available. A study update in 2017 found the availability of these antibiotics remained low, with only about 69% (25 out of 36) accessible in about half (20 out of 39) of countries (Pulcini et al., 2017[49]). The lack of market availability of "forgotten" antibiotics extends to LMICs, where only a small number of countries have approved these older yet potentially useful antibiotics (Tebano et al., 2019[50]). Reasons for no longer producing or supplying "forgotten" antibiotics include low profitability, lack of awareness of clinical usefulness and limited demand (Access to Medicine Foundation, 2020[51]). Economic motives seem to be a major driver (Pulcini et al., 2017[49]).

Vaccination can reduce the need for antibiotics, yet there are gaps in vaccination

Vaccines trigger an immune response that can protect individuals against bacterial carriage and infection (Sevilla et al., 2018[52]). Vaccines can also help prevent people from getting sick by conferring immunity before the pathogen takes a foothold in the host, reducing the need for outpatient and inpatient care, in turn lessening the likelihood of antibiotics being used for treatment (Buchy et al., 2020[53]). Pneumococcal conjugate vaccines (PCVs), specifically the 10-valent PCV (PCV10) and 13-valent PCV (PCV13), have been found to lead to a 17% and 31% reduction respectively, in hospitalisations due to clinically and radiologically confirmed cases of pneumonia among children under 2 years of age (Alicino et al., 2017[54]). Pneumococcal vaccination is also associated with reductions in antibiotic use in children aged 6 weeks to 6 years, as well as reductions in illness episodes that require antibiotics in children aged 12-35 months (Buckley et al., 2019[55]). In the United States, it has been estimated that the increased coverage of the 7-valent PCV (PCV7) resulted in a 5.4% reduction in all-cause antimicrobial prescribing (Tedijanto et al., 2018[56]). Remarkably, increased PCV7 coverage was associated with nearly the same proportional reduction in total antibiotic exposures for *S. pneumoniae*, *S. aureus*, and *E. coli*, even though PCV7 does not target the latter two pathogens.

Other studies have shown that increases in vaccination coverage for influenza are associated with declines in antibiotic prescribing. One recent meta-analysis found that influenza vaccines were associated with a 28.1% rate reduction in the number of days antibiotics were used among healthy adults (Buckley et al., 2019[55]). Similarly, a study using data between 2010 and 2017 in the United States found that a 10 percentage point increase in the influenza vaccination rate was associated with a 6.5% decrease in antibiotic use, the largest reductions observed among children (aged 0-18 years) and the elderly, i.e. those aged 65 years and over (Klein et al., 2020[57]). While the WHO recommends that 75% of elderly people be vaccinated against seasonal influenza (OECD, 2019[58]), average vaccination rates in the OECD have actually dropped between 2008 and 2018 (Figure 2.4). Only Mexico and Korea have vaccination rates of over 75%.

Figure 2.4. Vaccination rates for influenza among older people falling short of WHO target of 75%



Note: Three-year average for Iceland and Luxembourg for both years. Data are estimated for Norway. Averages for different country groups are unweighted.
Source: *OECD Health Statistics 2021*, https://doi.org/10.1787/health-data-en.

Sales of antibiotics for food-producing animals

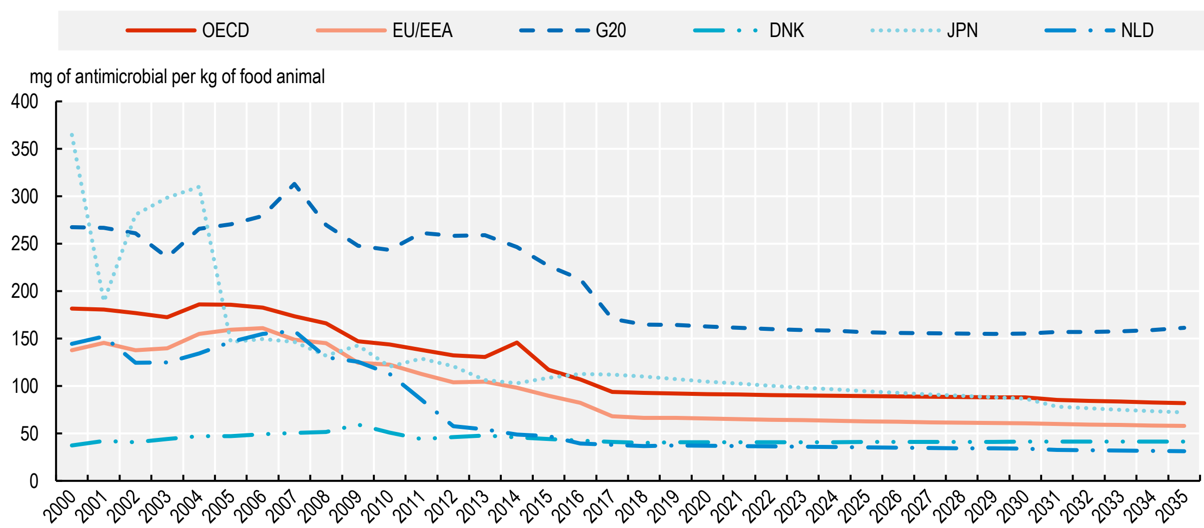
Worldwide, the consumption of antibiotics in animals far surpasses consumption in humans, with an estimated 73% of total antimicrobial sales globally being used in animals raised for food (Van Boeckel et al., 2019[20]). In 28 EU/EEA countries that report both animal and human consumption data, it is estimated that 70% of the active substance of antimicrobials was sold for use in food-producing animals (ECDC/EFSA/EMA, 2017[59]). Antimicrobials used in animals can serve different purposes, as discussed by Innes and colleagues (2020[60]). First and foremost, they can be used to treat animals with bacterial infections. Antimicrobials can also be administered to animals who have been in contact with infected animals as a form of disease control (also called metaphylaxis). When no animals exhibit signs of infection, antibiotics can be used prophylactically across groups to prevent disease. Finally, antimicrobials may be used without the purpose of treating, controlling or preventing disease but, for growth promotion, as a way to increase the rate of weight gain and the efficiency of feed (Wellcome, 2020[5]). Metaphylaxis, prophylaxis and growth promotion can result in large volumes of antibiotics being used.

Sales of antibiotics for animals in the OECD decreased over the last two decades

Over the last two decades, on average across OECD countries, sales of all classes of antimicrobials used in chicken, cattle and pig systems, adjusted for total production and importation of meat products, are estimated to have halved, with most of the decrease taking place from around 2014 (Figure 2.5). The trend is very similar in the EU/EEA but with the largest part of the reduction starting from 2010. While the figures are not directly comparable, these results are well aligned with the analyses in the latest ESVAC (2020[28]) report for Europe (see Figure 23 in the report). Consumption in animals in the G20 is estimated to have dropped as well over the last 20 years but remains at levels higher than those in the OECD and EU/EEA.

Historical data on antimicrobial consumption in animals are still developing and the figures presented here should be interpreted with caution. However, globally, countries in the EU/EEA and OECD have been collecting and reporting data for the longest periods, going as far back as 1980 (in Sweden). Three countries with established data reporting, Denmark, Japan and the Netherlands, are shown in Figure 2.5. The evolutions of antimicrobial consumption in animals in these countries illustrate that patterns are diverse. While consumption in both Japan and the Netherlands decreased over time, the levels are very different. In Denmark, consumption was mostly flat in the last two decades and at a lower level than in the EU/EEA and OECD averages.

Figure 2.5. Average total sales of antibiotic for animals in the OECD have dropped over the last two decades (2000-20)



Note: Averages for different country groups are unweighted. The denominator used to standardise antimicrobial consumption in animals was derived from data on total meat production and import quantities of bovine, poultry, pig and other meat from the Food and Agriculture Organization Corporate Statistical Database FAOSTAT. Because of this, data in this graph are not directly comparable to data in EMA (2020[28]), OIE (2020[10]) and Tisseo et al. (2020[18]). While numbers differ across studies, trends should be qualitatively similar. Estimates are not available for Cyprus. An EU-wide ban on the use of antibiotics as growth promoters in animal feed entered into effect on 1 January 2006. The US Food and Drug Administration banned the use of antibiotics as feed supplements to help livestock and poultry grow faster on 1 January 2017. In Canada, as of 1 December 2018, all Medically Important Antimicrobials for veterinary use can be sold by prescription only and growth promotion claims and related directions for use are no longer allowed on labels.
Source: OECD analysis of estimates and data from Tiseo, K. et al. (2020[18]), "Global trends in antimicrobial use in food animals from 2017 to 2030", https://doi.org/10.3390/antibiotics9120918.

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To ensure comparability across countries with very different systems of animal food production, antimicrobial consumption in animals is typically reported in the total weight of antibiotics consumed over the total weight of food animals produced and imported (commonly called animal biomass), in a given year. Changes over time in this ratio could then be driven by changes in total antimicrobial consumption, total food animal biomass or both. An exploration of both the numerator and denominator, suggests that the reductions in antimicrobial consumption in animals per animal biomass have been driven by both reductions in total antimicrobial consumption and increases in food animal biomass. Food animal production has increased in the last 20 years (OECD/FAO, 2019[61]) at the same time that total antimicrobial consumption in animals has decreased in most high-income countries (Tiseo et al., 2020[18]).

Shifts in policies and attitudes towards the use of antibiotics for growth promotion in high-income countries are likely behind reductions in antimicrobial use in animals. The use of medically important antibiotics (antibiotics used in human medicine that are classified by the WHO as important, highly important and critically important) for growth promotion is considered inappropriate by the WHO, WOAH and FAO. The EU, Canada and the United States have banned the use of antimicrobials for growth promotion and, more recently, India and Pakistan have moved toward banning or phasing out critically important antimicrobials for human use from animal use (Wellcome, 2020[5]). The WHO has recommended that, when the use of antimicrobials in animals is justified, priority should be given to antimicrobials of least importance for human health (WHO, 2017[62]).

Sales of antibiotics for animals could decrease further in the OECD if trends persist

If downward trends in the EU/EEA and OECD persist in the future, these regions could see further reductions in antimicrobial consumption in food animals per animal biomass. Antimicrobial consumption in food animals per animal biomass could decrease an estimated 10% in the OECD and 12% in the EU/EEA by 2035 compared to 2020, while stabilising in the G20 at 2020 levels. These estimates differ somewhat from forecasts by Tiseo et al. (2020[18]), who project a 6.7% increase in Europe, a 4.3% rise in North America and a 3.1% increase in Oceania by 2030. Reasons for these differences include the distinct geographical scope (Tiseo et al. report rates for continents rather than country groupings), though much more likely these differences reflect the inclusion in estimates presented here of recent data for 2017 and 2018 from ESVAC (2020[28]). Indeed, projections by Tiseo et al. of an 11.5% global increase by 2030 were already revised downward compared to previous estimates of a 53% increase in consumption by 2030 using sales data from 2013 (Van Boeckel et al., 2017[63]).

With aquatic animals representing 17% of global animal protein consumption, with global food fish consumption growing faster than consumption of meat from all terrestrial animals combined except poultry and with nearly 50% of the global supply of fisheries products for human consumption coming from aquaculture, antimicrobial consumption in aquaculture merits attention (Schar et al., 2020[19]). Drawing on a relatively limited collection of antimicrobial use point prevalence surveys,[8] Schar et al. (2020[19]) project that global antimicrobial consumption in aquaculture will rise by 33% between 2017 and 2030. In Europe, consumption could increase by 29.7% by 2030, yet the region's share of global consumption was small in 2017 (around 1.8%) and is projected to decrease (1.7%) by 2030 (Schar et al., 2020[19]). Estimates indicate that consumption per biomass is significantly higher in aquaculture than in humans and terrestrial animals and, worryingly, 96% of all antimicrobial use in aquaculture was for classes classified as highly important and critically important for humans. By 2030, Schar et al. (2020[19]) predict that aquatic food-producing animal use will account for almost 6% of total global antimicrobial consumption, including humans and animals.

The majority of sales of antibiotics for animals take place outside the OECD

According to estimates by Tiseo et al. (2020[18]), the largest consumer of antimicrobials in food animals in 2017 was China, representing almost half of global consumption. The top ten countries by estimated total consumption were China, Brazil, the United States, Thailand, India, Iran, Spain, Mexico and Argentina, which together accounted for a projected 75% of all antimicrobials used in food animals in 2017 (Tiseo et al., 2020[18]). In aquaculture, the Asia-Pacific region accounts for the overwhelming majority of global consumption, with China, India, Indonesia and Viet Nam being the largest consumers (Schar et al., 2020[19]). The African and Latin America regions are projected to grow significantly but the Asia-Pacific region is likely to remain the largest consumer globally by 2030 (Schar et al., 2020[19]).

Naturally, these rankings mirror, to a large extent, the ranking of countries with the largest meat and aquaculture productions (OECD/FAO, 2019[61]; Schar et al., 2020[19]). While individual European countries remain relatively small meat producers in comparison to Brazil and China, the EU as a whole is one of the largest producers globally. Global aquaculture production is dominated by the Asia-Pacific region, with China alone accounting for 61% of global production in 2016 (Schar et al., 2020[19]). Beyond being a One Health issue, AMR is also a One World issue, with resistant microorganisms spreading across populations, regions and national borders (OECD, 2018[3]).

While meat trade growth is expected to slow down compared to the last decade, meat exports at the global level (excluding live animals and processed products) are still projected to be 18% higher in 2028 than in 2019 (OECD/FAO, 2019[61]). Brazil and the United States will continue to contribute the majority of meat exports. The Asian region is projected to continue to dominate meat imports, with Japan's younger populations increasingly favouring meat over fish (OECD/FAO, 2019[61]). As for fish, the EU, China, Japan and the United States will remain top importers. While most consumption of antimicrobials in animals may be taking place outside the OECD, global trade requires global antibiotic stewardship.

Antimicrobials in plants and the environment

Besides causing infections in humans and animals, bacteria can also cause plant disease, which in turn can lead to both health (foodborne disease) and economic (production losses) costs. At least 20 countries have approved the use of antibiotics to treat plant diseases (FAO, 2018[64]). In certain countries with strong regulatory oversight, antibiotic use in plants is minimal (FAO, 2018[64]) but this is not the case everywhere, with the Commission on Phytosanitary Measures, which governs the International Plant Protection Convention, finding that significant amounts of antimicrobials are used to control plant pests (WHO/OIE/FAO, 2020[65]). As discussed, the more antibiotics are used the less effective they become. There is concern that climate change may exacerbate plant disease, in turn increasing the need for antibiotics, which in turn will make these agents less effective in fighting bacteria (FAO, 2018[64]).

Experts interviewed by Wellcome (2020[5]) have indicated that while most high-income countries either ban antimicrobials in horticulture or restrict their use to plant health emergencies, this is not the case in lower-middle-income countries (LMICs), where the sale and use of antimicrobials in plants are either unregulated or insufficiently enforced. Based on recent studies, care should be taken when combining antibiotics with herbicides as this may massively increase the rate at which AMR develops (Wellcome, 2020[5]).

Antimicrobials may also be present in the environment at large, from soils to waterways, exerting selective pressure on microorganisms and promoting the development or acquisition of mechanisms that allow microorganisms to survive and reproduce where antimicrobials are present. Antimicrobials can be present in the environment for different reasons. A large part of the antibiotic volume ingested by both humans and animals (estimates vary, but around 80% in animals) is excreted in its active form, depending on the class of antimicrobial and how it is used (Wellcome, 2020[5]; OIE/FAO/WHO, 2020[13]; Singer et al., 2016[66]). Animal and human waste goes into sewage systems, directly in soils and waterways or can be used in the form of manure. Both human and animal waste may or may not be treated. A study conducted in 40 swine and cattle farms in the Netherlands found antibiotics in animal waste, with over 1 in 3 samples containing more than 1 antibiotic, and concentrations that exceeded those needed to select for resistance (Singer et al., 2016[66]; Berendsen et al., 2015[67]).

Antibiotics that have expired or are no longer necessary are often discarded in general waste or wastewater. Antibiotics that are sprayed onto crops will naturally go into the soil and waterways. Fish feed containing antibiotics may also lead to concentrations in rivers and seabeds (Wellcome, 2020[5]). Finally, antimicrobial manufacturing can also release antibiotics into the environment (OECD, 2019[11]). Studies have found concentrations of antimicrobials in water downstream of manufacturing sites that were higher than blood concentrations in humans taking antimicrobials (OIE/FAO/WHO, 2020[13]).

Concentrations of antimicrobials in manufacturing plant run-off are particularly problematic in China and India, where most antimicrobials are produced (OIE/FAO/WHO, 2020[13]). While there are no international guidelines on this matter, the pharmaceutical industry has made steps to address the issue. Of 17 companies assessed in an Access to Medicine Foundation report (2020[51]), 13 had an environmental risk-management strategy to address AMR and 12 set antimicrobial discharge limits at their facilities. However, only six companies ask their suppliers to set discharge limits and no company makes any data from monitoring limits publicly available. None of the 17 companies monitor discharge levels of private waste-treatment plants that are contracted to dispose of their manufacturing waste (Access to Medicine Foundation, 2020[51]).

Trends in antimicrobial resistance in humans

Recent trends in national resistance proportions are very heterogeneous

Average resistance proportions in the OECD in 2019 differ by more than a factor of seven

According to OECD analyses of the latest figures from national and international surveillance networks collated in ResistanceMap, the unweighted average of estimated resistance proportions, across 12 priority antibiotic-bacterium combinations, was 20% in OECD countries in 2019 (Table 2.1). Denmark and Norway had the lowest estimated average resistance proportions, at around 6%, while in Greece and Türkiye, more than 44% of infections were estimated to be due to resistant bacteria, on average, across all 12 antibiotic-bacterium combinations. India had projected average resistance proportions in excess of 55%. For some antibiotic-bacterium combinations, over 95% of infections were from resistant bacteria in the countries with the highest resistance proportions. Average resistance proportions in 2019, across 12 antibiotic-bacterium combinations, were estimated to be higher in G20 countries (30%), followed by countries in the EU/EEA (22%).

The lowest resistance proportion across all country-antibiotic-bacterium combinations was 0% (multiple examples), while the highest was 97% (for fluoroquinolone-resistant *A. baumannii*). There was enormous variation in resistance proportions across countries, across antibiotic-bacterium combinations, across countries within antibiotic-bacterium combinations and across antibiotic-bacterium combinations within countries. The estimated average resistance proportion, across 12 antibiotic-bacterium pairs, was almost ten times higher in India than in Norway. In Ireland, where resistance proportions across 12 antibiotic-bacterium pairs average just under 15%, the resistance proportion for vancomycin-resistant *E. faecium* was 38%, double the OECD average (19%).

Data on resistance proportions in the EU/EEA, G20 and OECD countries for infections due to *Salmonella* and *Campylobacter* in humans remain very limited and these bacteria are thus not shown in Table 2.1. The ECDC and the European Food Safety Authority (EFSA) have reported that resistance to ciprofloxacin, a fluoroquinolone that is categorised as a Watch antibiotic in WHO AWaRe, was 13% in *Salmonella* spp. in 12 member states and that 16 out of 19 countries reported very high or extremely high resistance to ciprofloxacin in *Campylobacter* (EFSA/ECDC, 2020[68]). In the United States, the National Antimicrobial Resistance Monitoring System (NARMS)[9] shows resistance to *Salmonella Typhi* increasing from close to zero in 1999 to 18% in 2018. On a positive note, simultaneous resistance to two critically important antibiotics in these bacteria remains low and resistance in *Salmonella* to carbapenems, a last-line antibiotic, remains rare (EFSA/ECDC, 2020[68]). Again, there was significant heterogeneity in resistance proportions, with, for example, 3% of infections due to *Salmonella* spp. in Latvia being resistant to ciprofloxacin compared to 27% in Belgium.

Table 2.1. Estimated resistance proportions for 12 priority antibiotic-bacterium combinations, 2019

Country	FRAB	CRAB	3GCRKP	FREC	CRPA	3GCREC	MRSA	VREFm	PRSP	CRKP	CREC	VREFs	Average
India	87.9*	71	90	86	44.6*	83	68	26.0*	12.5*	65	41	4.8*	56.7
Türkiye	97	91	73	57	41	54	31	13	51	45	4	1	46.5
Greece	97	94	65	33	49	21	43	47	17.0*	59	2	1	44
Saudi Arabia	76.7*	82	72	50	32.7*	58	49	29.2*	23.0*	46	3	1.9*	43.6
Indonesia	76.3*	53	76	72	33.4*	71	40	26.7*	19.3*	17	5	2.1*	41
Romania	91	88	64	28	55	20	47	36	20	32	1	1	40.2
Mexico	86.7*	68.5*	44.2*	68.7*	31.4*	58.8*	44.8*	25.8*	17.4*	9.5*	2.5*	1.2*	38.3
Cyprus	91	91	50	48	21	20	36	50	14.2*	14	0	3	36.5
China	3.5*	68.9*	54.0*	65.9*	25.3*	59.1*	33.5*	12.3*	8.6*	24.4*	2.9*	0.9*	35.8
Italy	91	80	58	44	19	34	35	21	12	31	1	2	35.7
Argentina	75.0*	69	56	31	28.3*	18	42	57.2*	25	19	1	2.1*	35.3
Bulgaria	100	72	76	40	26	39	15	12	9	27	0	0	34.7
Croatia	94	94	54	30	32	16	25	26	27	15	0	2	34.6
South Africa	69.2*	80	73	30	39.9*	31	21	15.6*	28	18	1	0.9*	34
Poland	90	72	58	36	27	17	15	44	15	8	0	3	32.1
Slovak Republic	94	58	58	39	42	24	27	29	5	6	0	0	31.8
Korea	61.1*	77	25	42	24.5*	38	49	20.9*	42	1	0	1.0*	31.8
Lithuania	99	90	55	19	20	21	9	40	11	4	0	6	31.2
Brazil	65.6*	67	54	49	28.4*	28	21	21.1*	16.3*	21	1	1.0*	31.1
Latvia	87.2*	85	37	28	45	19	8	40	10	1	0	8	30.7
Hungary	99	54	37	31	34	21	19	36	6	1	0	0	28.2
Colombia	67.5*	59.0*	43.6*	23.1*	28.2*	30.8*	30.6*	21.0*	15.4*	14.5*	2.5*	1.7*	28.2
Costa Rica	69.8*	61.4*	42.5*	21.5*	29.7*	25.1*	31.1*	16.0*	16.5*	12.0*	2.4*	1.5*	27.4
Peru	64.3*	49.5*	38.7*	23.7*	23.7*	28.9*	27.4*	26.3*	14.6*	11.3*	1.8*	2.4*	26
Malta	58.9*	47.1*	42	42	13	19	23	16.7*	21.3*	14	0	0	24.8
United States	50.1*	26.3*	16.4*	25.3*	15.8*	11.3*	43.6*	68.7*	22.4*	8.0*	1.1*	4.3*	24.5
Czech Republic	100	32	52	26	25	16	13	20	5	1	1	0	24.2
Chile	57.9*	48.1*	34.8*	29.6*	22.2*	21.8*	26.3*	21.2*	15.0*	10.4*	1.2*	1.4*	24.2
Portugal	57	31	50	29	19	17	35	9	14	12	0	0	22.8
Spain	57	58	26	30	25	14	22	1	20	7	2	0	21.8
Israel	53.4*	37.0*	27.7*	24.3*	17.4*	18.0*	23.3*	26.9*	14.7*	9.0*	1.4*	2.1*	21.3
Slovenia	100	25	17	20	23	10	7	3	11	1	0	0	18.1
Canada	43.0*	33.6*	12.9*	25.3*	22.5*	12.8*	16.0*	27.8*	9.8*	7.0*	1.1*	0.8*	17.7
New Zealand	44.5*	30.0*	16.3*	11.3*	17.2*	9.8*	20.3*	23.2*	14.5*	5.2*	0.7*	2.1*	16.3
Germany	60	3	13	19	39	12	7	26	6	1	0	0	15.5
Ireland	45	3	18	22	9	14	15	38	14	1	0	0	14.9
Japan	40.0*	1	6	31	14.9*	21	36	24.3*	1	0	0	1.2*	14.7
Luxembourg	39.4*	29.6*	26	23	10	12	6	3	21	1	1	0	14.3
Iceland	43.7*	28.5*	8.8*	13	16.1*	8	7	20.3*	16	3.4*	1.0*	0	13.8
France	42	10	31	15	19	9	12	1	25	1	0	0	13.8
Australia	23.2*	3	10	19	10.7*	13	18	45.0*	14.2*	1	0	0.8*	13.2
Austria	74	9	13	19	16	9	5	3	6	2	0	0	13
Sweden	85	6	9	19	15	8	2	1	7	0	0	0	12.7
Estonia	41.8*	27.4*	13	20	10	12	3	4	4	0	0	0	11.3
United Kingdom	30	4	15	19	8	13	10	22	5	2	0	2	10.8

Country	FRAB	CRAB	3GCRKP	FREC	CRPA	3GCREC	MRSA	VREFm	PRSP	CRKP	CREC	VREFs	Average
Switzerland	48	5	7	18	13	10	3	2	6	0	9	0	10.1
Belgium	15	0	21	23	16	11	7	1	10	2	0	1	8.9
Finland	49	0	7	14	11	8	2	0	12	0	0	0	8.6
Netherlands	35	1	10	21	7	7	2	1	4	0	0	0	7.3
Norway	14.5*	9.1*	9	13	10	6	1	1	6	0	0	0	5.8
Denmark	18	0	8	12	4	8	2	11	5	0	0	0	5.7
G20 Countries	64	49	43	42	27	35	32	27	19	18	4	2	30
All countries	65.3	44.8	36.7	31	23.7	22.9	22.3	21.8	14.6	11.6	1.8	1.3	24.8
EU/EEA countries	67	40	33	26	22	16	15	19	12	8	0	1	22
OECD countries	59	33	27	26	21	17	18	19	13	7	1	1	20

Note: * Indicates value was imputed and the mean of 300 multiple imputations is shown.
The colour scheme is based on a two-point scale (minimum in light grey, maximum in blue and points in between coloured proportionally). Countries (and country groupings) are sorted from top to bottom from highest to lowest average resistance proportions (across antibiotic-bacterium combinations). Antibiotic-bacterium combinations are sorted from left to right from highest to lowest average resistance proportions (across countries).
VREFs: vancomycin-resistant *E. faecalis*; VREFm: vancomycin-resistant *E. faecium*; 3GCREC: third-generation cephalosporin-resistant *E. coli*; CRKP: carbapenem-resistant *K. pneumoniae*; 3GCRKP: third-generation cephalosporin-resistant *K. pneumoniae*; CRPA: carbapenem-resistant *P. aeruginosa*; MRSA: meticillin-resistant *S. aureus*; PRSP: penicillin-resistant *S. pneumoniae*; FRAB: fluoroquinolone-resistant *A. baumannii*; CRAB: carbapenem-resistant *A. baumannii*; FREC: fluoroquinolone-resistant *E. coli*; CREC: carbapenem-resistant *E. coli*.
Averages for different country groups are unweighted.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

A small average increase in resistance between 2009-19 masks wide variation

Between 2009 and 2019, predicted resistance proportions for 12 antibiotic-bacterium combinations in OECD countries, increased, on average, by only 2 percentage points from 18% in 2009 to 20% in 2019 (Table 2.2). Average resistance proportions increased by 3 percentage points in G20 countries and in EU/EEA countries. Across all EU/EEA, G20 and OECD countries, the average largest projected increases in resistance proportions were for *A. baumannii* resistant to fluoroquinolone while the largest projected reductions were in meticillin-resistant *S. aureus*.

In 8 countries, projected resistance proportions went down, on average across all antibiotic-bacterium-country combinations, by 1.4 percentage points. In the majority of countries, however, resistance proportions, averaged across all 12 antibiotic-bacterium pairs increased between 2009 and 2019, by as much as 8 percentage points in OECD countries (e.g. the Czech Republic and Italy). However, these averages mask significant variation within countries across antibiotic-bacterium combinations. Despite average reductions in a few countries, it is estimated that in no country have resistance proportions for all 12 antibiotic-bacterium combinations gone down between 2009 and 2019. In all countries, both increases and reductions were predicted, in some cases are very significant. This is also true for *Salmonella* and *Campylobacter* in the EU/EEA, where trends varied by country for different serotypes and antimicrobials (EFSA/ECDC, 2020[68]). Resistance to ampicillin and tetracyclines in *Salmonella Typhimurium* declined in many countries between 2013-18, but in certain types of *Salmonella*, resistance to high concentrations of ciprofloxacin increased overall from 1.7% in 2016 to 4.6% in 2018 (EFSA/ECDC, 2020[68]).

In Italy, for example, the proportion of *K. pneumoniae* resistant to carbapenem increased by 30 percentage points (from 1% to 31%) between 2009 and 2019, while the proportion of *P. aeruginosa* resistant to carbapenem went down by 16 percentage points (from 35% to 19%) over the same 10 years. In Poland, while the proportion of *S. pneumoniae* resistant to penicillin went down by a projected 15 percentage points (from 30% to 15%), the proportion of *E. faecium* resistant to vancomycin increased by an estimated 37 percentage points (from 7% to 44%).

It is likely that differences in baseline resistance proportions and rates of change across countries and antibiotic-bacterium combinations are associated with differences in antimicrobial use, infection prevention and control, as well as the use of healthcare services, not to mention differences in measurement. However, the problem goes beyond the human health sector with links to the animal sector and the environment. The list of potential correlates and drivers of resistance is long, ranging from human and animal health and sanitation, agricultural and livestock production, urbanisation and population density, migration and trade, economic growth and governance, immunisation and population structure (Harbarth and Samore, 2005[23]; Byarugaba, 2004[24]; Chatterjee et al., 2018[25]; Holmes et al., 2016[26]). A 2018 systematic review of risk factors for antibiotic resistance in humans over the previous 10 years found the most supporting evidence for underlying disease, antibiotic use and invasive procedures in healthcare settings as main drivers (Chatterjee et al., 2018[25]). However, the review highlighted the lack of inclusion of community-level risk factors in studies, and that there was a general paucity of studies seeking to establish causal relationships between risk factors and resistance (Chatterjee et al., 2018[25]).

Table 2.2. Estimated percentage point changes in resistance proportions for 12 priority antibiotic-bacterium combinations between 2009 and 2019

Country	FRAB	VREFm	3GCREC	CRKP	FREC	3GCRKP	CREC	PRSP	CRAB	VREFs	CRPA	MRSA	Average
Italy	12.4	16.0*	16.0*	30.0*	8.0*	20.0*	1.0*	6.0*	10	-2.0*	-16.0*	-2.0*	8.3
Czech Republic	66.3*	14.0*	6.0*	1.0*	3.0*	0.0*	1.0*	1.0*	9.7	0.0*	-4.0*	-2.0*	8
Bulgaria	27.7	6	20.0*	26.0*	10.0*	7.0*	-1.0*	-9.8	10.7	0.0*	-3.0*	-1.0*	7.7
Saudi Arabia	6.4	8.5	14.2*	19.0*	12.3	15.4	0.9	-0.2	8.5	-0.3	-1.1	5	7.4
Poland	13.4	37.0*	7.0*	7.0*	11.0*	9.0*	0.0*	-15.0*	15.8	3.0*	1.0*	-5.0*	7
India	-3.1	1.7	1.0*	31.0*	-4.0*	3.0*	36.0*	0.5	-16.0*	1	-10.4	39.0*	6.6
Slovak Republic	42.3*	14.8	3.1	2.9	6.8	0.8	-0.7*	-9.6	18.2	-0.9*	-3	4	6.6
Sweden	65.7*	-2	3.2	-2.3*	5.7*	2.9	-0.5*	1.4	-0.7	-0.5*	5.6*	-1.5	6.4
Cyprus	15.9	10	6.0*	-5.0*	5.0*	8.0*	0.0*	-0.3	22	3.0*	8.0*	3.0*	6.3
Croatia	10.4	16.1*	8	10.5*	13.6*	4.9	-1.1*	7.3	11	0.6	-1.5	-4.9	6.3
Germany	43.3*	20.0*	3.0*	1.0*	-4.0*	-1.0*	0.0*	4.0*	-8.6	-1.0*	25.0*	-11.0*	5.9
Romania	12.9	16.2*	6.0*	11.2	10.0*	0.6	0.6	-16.0*	13.8	-1.4	-0.7	13.0*	5.5
Türkiye	7.2	0.4	10.7*	14.7*	14.3	10.1	0.1	3.1	2.3	-0.8	-1.2	-0.1	5.1
Hungary	30.3*	35.0*	8.0*	0.0*	0.0*	-1.0*	0.0*	-6.0*	-2.3	0.0*	4.0*	-10.0*	4.8
Austria	50.6*	-1.0*	1.0*	2.0*	-2.0*	5.0*	0.0*	1.0*	-4	-1.0*	6.0*	-1.0*	4.7
Latvia	8	29.9*	6.0*	1.0*	3.0*	-18.0*	-2.0*	10.0*	8	5.2*	4.7	-1.0*	4.6
China	9.2	4.9	5.3	6.4	19.8	5.6	0.6	1.2	4.9	-0.5	-0.4	-2.5	4.6
Greece	9.1	18.0*	9.0*	7.0*	9.0*	-6.0*	1.0*	-2	11.1	-7.0*	2.0*	3.0*	4.5
South Africa	5.7	3.7	9.6	11.6*	5.3	9.1	0.3	4.2	8.7	-0.3	2.8	-9.8	4.2
Brazil	2.7	1.7	7.7	6.7	15.7	9.4	0.1	-0.7	9.7	-0.9	0	-3.6	4.1
Iceland	4.5	4.3	6.0*	1.1	6.0*	1.5	0	16.0*	-0.4	-1.1*	-1.5	7.0*	3.6
Netherlands	22	0.0*	3.0*	0.0*	10.0*	4.0*	0.0*	3.0*	-7	0.0*	2.0*	1.0*	3.2
Indonesia	-1	6.1	12.2	4.9	16.9	8.6	0.4	-0.3	-5.1	-0.3	-3.6	-4.7	2.9
Malta	0	4.5	4.0*	14.0*	12.0*	42.0*	-1.0*	4	-0.3	0.0*	-9.0*	-36.0*	2.8
Finland	28.5	-1.0*	5.0*	-1.0*	4.0*	6.0*	0.0*	-1.0*	-8.9*	0.0*	1.0*	0.0*	2.7
Lithuania	10.5	17.1*	12.0*	4.0*	2.0*	-2.0*	0.0*	2.0*	2.1	-5.0*	-10.6	-2.0*	2.5
Costa Rica	0.2	0.5	4.9	2.6	7.1	7.8	0.4	0.6	5	-0.6	2.6	-1.6	2.4
Peru	5.3	4.3	5.5	4.5	6.1	3.9	0.5	-0.1	0.4	-0.6	-0.8	-0.7	2.4
New Zealand	5.3	6.5	5.8	5.2	2.3	3.3	0.7	-1.1	0.7	-0.2	-0.7	-3.6	2
Slovenia	44.8*	-1.0*	3.0*	0.0*	1.0*	-16.0*	0.0*	-4.0*	-7.8	0.0*	7.0*	-3.0*	2
Norway	4.1	1.0*	3.0*	-1.0*	1.0*	4.0*	0.0*	4.0*	1.9	0.0*	1.0*	1.0*	1.7
Spain	-5	-2.0*	3.0*	7.0*	-3.0*	15.0*	2.0*	-2.0*	0.3	0.0*	6.0*	-4.0*	1.4
Ireland	30.3*	0.0*	7.0*	1.0*	0.0*	7.0*	0.0*	-6.0*	-8.2	-1.0*	-1.0*	-12.0*	1.4

Country	FRAB	VREFm	3GCREC	CRKP	FREC	3GCRKP	CREC	PRSP	CRAB	VREFs	CRPA	MRSA	Average
Switzerland	26.8	-2.4	3	-1.7*	1.9	-2	7.5*	-1.9	-7.2	-0.9*	-0.2	-6.6	1.4
Colombia	2.9	6	4.2	3.3	3.8	2.4	0.5	-0.3	-0.1	-0.2	-2.5	-3.9	1.3
Chile	1.1	6.1	4	2.3	7.6	2.3	0.2	0	-1.6	-0.1	-2.9	-3.1	1.3
Australia	4.6	5.5	5.4	-1.1	8.9*	1.7	-0.7*	0.4	-7.6	-0.2	-0.1	-3.3	1.1
Argentina	-2.9	9.4	-1.4	5.7	6.5	5	-0.1	3.7	-4.4	-0.7	-6	-2	1.1
Canada	3.6	6	2.1	3.6	2.6	1.3	0.5	-1.3	-0.9	-0.1	-2.5	-3.5	1
Korea	-2.3	3.9	8.2	-1.7	9	-6.8	-0.6*	9	4.9	-1	-4.8	-7.5	0.9
France	20.3	0.0*	1.0*	1.0*	-6.0*	11.0*	0.0*	-2.0*	-1.5	0.0*	-5.0*	-11.0*	0.7
United Kingdom	13.1	8.0*	3.0*	1.0*	1.0*	7.0*	0.0*	2.0*	-8.8	0.0*	-7.0*	-18.0*	0.1
Estonia	-1.4	4.0*	10.0*	0.0*	11.0*	-4.0*	0.0*	3.0*	-6.3	0.0*	-16.8*	0.0*	0
Israel	1.7	5.2	1.6	-0.2	2.9	-1.2	0	-0.3	-7	0.4	-2.6	-2.2	-0.2
Denmark	4.3	9.0*	1.0*	0.0*	-3.0*	-4.0*	0.0*	1.0*	-9.0*	-2.0*	0.0*	0.0*	-0.2
Belgium	-3.9	-3.0*	3.0*	1.0*	3.0*	6.0*	-0.6*	10.0*	-11.7*	-1.0*	4.0*	-14.0*	-0.6
Portugal	5	-14.0*	7.0*	11.0*	1.0*	21.0*	0.0*	-4.0*	-17.4	-4.0*	-1.0*	-14.0*	-0.8
Mexico	2.7	4.1	-8.2	3.9	-4.3	0.9	1	-1.1	-9.5	0	0.4	-5.3	-1.3
United States	-10.9	-3.3	4.3	3	-2.7	1.4	1.1	17.4*	-23.7	-1.7	-1.2	-6.4	-1.9
Luxembourg	-5.7	-6.8	3.0*	-0.9	-3.0*	7.6	1.0*	2.0*	-10.2	-10.0*	-5.0*	-7.0*	-2.9
Japan	-3.2	7.8	0.6	-2.3*	0.7	-6.8	-0.5*	-3.7	-16.9	0.2	-5.5	-8.5	-3.2
EU/EEA countries	19	8	6	4	4	5	0	0	1	-1	0	-4	3
G20 countries	6	6	5	8	6	5	2	2	-3	0	-2	-3	3
All countries	12.6	6.6	5.4	4.9	4.9	4.2	1	0.6	-0.7	-0.7	-1	-3.2	2.9
OECD countries	15	6	5	3	3	2	0	1	-3	-1	0	-4	2

Note: * Indicates either that there was an increase or decrease in more than 95% of the uncertainty sets, or that there was complete historical data and so no multiple imputations were used.
The colour scheme is based on a two-point scale (minimum in light grey, maximum in blue and points in between coloured proportionally). Countries (and country groupings) are sorted from top to bottom from highest to lowest average resistance proportions (across antibiotic-bacterium combinations). Antibiotic-bacterium combinations are sorted from left to right from highest to lowest average resistance proportions (across countries).
VREFs: vancomycin-resistant *E. faecalis*; VREFm: vancomycin-resistant *E. faecium*; 3GCREC: third-generation cephalosporin-resistant *E. coli*; CRKP: carbapenem-resistant *K. pneumoniae*; 3GCRKP: third-generation cephalosporin-resistant *K. pneumoniae*; CRPA: carbapenem-resistant *P. aeruginosa*; MRSA: meticillin-resistant *S. aureus*; PRSP: penicillin-resistant *S. pneumoniae*; FRAB: fluoroquinolone-resistant *A. baumannii*; CRAB: carbapenem-resistant *A. baumannii*; FREC: fluoroquinolone-resistant *E. coli*; CREC: carbapenem-resistant *E. coli*.
Averages for different country groups are unweighted.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

The impact of the COVID-19 pandemic on antimicrobial resistance is still unclear

The COVID-19 pandemic and the actions taken by governments and populations in response to it are highly likely to have affected reporting on bacterial invasive isolates (mostly bloodstream infections) and observed resistance proportions in 2020. In the EU/EEA, for all bacterial species under surveillance by the European Antimicrobial Resistance Surveillance Network (EARS-Net), except for *S. pneumoniae*, the number of reported bacterial invasive isolates (mostly bloodstream infections) increased at EU/EEA level in 2020 compared to 2019, although this was not the case for every individual country in the region (OECD et al., 2022[35]). For *S. pneumoniae*, the number of reported invasive isolates decreased by 44%, from 15 608 in 2019 to 8 689 in 2020 (OECD et al., 2022[35]).

The COVID-19 pandemic has led to massive changes in human behaviour, which may have limited the spread of resistant organisms. The wide-ranging effects on human behaviour included drastically reduced mobility in 2020, likely substantially reducing opportunities to spread drug-resistant microorganisms and consequently reducing infections due to resistant pathogens (Murray, 2020[69]). This is illustrated by the sharp drop in the incidence of infections due to respiratory viruses, most notably influenza (flu) but also respiratory syncytial virus (Jones, 2020[70]). International tourist arrivals (overnight visitors) dropped 74% in 2020 compared to 2019, with around 300 million fewer arrivals in Asia and the Pacific alone and 500 million fewer international tourists in Europe alone (UNWTO, 2021[71]). At the national and regional levels, data from Google's COVID-19 Community Mobility Reports[10] suggest that populations radically reduced their movements (n.b. these data have important limitations and Google provides guidance on how to use and interpret the data). At the beginning of March 2021, mobility remained heavily constrained (Our World in Data, 2021[72]). During the pandemic, an estimated 40% of paid work by dependent employees in Europe was carried out at home, with more than a third of employees working exclusively from home (Eurofound, 2020[73]).

Undoubtedly at great cost, reductions in mobility and social contacts are likely to have reduced the spread of infectious diseases other than COVID-19. However, the pandemic has also affected the reporting of bacterial invasive isolates and changes in the reported number of bacterial invasive isolates in turn affect the resulting resistant proportions and make the observed changes in AMR between 2019 and 2020 difficult to interpret (OECD et al., 2022[35]). Robust surveillance systems will continue to be vital to monitor the situation and to assess the consequences and inform public health decisions (OECD et al., 2022[35]).

Average resistance proportions in the OECD are projected to drop slightly

Based on new historical data on resistance proportions and correlates of AMR (e.g. antimicrobial consumption in animals), it is now projected that between 2019 and 2035, resistance proportions, averaged across 12 priority antibiotic-bacterium combinations, will drop very slightly by on average 1 percentage point. Table 2.3 shows the percentage point changes in resistance proportions between 2019 and 2035, indicating an average reduction, across OECD countries and 12 antibiotic-bacterium combinations, of 1 percentage point. In OECD countries, resistance proportions averaged across 12 antibiotic-bacterium combinations are estimated to have increased from 18% (range across countries: 4.1-41.4%) in 2009 to 20% (range across countries: 5.7-46.5%) in 2019, and may drop to 19% (range across countries: 5.5-43.8%) by 2035 if current trends in resistance, and correlates of resistance, continue into the future and no other policy actions are taken beyond the ones currently in place. Similar reductions of around 1 percentage point for average resistance proportions are also projected for EU/EEA countries and G20 countries.

Across EU/EEA, G20 and OECD countries, resistance proportions averaged across 12 antibiotic-bacterium combinations are projected to increase in 18 countries, remain at their 2019 average levels in 1 country and decrease in 32 countries (these are averages; there might be increases or drops in these countries for different antibiotic-bacterium combinations, see Table 2.3). Peru is the only country where resistance proportions are projected to increase for all 12 antibiotic-bacterium combinations simultaneously – all other countries are projected to see both increases and reductions depending on the antibiotic-bacterium combination. Resistance proportions are projected to increase in 56% of country-antibiotic-bacterium combinations and are estimated to decrease in 39% of combinations.

In absolute terms, China, Luxembourg and Poland could see the largest percentage point increases, on average across 12 antibiotic-bacterium combinations, between nearly 3 and 6 percentage points higher in 2035 than in 2019. Conversely, the Czech Republic, Germany and Sweden could see the largest percentage point drops in average resistance proportions, projected to decrease around 4 to 5 percentage points. However, there is a very large uncertainty, as highlighted by the few estimates in Table 2.3 for which there were increases or decreases in more than 95% of the uncertainty sets (indicated by an asterisk). It remains very challenging to model future resistance proportions when so many data points are missing and when levels and trends differ so much across countries and antibiotic-bacterium combinations.

Table 2.3. Projected percentage point changes in resistance proportions for 12 priority antibiotic-bacterium combinations between 2019 and 2035

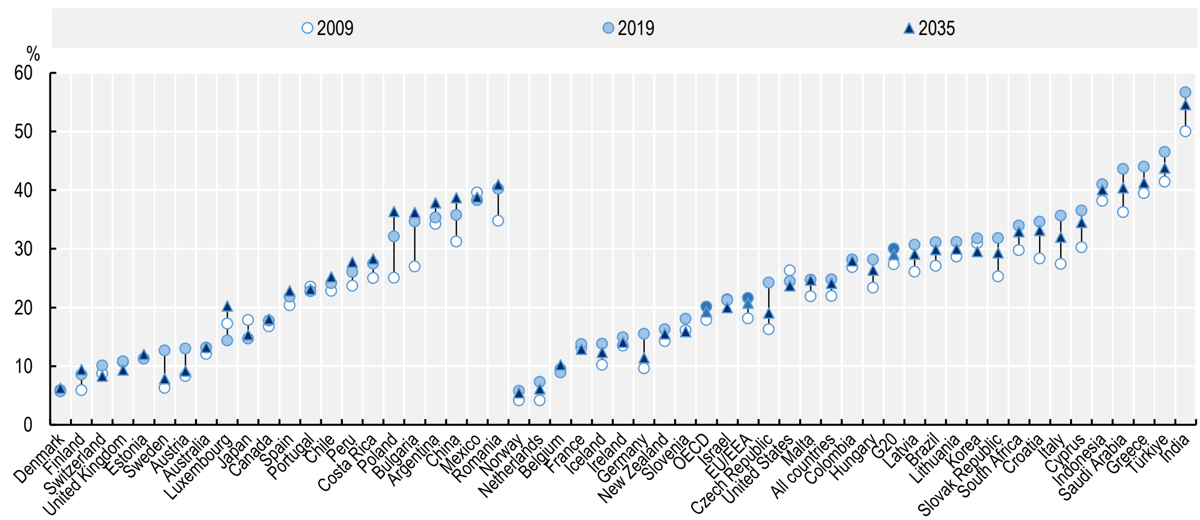
Country	FREC	CRPA	3GCREC	VREFs	PRSP	CRKP	CREC	3GCRKP	MRSA	VREFm	CRAB	FRAB	Average
Luxembourg	5	8.4	8.9	8.4*	-1	8	6.6	8.2	5.4	8	3.5	-0.1	5.8
Poland	10.4	7	6.1	6.3	3.8	8.5	7	3.6	7.7	2.9	-5.8	-6.3	4.3
China	-2.1	5.5	0.7	6.6	4.4	5.5	6	-0.2	6	3.1	-1.2	-2	2.7
Argentina	6.4	5	4.6	3.5	-1.4	2.1	3.1	0.2	2.1	1.7	3	-1.4	2.4
Peru	3.9	2.4	0.1	2.3	2.2	0.8	2.1	1.8	1.3	1.7	1.6	0.6	1.7
Bulgaria	4.4	5.5*	6.1	0.4	2.2	12.8	0.5*	0.1	1.7	-0.4	0.7	-15.9*	1.5
Belgium	0.9	-2.5	2	-0.1	4	-0.2	0	0.3	3.3*	1.9	4.3	1.4	1.3
Chile	3.7	2.2	2.6	0.5	0	0.5	0.5	1.9	0.5	1.2	1.2	-2.1	1.1
Spain	2.9	-2.1	2.0*	0	1.8	0	-1	1	2.8	1.5	-1.8	4.6	1
Costa Rica	3.1	1.7	2.2	1.5	0.7	0.3	0.9	1.4	1.3	1.5	-2.3	-1	0.9
Finland	1.7	0.2	0.4	0.2	2.1	0.3	0	0.5	0.5*	0.6*	2.7	0.3	0.8
Estonia	1.8	7.1	-1.3	0.1	1.6	0.6	0.2*	2.8	0.5	-0.3	-2.8	-1.2	0.8
Japan	1.6	3.3	-0.1	0.1	2	1.6	0.7	1.9	-4.4	-1.2	4.6	-1.5	0.7
Romania	3.1	0.9	4.4*	0.9	8.1	5.9	-0.7*	3.4	-3.5	-1.6	-6.6	-6.1	0.7
Denmark	2.2	2.3*	0.8	0.1	0.5	0.3	0	1.1	0.1	2.6	2.6*	-5.8	0.6
Canada	4	1.6	1.8	0.5	0.3	0.1	0.6	0.5	-1.6	3.1	-2.6	-2.8	0.5
Mexico	-0.3	2.2	0	0.7	1	-0.1	0.6	2.8	-0.4	0.3	0.6	-2.7	0.4
Portugal	0.9	2.4	0.9	0.9	-0.6	2.6	0.2	0.2	0.8	0.6	4.4	-9.2	0.3
Malta	-1.2	5.3	-0.6	3.9*	1.4	2.4	3.6	-1.6	-4.8	3.6	-6	-4.9	0.1
Australia	1.2	-0.5	0.2	-0.3	-0.4	1.2	0.2	0	-1.8	2.5	3.8	-6.2	0
Colombia	1.7	1	-1.8	0.6	0.4	-2	0.1	0.2	1.6	-1.1	-2.7	0.7	-0.1
Norway	2.0*	1.4	0.6*	0.7	0.2	0.1	0	0.3	0.5	0.2	-5.6	-5.4	-0.4
United States	0.8	0.5	2.6	-0.4	-3.4	-0.3	0.5	-0.4	-3.1	-1.4	-1.1	-2	-0.6
New Zealand	3.1	-0.9	3.1	-0.5	0	1.9	0.4	1.1	-4.1	0	-6.3	-6.4	-0.7
Ireland	2.3	3.3*	1	1.3	15.6*	0.3	0.4	-0.1	-3.3	-1.1	0.8	-30.8*	-0.8
France	3.5	0.8	2.5	0.9	4.7	0.6	0.9	-0.7	-1.4	1	-3.1	-20.1*	-0.9
South Africa	1.4	-1.7	-1.4	0.2	-0.8	-3.9	0.2	-2.3	4.9	-1.5	-4.8	-3	-1.1
Brazil	1	1	-1.8	0.1	-0.4	-0.4	-0.2	-1.6	-1.3	0	-6.8	-2.8	-1.1
Indonesia	-8.5	1.3	-8.1	1.6	-0.7	-0.2	0.8	-3.6	4.5	-0.8	0.5	-0.5	-1.1
Lithuania	5.0*	4.8*	-0.2	-3.4*	3.3*	0.6	0	-3.8	0.4	-1.3	-8.4	-11.4	-1.2
Netherlands	-2.0*	0.7	1.6	0	0.6	0.3	0	1	-0.3	0.2	1.6	-18.3*	-1.2
Israel	-0.1	-0.3	-1.2	-0.5	-0.8	-1.2	-0.4	-0.6	-3	0.9	-2.8	-4.9	-1.2
Iceland	2.4	0.3	2.4	0.3	-4.1	-0.6	-0.2	0	-4.6*	-0.9	-4.5	-6.6	-1.3
Croatia	4.3	2.1	1	-1.1*	-8.2*	8.6	0	-3.9	0.8	-2.3	-9.3	-9.1	-1.4
United Kingdom	0.7	0.7	0.2	0	0.4	-1.0*	0	-1.6	-2.5	1.3	-0.8	-15.7*	-1.5
Latvia	0.7	-8.3	1.4	-3.5	8.7	2.4	0.2	4.2	-1.9	-4.8	-11.3	-7	-1.6
Switzerland	1.8	-0.6	0.2	0.2	-0.3	1.9*	-3.8	1.4	0.6	0.7	1.7	-25.4*	-1.8
Hungary	-0.3	0.1	1.7	0	3.2	1	0	3.2	2.4*	-9.6	-0.9	-22.7*	-1.8
India	-2	0.4	-2.2	6.8	4.4	-3	-12.3	-6.2	-5.5	1.5	1	-6.8	-2
Cyprus	-1	4.5	11.1*	-2.1*	-0.5	2	1.1*	-3.5	0.7	-10.9	-14.3	-11.8	-2.1
Korea	2.9	2.6	-2	2.2	-9.3	3.5	2.5	7.9	-5.6	0	-22.5	-7.6	-2.1
Slovenia	2.9*	-1.9	2	0.5	-0.4	-0.1	0.6	3.1	1.8	-0.3	5.3	-39.7*	-2.2
Slovak Republic	5	0.9	3.8	0.1	7.5*	0.6	0	-2.8	1.5	-0.6	-15.5*	-30.6	-2.5
Greece	-0.7	-1.9	2.9	-0.1	1	0.8	-0.8*	3.8	-5.6	-17.1*	-7.7	-7.2	-2.7
Türkiye	-0.2	1.7	-5.8	3	-8.6	-7.8	1.8	-2.4	-2.3	4.8	-6.1	-11.1	-2.7
Saudi Arabia	-0.5	1.1	-7.9	2.6	1	-10.2	2.2	-9.7	-4.7	-2.4	-5.4	-6.7	-3.4
Italy	-2.1	1.8	-3.3	-0.3	-1.3	-8.9	-0.3	-4.2	-0.5	-1.5	-9.2	-14.6	-3.7
Austria	2.4*	0.5	1.5	0.1	-1.3	-1	0	-2.4	1.2	0.6	-1.5	-46.1*	-3.8

Country	FREC	CRPA	3GCREC	VREFs	PRSP	CRKP	CREC	3GCRKP	MRSA	VREFm	CRAB	FRAB	Average
Germany	3.1*	-18.1*	2	0	-1	-0.6*	0	0.2	1.3	0.2	1.4	-37.4*	-4.1
Sweden	0.7	-3.9*	1.3	0	-0.4	0.3	0	0.2	0.6	-0.2	-2.7	-53.8	-4.8
Czech Republic	0.2	-2.4	0	0.3*	-0.5	0.1	-0.6	-1.6	0.6	1.8	-9.9	-50.5*	-5.2
OECD countries	2	0	1	1	1	0	0	1	0	0	-2	-14	-1
EU/EEA countries	2	1	2	0	2	2	1	0	0	-1	-3	-16	-1
All countries	1.6	1	1	0.9	0.8	0.7	0.5	0.1	-0.2	-0.2	-2.9	-11.3	-0.7
G20 countries	1	1	-1	2	-1	-1	0	-1	-1	1	-3	-8	-1

Note:
* Indicates either that there was an increase or decrease in more than 95% of the uncertainty sets.
The colour scheme is based on a two-point scale (minimum in light grey, maximum in blue and points in between coloured proportionally). Countries (and country groupings) are sorted from top to bottom from highest to lowest average resistance proportions (across antibiotic-bacterium combinations). Antibiotic-bacterium combinations are sorted from left to right from highest to lowest average resistance proportions (across countries).
VREFs: vancomycin-resistant *E. faecalis*; VREFm: vancomycin-resistant *E. faecium*; 3GCREC: third-generation cephalosporin-resistant *E. coli*; CRKP: carbapenem-resistant *K. pneumoniae*; 3GCRKP: third-generation cephalosporin-resistant *K. pneumoniae*; CRPA: carbapenem-resistant *P. aeruginosa*; MRSA: methicillin-resistant *S. aureus*; PRSP: penicillin-resistant *S. pneumoniae*; FRAB: fluoroquinolone-resistant *A. baumannii*; CRAB: carbapenem-resistant *A. baumannii*; FREC: fluoroquinolone-resistant *E. coli*; CREC: carbapenem-resistant *E. coli*.
Averages for different country groups are unweighted.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

Figure 2.6 suggests that, in a minority of countries, resistance proportions, averaged across 12 antibiotic-bacterium combinations, are estimated to increase or decrease in both periods, 2009-19 and 2019-35. While the temporal variation across countries for average resistance proportions is small, Figure 2.6 illustrates the wide range in average resistance proportions across countries, broad differences that seem to remain over time. There is little evidence of any convergence in resistance proportions across countries. Countries with historically low average resistance proportions are likely to maintain these into 2035. Countries with historically high average resistance proportions are estimated to have experienced most of the growth in 2009-19, with average resistance proportions either flattening or dropping slightly by 2035.

Figure 2.6. Projected average proportion of infections caused by bacteria resistant to antimicrobial treatment for 12 antibiotic-bacterium combinations in 2009, 2019 and 2035



Note: For countries on the left of this graph, resistance proportions are higher in 2035, compared to 2019. For countries on the right, rates are be lower in 2035. Otherwise, countries are sorted left to right based on ascending resistance proportions in 2019. Averages for different country groups are unweighted.

Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

StatLink https://stat.link/8l5h7e

Despite a projected overall stabilisation of resistance proportions, averaged across 12 antibiotic-bacterium combinations, resistance proportions for certain countries and antibiotic-bacterium pairs are projected to remain dangerously high. In 2035, it is projected that in G20 countries around half of infections due to *A. baumannii* could be resistant to either fluoroquinolones or carbapenems (Table 2.4).

Table 2.4. Estimated resistance proportions for 12 priority antibiotic-bacterium combinations, 2035

Country	FRAB	CRAB	3GCRKP	FREC	CRPA	3GCREC	MRSA	VREFm	PRSP	CRKP	CREC	VREFs	Average
India	79.9	72	83.8	84	45.2	80.8	62.5	27.4	16.6	62	28.7	11.7	54.6
Türkiye	85.9	84.9	70.6	56.8	42.7	48.2	28.7	17.8	42.4	37.2	5.8	4	43.8
Greece	89.8	86.3	68.8	32.3	47.1	23.9	37.4	29.9	18	59.8	1.2	0.9	41.3
Romania	84.9	81.4	67.4	31.1	55.9	24.4	43.5	34.4	28.1	37.9	0.3	1.9	40.9
Saudi Arabia	70.9	76.6	62.3	49.5	34	50.1	44.3	27.1	24.3	35.8	5.2	4.6	40.4
Indonesia	77	53.5	72.4	63.5	35.2	62.9	44.5	26.2	18.9	16.8	5.8	3.8	40
Mexico	84.5	69.3	47.2	69.2	33.3	59	44.3	25.9	18.3	9.7	3.1	1.9	38.8
China	71.1	68.3	54.6	64.5	30.8	60.4	39.2	15.5	13	30.3	9	7.5	38.7
Argentina	74.7	72	56.2	37.4	33.5	22.6	44.1	58.7	23.6	21.1	4.1	5.7	37.8
Poland	83.7	66.2	61.6	46.4	34	23.1	22.7	46.9	18.8	16.5	7	9.3	36.3
Bulgaria	84.1	72.7	76.1	44.4	31.5	45.1	16.7	11.6	11.2	39.8	0.5	0.4	36.2
Cyprus	79.2	76.7	46.5	47	25.5	31.1	36.7	39.1	14	16	1.1	0.9	34.5
Croatia	84.9	84.7	50.1	34.3	34.1	17	25.8	23.7	18.8	23.6	0	0.9	33.2
South Africa	66.4	75.2	70.7	31.4	37.8	29.6	25.9	14	27.2	14.1	1.2	1.2	32.9
Italy	76.4	70.8	53.8	41.9	20.8	30.7	34.5	19.5	10.7	22.1	0.7	1.7	32
Lithuania	87.6	81.6	51.2	24	24.8	20.8	9.4	38.7	14.3	4.6	0	2.6	30

Country	FRAB	CRAB	3GCRKP	FREC	CRPA	3GCREC	MRSA	VREFm	PRSP	CRKP	CREC	VREFs	Average
Brazil	61.7	60.2	52.4	50	29.1	26.2	19.7	20.6	15.6	20.6	0.8	1	29.8
Korea	53.1	54.5	32.9	44.9	26.7	36	43.4	20.4	32.7	4.5	2.5	3.2	29.6
Slovak Republic	63.4	42.5	55.2	44	42.9	27.8	28.5	28.4	12.5	6.6	0	0.1	29.3
Latvia	80.3	73.7	41.2	28.7	36.7	20.4	6.1	35.2	18.7	3.4	0.2	4.5	29.1
Costa Rica	69.2	58.6	44.2	24.4	31	26.9	32.3	17	16.9	12.2	3.4	2.9	28.3
Colombia	67.5	56.5	43.6	24.5	29.3	28.6	32.4	19.8	16.1	12.5	2.6	2.3	28
Peru	64.5	50.6	40.5	27.5	26.5	29.1	28.7	27.9	16.6	12.4	3.8	4.7	27.7
Hungary	76.3	53.1	40.2	30.7	34.1	22.7	21.4	26.4	9.2	2	0	0	26.4
Chile	56.5	48.9	36.6	32.9	24.4	24	27	22.4	14.9	11.2	1.6	2	25.2
Malta	53.5	40.5	40.4	40.8	18.3	18.4	18.2	19.8	22.5	16.4	3.6	3.9	24.7
United States	47.3	24.8	15.5	26.4	16.3	13.8	40.7	67.1	19.3	7.7	1.7	3.9	23.7
Portugal	47.8	35.4	50.2	29.9	21.4	17.9	35.8	9.6	13.4	14.6	0.2	0.9	23.1
Spain	61.6	56.2	27	32.9	22.9	16	24.8	2.5	21.8	7	1	0	22.8
Luxembourg	40.7	33.6	34.2	28	18.4	20.9	11.4	11	20	9	7.6	8.4	20.3
Israel	48.1	33.9	26.9	24.4	17.1	16.9	20.2	28	14.2	7.7	0.9	1.6	20
Czech Republic	49.5	22.1	50.4	26.2	22.6	16	13.6	21.8	4.5	1.1	0.4	0.3	19
Canada	39.4	31	13	29.2	24.2	14.7	14	30.8	9.8	7	1.6	1.3	18
Slovenia	60.3	30.3	20.1	22.9	21.1	12	8.8	2.7	10.6	0.9	0.6	0.5	15.9
New Zealand	38.4	23	17.4	14.4	16.1	12.7	16.3	23.5	14.4	7.1	1.1	1.6	15.5
Japan	38	5.6	7.9	32.6	17.8	20.9	31.6	23.1	3	1.6	0.7	1.3	15.3
Ireland	14.2	3.8	17.9	24.3	12.3	15	11.7	36.9	29.6	1.3	0.4	1.3	14.1
Australia	17.1	6.8	10	20.2	10.3	13.2	16.2	47.7	13.8	2.2	0.2	0.5	13.2
France	21.9	6.9	30.3	18.5	19.8	11.5	10.6	2	29.7	1.6	0.9	0.9	12.9
Iceland	36.8	24	8.6	15.4	16	10.4	2.4	19.1	11.9	2.7	0.7	0.3	12.4
Estonia	40.9	24.5	15.8	21.8	17.1	10.7	3.5	3.7	5.6	0.6	0.2	0.1	12
Germany	22.6	4.4	13.2	22.1	20.9	14	8.3	26.2	5	0.4	0	0	11.4
Belgium	16.4	4.3	21.3	23.9	13.5	13	10.3	2.9	14	1.8	0	0.9	10.2
Finland	49.3	2.7	7.5	15.7	11.2	8.4	2.5	0.6	14.1	0.3	0	0.2	9.4
United Kingdom	14.3	3.2	13.4	19.7	8.7	13.2	7.5	23.3	5.4	1	0	2	9.3
Austria	27.9	7.5	10.6	21.4	16.5	10.5	6.2	3.6	4.7	1	0	0.1	9.2
Switzerland	22.6	6.7	8.4	19.8	12.4	10.2	3.6	2.7	5.7	1.9	5.2	0.2	8.3
Sweden	31.2	3.3	9.2	19.7	11.1	9.3	2.6	0.8	6.6	0.3	0	0	7.9
Denmark	12.2	2.6	9.1	14.2	6.3	8.8	2.1	13.6	5.5	0.3	0	0.1	6.2
Netherlands	16.7	2.6	11	19	7.7	8.6	1.7	1.2	4.6	0.3	0	0	6.1
Norway	9.6	3.8	9.3	15	11.4	6.6	1.5	1.2	6.2	0.1	0	0.7	5.5
G20 countries	56	47	42	42	27	34	31	27	18	16	4	3	29
ALL countries	54	41.9	36.8	32.6	24.7	23.8	22.1	21.6	15.4	12.3	2.3	2.2	24.1
EU/EEA countries	51	37	34	28	23	18	16	18	14	10	1	1	21
OECD countries	45	30	28	28	21	18	17	19	14	7	1	2	19

Note: The colour scheme is based on a two-point scale (minimum in light grey, maximum in blue and points in between coloured proportionally). Countries (and country groupings) are sorted from top to bottom from highest to lowest average resistance proportions (across antibiotic-bacterium combinations). Antibiotic-bacterium combinations are sorted from left to right from highest to lowest average resistance proportions (across countries). VREFs: vancomycin-resistant *E. faecalis*; VREFm: vancomycin-resistant *E. faecium*; 3GCREC: third-generation cephalosporin-resistant *E. coli*; CRKP: carbapenem-resistant *K. pneumoniae*; 3GCRKP: third-generation cephalosporin-resistant *K. pneumoniae*; CRPA: carbapenem-resistant *P. aeruginosa*; MRSA: meticillin-resistant *S. aureus*; PRSP: penicillin-resistant *S. pneumoniae*; FRAB: fluoroquinolone-resistant *A. baumannii*; CRAB: carbapenem-resistant *A. baumannii*; FREC: fluoroquinolone-resistant *E. coli*; CREC: carbapenem-resistant *E. coli*.
Averages for different country groups are unweighted.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

In the OECD, Greece and Türkiye are likely to continue to exhibit very significant average resistant proportions, with more than half of infections due to *K. pneumoniae* in Greece projected to be resistant to carbapenem and over half of infections due to *E. coli* estimated to be resistant to fluoroquinolones in Türkiye in 2035.

Box 2.2. Comparison of projections presented here and those published in 2018

Some of the estimates of resistance proportions, especially the averages, presented here are not strictly comparable to the estimates published in the OECD report *Stemming the Superbug Tide* (2018[3]), for two reasons. First, the new estimates presented in this report are for 12 antibiotic-bacterium combinations compared to 8 in 2018. Second, the reference years are slightly different: whereas 2005, 2015 and 2030 were used in *Stemming the Superbug Tide*, 2009, 2019 and 2035 are used in this report.

While this complicates comparisons of averages, it is possible to compare estimates for antibiotic-bacterium combinations in individual countries in specific years. This comparison shows that new estimates of resistance proportions are lower than estimates from 2018. The differences are largest for countries where data are missing the most, including Brazil, China, Costa Rica, Indonesia, Israel and Saudi Arabia. This is aligned with expectations that when new data became available, it would be the countries with the most missing data that would see the biggest changes. Oldenkamp et al. (2021[16]) recently explored the impact new surveillance data could have on predictions of resistance proportions, using an approach similar to the one used here. They found that predictions for countries like Brazil and Indonesia were volatile and more affected by uncertainty in the estimation procedures.

A key characteristic of the methodology employed here, and by Oldenkamp et al. (2021[16]), is that missing data are imputed based on existing surveillance data and relationships with covariates. When new data become available, it is likely that all estimates – even those for countries where no new data exist – will be revised in light of the new evidence. While a formal assessment of the key drivers behind these changes was not conducted, it is likely that new lower estimates are driven by at least four factors. One, there were more countries where resistance proportions, averaged across 12 antibiotic-bacterium combinations, exhibited a downward trend in the period 2009-19 than in the period 2005-15. Second, antibiotic consumption in humans in the EU/EEA (a region that accounts for more than half of the 51 countries included here and most of the existing data) has decreased between 2010 and 2019. Third, antimicrobial consumption in animals – included in the estimation procedures for the first time under a One Health approach – has shown a downward trend in the EU/EEA and the OECD in the last years. Fourth, recent trends in AMR in the EU/EEA between 2016 and 2020 show some reductions.

For all this, when interpreting the results presented here, it is crucial to consider the (often significant) uncertainty that underlies the estimates – especially for countries where data are sparser. It is also vital that countries continue to invest in comprehensive and standardised surveillance efforts so that efforts to fill data gaps lead to more accurate and robust estimates.

Source: OECD (2018[3]), *Stemming the Superbug Tide: Just A Few Dollars More*, https://doi.org/10.1787/9789264307599-en; Oldenkamp, R. et al. (2021[16]), “Filling the gaps in the global prevalence map of clinical antimicrobial resistance”, https://doi.org/10.1073/PNAS.2013515118.

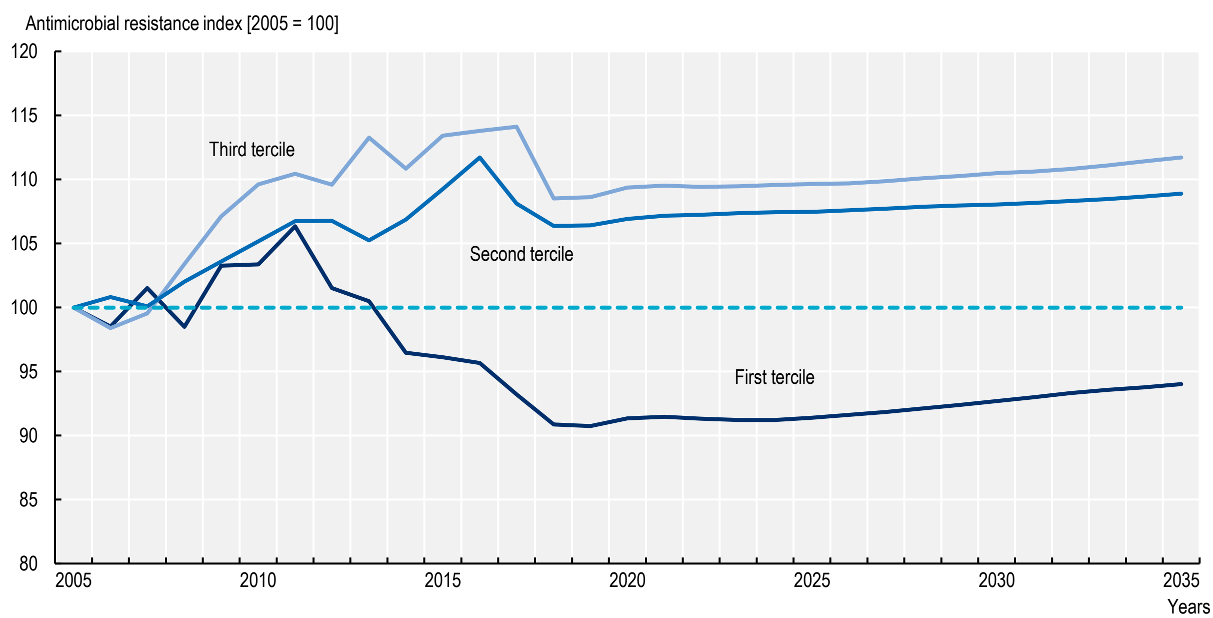
Resistance proportions are forecasted to remain high compared to 2005

There is no clear projected reduction in the broad range between the highest average resistance proportions and the lowest average resistance proportions in OECD countries (Figure 2.7). Between 2005 and around 2011, in countries at different levels of resistance, averaged across 12 antibiotic-bacterium combinations, AMR evolved similarly, with resistance proportions growing compared to the 2005 baseline. However, from around 2011, in countries in the bottom tercile of resistance proportions (based on 2005 levels), resistance proportion started to decrease, while continuing their upward trends in countries in the second and third terciles. While from 2017, resistance proportions in countries in the bottom tercile have trended significantly upward, there is still a significant gap between resistance proportions in the top tercile and the bottom tercile.

Countries in the top two terciles face significant challenges. Not only are they starting in 2005 with higher resistance proportions than in countries in the bottom tercile but resistance proportions have increased more since 2005 compared to countries in the bottom tercile. Moreover, the projection is that the gaps between countries in the bottom and top terciles will slightly widen in coming years. The range in average resistance proportions across countries is projected to go from 5.7-46.5% in 2019 to 5.5-43.8% by 2035, barely changing. This indicates that countries on the higher end of the range need to do more to reverse current trends or they will continue to face persistently high resistance.

Figure 2.7. In OECD, resistance proportions estimated to remain persistently higher than in 2005

Countries are grouped into terciles based on average resistance proportions for 2005 and resistance proportions are then normalised to average antimicrobial resistance in 2005 (equal to 100) for each tercile



Note: Countries were split into terciles based on 2005 resistance proportions, averaged across 12 antibiotic-bacterium combinations. Data were normalised to average antimicrobial resistance in 2005 (equal to 100) for each tercile (e.g. a value of 112 for resistance in second tercile countries in 2017 means that resistance is 12% higher than it was in 2005 in those countries). Averages for different country groups are unweighted. Historical data go from 2005 to 2020 and forecasts start in 2021.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

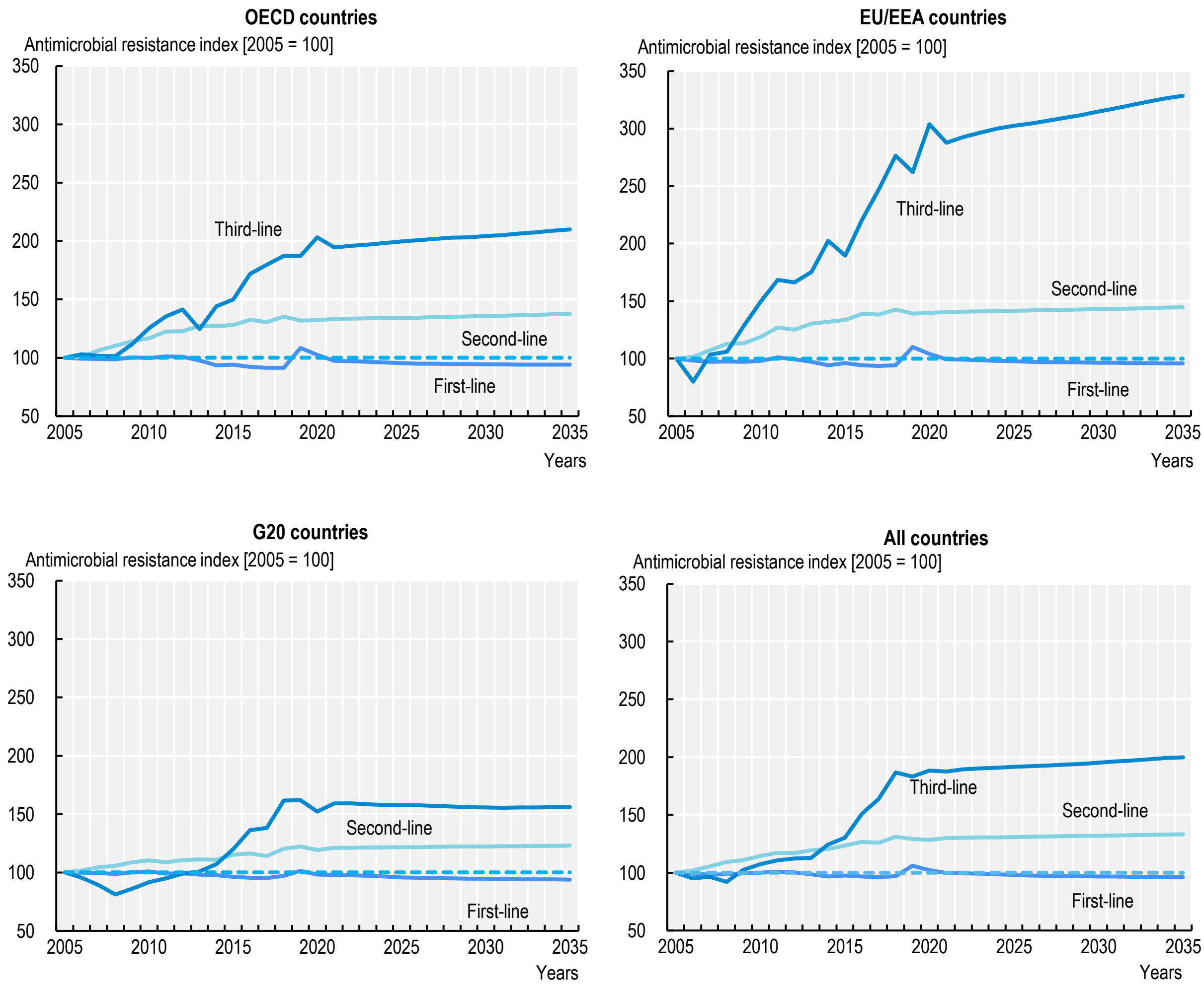
StatLink https://stat.link/1kj0xf

Concerning trends in resistance to third-line antimicrobials and multidrug resistance

Of added concern are also trends in resistance to first-, second- and third-line antimicrobials which indicate that, from 2005, relative growth rates for resistance to second- and third-line antibiotics are higher than for resistance to first-line treatments (Figure 2.8). Resistance to third-line antimicrobials specifically has increased markedly between 2005 and 2019 in EU/EEA, G20 and OECD countries, albeit from still mostly low levels (Table 2.1) which should remain relatively low (Table 2.4). However, resistance to carbapenems, a third-line treatment, in infections due to *K. pneumoniae* is very high in Greece and quite high in Bulgaria, Romania and Türkiye. Furthermore, while the overall consumption of antimicrobials in humans is likely to decrease or stagnate in the future, the consumption of carbapenems is projected to increase. The more these treatments are used, the more likely it is that resistance develops. As resistance develops, and in absence of new antibiotics, the only options left to treat infections with resistant bacteria will be older antimicrobial agents, including those with potentially lower efficacy, such as polymyxins (e.g. colistin) or combination therapy.

Resistance among difficult-to-treat microorganisms *P. aeruginosa* is also concerning. These bacteria are intrinsically resistant to several antimicrobial agents and remain a major cause of healthcare-associated infections (ECDC, 2020[74]; CDC, 2019[75]). Resistance proportions for carbapenem-resistant *P. aeruginosa* have actually decreased on average in the EU/EEA and the United States in the recent past, resistance proportions are projected to increase slightly up to 2035 (Table 2.3). Already in 2019, on average across OECD countries, one in five infections due to *P. aeruginosa* were already resistant to carbapenems. Resistance proportions in Greece, Hungary and the Slovak Republic were particularly high. With consumption of carbapenems projected to increase up to 2035, certainly, it remains crucial to balance access to antimicrobial therapies with prudent and appropriate use (stewardship). Interventions for infection prevention and control, especially in healthcare settings, are also essential to prevent further emergence and spread of resistance. Finally, multidrug resistance is already high in certain pathogens. According to the latest European data (EFSA/ECDC, 2020[68]), almost a third of *Salmonella* spp. isolates from humans were multidrug resistant in 2018 (OECD et al., 2022[35]).

Figure 2.8. Trends in antimicrobial resistance in selected regions and country groups among priority antibiotic-bacterium combinations, by line of antimicrobial treatment



Note: Data were normalised to average antimicrobial resistance in 2005 (equal to 100) for each treatment line (e.g. a value of 150 for resistance to second-line treatments in 2015 in G20 countries means that resistance to second-line treatments is 50% higher than it was in 2005 in G20 countries). Resistance to first-line treatments is defined as the average of the proportions of penicillin-resistant *S. pneumoniae*, MRSA, fluoroquinolone-resistant *A. baumannii*, and carbapenem-resistant *A. baumannii*. Resistance to second-line treatments is the average of the proportions of *E. coli* and *K. pneumoniae* resistant to third-generation cephalosporins, *E. coli* resistant to fluoroquinolones, vancomycin-resistant *E. faecalis*, vancomycin-resistant *E. faecium*, and carbapenem-resistant *P. aeruginosa*. Resistance to third-line treatments is defined as the average of the proportions of *K. pneumoniae* resistant to carbapenems and carbapenem-resistant *E. coli*. Averages for different country groups are unweighted. Historical data go from 2005 to 2020, and forecasts start in 2021.
Source: OECD analyses of data from surveillance networks included in OneHealthTrust/IQVIA (2022[33]), *ResistanceMap – Antibiotic Use*, https://resistancemap.cddep.org/AntibioticUse.php.

StatLink https://stat.link/cyqbpn

Conclusion

Over the last two decades, on average across OECD countries, antimicrobial consumption in humans increased only slightly and, in the last couple of years, the trend has been downward. While the levels and trends across individual countries were very heterogeneous, recent data seem to suggest that antimicrobial stewardship may be leading to real change. If total antibiotic consumption continues to evolve along the same lines as in the period 2000-15, then it is estimated that consumption will decrease between 2015 and 2035 by 3% in the OECD as a whole. Also in the food animal sector, antimicrobial is projected to decrease, following a pattern of reductions in the last decade in the EU/EEA and OECD. Despite these positive projections, consumption of highest priority and third-line antibiotics is growing. In 2015, there were 14 OECD countries, along with Brazil, China and India, that did not meet the WHO target for Access antibiotics to make up at least 60% of total national consumption. Vaccination targets for seasonal influenza among older populations, which could help reduce the need for antimicrobials, are also widely missed.

Alongside downward trends in total antimicrobial consumption in humans and animals, resistance proportions are projected to drop slightly by 2035, on average across 12 priority antibiotic-bacterium combinations, if current trends in resistance, and correlates of resistance, continue into the future and no other policy actions are taken beyond the ones currently in place. However, regional averages mask the ten-fold difference in average resistance proportions across OECD countries, with more than half of infections due to *K. pneumoniae* in Greece projected to be resistant to carbapenems and over half of infections due to *E. coli* estimated to be resistant to fluoroquinolones in Türkiye in 2035. What is worse, there is no evidence of a convergence in resistance proportions across countries; in fact, it is projected that the range between the countries with the most resistance and those with less resistance will slightly widen in 2035. This indicates that countries on the higher end of the range need to do more to reverse current trends, or they will continue to face persistently high resistance.

While modelling has been increasingly used to make up for gaps in data collection and while it can be useful when data are unavailable or are difficult to compare without manipulation, modelling is not a substitute for comprehensive high-quality surveillance and should not detract from efforts to expand and improve surveillance networks. Furthermore, it is intrinsically difficult to predict a new resistance mechanism using models. Despite recent progress in surveillance, there are still gaps in the collection and reporting of comprehensive, internationally comparable, standardised data on antimicrobial consumption and resistance. Without these data, there can be no accurate understanding of the AMR challenge, its consequences, its evolution and whether actions to tackle the challenge are effective. Efforts to standardise and harmonise data collection from a One Health approach have been especially slow.

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Notes

[1]See *List of Enrolled Countries* link in https://www.who.int/initiatives/glass/country-participation (accessed March 2023).

[2] See https://www.ecdc.europa.eu/en/about-us/networks/disease-networks-and-laboratory-networks/ears-net-data (accessed March 2023).

[3] Ibid.

[4] Not all sales of antimicrobials lead to consumption, however data on consumption are difficult to obtain, if not impossible in the community. As such, sales are used throughout this chapter as an imperfect yet pragmatic proxy for consumption. The IQVIA MIDAS database estimates antibiotic consumption from the volume of antibiotics sold in retail and hospital pharmacies based on national sample surveys done by pharmaceutical sales distribution channels (i.e. from manufacturer to wholesaler to retailer).

[5] DDD is a standard measure for drugs, calculated as the assumed average maintenance dose per day for a drug used for its main indication in adults (WHO, 2003[77]). The unit used throughout this chapter is DDD per 1 000 inhabitants per day.

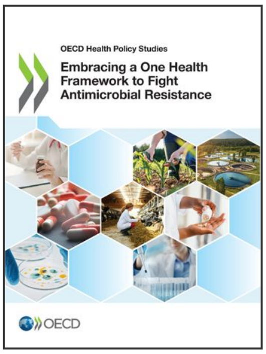
[6] Broad-spectrum antibiotics: broad-spectrum penicillins (ATC groups J01CR, J01CD), broad-spectrum cephalosporins (J01DC, J01DD), macrolides (J01 FA) except erythromycin (J01FA01) and fluoroquinolones (J01MA); narrow-spectrum antibiotics: narrow-spectrum penicillins (J01CA, J01CE, J01CF), narrow-spectrum cephalosporins (J01DB) and erythromycin (J01FA). Consumption expressed in DDD per 1 000 inhabitants per day.

[7] Proportion (%) of glycopeptides, third- and fourth-generation cephalosporins, monobactams, carbapenems, fluoroquinolones, polymyxins, piperacillin and enzyme inhibitors, linezolid, tedizolid and daptomycin (DDD per 1 000 inhabitants per day) out of total hospital consumption of antibiotics for systemic use.

[8] Canada's National Aquaculture Public Reporting Data provide a comprehensive dataset containing a list of the type and quantities of drug and pesticide products used at aquaculture facilities to combat pests and microbial pathogens (Government of Canada, 2022[76]).

[9] NARMS Now: Human Data, an interactive tool from CDC, can be accessed from https://wwwn.cdc.gov/NARMSNow.

[10] Reports can be found at http://www.google.com/covid19/mobility/ (last accessed June 2022).


OECD Health Policy Studies
Embracing a One Health Framework to Fight Antimicrobial Resistance
OECD