How coronavirus disease has changed the environment and health landscape

WEB ANNEX: A RAPID REVIEW OF REVIEWS
Abstract

This document presents a rapid review of reviews that was undertaken to establish evidence of the relation between environmental health and the coronavirus disease (COVID-19) pandemic. The review was prepared as a background document for a policy brief entitled How coronavirus disease has changed the environment and health landscape: a policy brief to underpin discussions about the future of environmental health, in preparation for the seventh Ministerial Conference of the European Environment and Health Process. The review explores possible contributions to the genesis and spread of the SARS-CoV-2 virus that causes COVID-19 in humans, as well as the impact of the COVID-19 pandemic itself and also of the mitigation measures used to reduce the spread of disease. In many cases, the extreme pressure created by the disease and its mitigation revealed weaknesses in the resilience and flexibility of environmental health and related systems; in other cases, it showed what could be done to address other existential pressures, such as climate change. A number of reviewers have seen the pandemic as a pivotal point for change and improvement.

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How coronavirus disease has changed the environment and health landscape

WEB ANNEX: A RAPID REVIEW OF REVIEWS
Contents

Acknowledgements ........................................................................................................ vi
Acronyms ......................................................................................................................... vii

1 Introduction .................................................................................................................... 1

2 Methods ......................................................................................................................... 2
  2.1 Search strategy ........................................................................................................... 3
  2.2 Inclusion and exclusion criteria ................................................................................. 3
  2.3 Screening ..................................................................................................................... 4
  2.4 Synthesis .................................................................................................................... 6
  2.5 Outcomes selected ..................................................................................................... 6

3 Results ............................................................................................................................. 10
  3.1 Origins of COVID-19 and zoonotic disease ............................................................... 12
  3.2 Transmission of SARS-CoV-2 in the environment ...................................................... 13
  3.3 The home environment and other indoor settings ..................................................... 14
  3.4 COVID-19, water, sanitation, and hygiene (WASH) and wastewater management .... 19
  3.5 COVID-19, waste and waste management ................................................................ 21
  3.6 COVID-19 and ambient air ....................................................................................... 24
  3.7 COVID-19 and food ................................................................................................... 28
  3.8 COVID-19 and public places ..................................................................................... 30
  3.9 COVID-19 and the health sector ............................................................................... 34
  3.10 COVID-19 and global systems ............................................................................... 36

4 Building forward better ................................................................................................. 40
  4.1 Improving the resilience of waste systems ............................................................... 41
  4.2 Improving the resilience of the energy sector ............................................................ 41
  4.3 Improving the resilience of food supply chains ........................................................ 42
  4.4 Improving the resilience of health systems ............................................................... 43
  4.5 Improving the resilience of the places in which people live ....................................... 43
  4.6 The global economy, the social sector and the environment ..................................... 45
  4.7 COVID-19 as a tipping point for action on climate change ....................................... 46
  4.8 Future action on biodiversity .................................................................................... 47
  4.9 One Health ............................................................................................................... 47

5 Gaps in knowledge .......................................................................................................... 48

6 Conclusions ..................................................................................................................... 49

References .......................................................................................................................... 50

How coronavirus disease has changed the environment and health landscape v
Acknowledgements

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Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACE-2</td>
<td>angiotensin-converting enzyme 2</td>
</tr>
<tr>
<td>AMR</td>
<td>antimicrobial resistance</td>
</tr>
<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>COVID-19</td>
<td>coronavirus disease</td>
</tr>
<tr>
<td>MSW</td>
<td>municipal solid waste</td>
</tr>
<tr>
<td>NO₂</td>
<td>nitrogen dioxide</td>
</tr>
<tr>
<td>O₃</td>
<td>ozone</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>PM₀₂₅</td>
<td>particulate matter measuring ≤ 2.5 µm</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>particulate matter measuring ≥ 10 µm</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protective equipment</td>
</tr>
<tr>
<td>PRISMA</td>
<td>Preferred Reporting Items for Systematic Reviews and Meta-Analyses</td>
</tr>
<tr>
<td>SARS-CoV-2</td>
<td>severe acute respiratory syndrome coronavirus 2</td>
</tr>
<tr>
<td>SO₂</td>
<td>sulfur dioxide</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compounds</td>
</tr>
<tr>
<td>WASH</td>
<td>water, sanitation and hygiene</td>
</tr>
</tbody>
</table>
1 Introduction
This rapid review of reviews was undertaken to establish evidence of the relation between environmental health and the coronavirus disease (COVID-19) pandemic, which was declared a public health emergency of international concern by the World Health Organization (WHO) on 11 March 2020. The review was prepared as a background document for a policy brief entitled How coronavirus disease has changed the environment and health landscape (I) to underpin discussions about the future of environmental health, in preparation for the seventh Ministerial Conference of the European Environmental Health Process. The structure of this document is therefore similar to that of the policy brief, to facilitate cross-referencing.

Research on the issues identified in the reviews took two main directions. The first was to explore possible contributions to the genesis and spread of the SARS-CoV-2 virus that causes COVID-19 in humans. These studies investigated theoretical or early observations of associations and discussed the wider implications of the findings for COVID-19 itself or for future disease outbreaks. A second direction was the impact of the COVID-19 pandemic itself and also of the mitigation measures used to reduce the spread of disease. In many cases, the extreme pressure created by the disease and its mitigation revealed weaknesses in the resilience and flexibility of environmental health and related systems; in other cases, it showed what could be done to address other existential pressures, such as climate change. A number of reviewers have seen the pandemic as a pivotal point for change and improvement.
2 Methods
2 Methods

2.1 Search strategy

The initial searches were undertaken on 9 September 2021 in LitCovid (from the National Library of Medicine), with a list of keywords as search terms. The next stage was undertaken between 22 and 29 September 2021 in LitCovid, LOVE (by Epistemonikos), the WHO COVID-19 Database, CAB Abstracts (accessed via WHO), the Web of Science Core Collection (accessed via WHO) and Google Scholar with Publish or Perish software. The results were downloaded into Endnote V9 and duplicates removed with the default Endnote option and the deduplicator tool of the Systematic Review Accelerator (2).

Forward citation searching was undertaken in the Web of Science for grey literature. The list was then searched with the keyword “covid” for potentially relevant literature.

Targeted searches were undertaken between 14 and 21 October 2021 in LOVE, LitCovid, WHO COVID-19 Database and Google Scholar. Keyword searches and the “similar publications” option in LitCovid were also used.

The search terms were derived initially from topics provided by WHO, then with keywords identified in initial searches and email discussions. Specific fields were searched when available, with relevant truncation and phrase searching when appropriate.

Updated searches were undertaken in January and February 2023. In accordance with the search summary table from the initial searches, only LitCovid, LOVE, WHO COVID-19 database and Web of Science were searched. The same search terms were used as in 2021, with the additional search term “review” and a date restriction of 2022.

Forward citation searching was undertaken in spidercite for the 122 references selected in the initial stage, and the records were downloaded to Endnote and searched in a simple review. All records were downloaded into Endnote V20 and de-duplicated.

2.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria used in both rounds of screening are listed in Table 1.

Table 1. Inclusion and exclusion criteria

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant setting</td>
<td>Reviews of studies conducted in Europe or in the global North, such as</td>
<td>Conducted wholly in the global South, such as Africa, Asia and South</td>
</tr>
<tr>
<td></td>
<td>Australia, Canada and the United States of America (USA)</td>
<td>America</td>
</tr>
<tr>
<td></td>
<td>Reviews in which most studies were conducted in the global North context</td>
<td>Reviews in which studies conducted in the global South and the global</td>
</tr>
<tr>
<td></td>
<td>or in which studies conducted in the global North were reported separately from those in the global South, or where context was relevant to the global North</td>
<td>North were not separated</td>
</tr>
<tr>
<td>Relevant COVID-19 focus</td>
<td>Clear focus on COVID-19</td>
<td>No clear focus on COVID-19</td>
</tr>
<tr>
<td></td>
<td>COVID-19 mentioned only to contextualize the review</td>
<td></td>
</tr>
</tbody>
</table>
2 Methods

### 2.3 Screening

#### 2.3.1 Initial screening (2021)

The reviews retrieved in the initial searches were reviewed in September and October 2021 for their relevance to the literature review, according to their titles and abstracts, by all four of the original review team: GM, SB, AB and JE. Each team member assessed the reviews independently, followed by a live discussion amongst the team, including differences in assessments. The discussion included drawing up a list of keywords based on the topics for the review. Colleagues at WHO provided feedback and proposed additional topics, which were added to the keyword list.

In 2021, articles were searched, screened and categorized in four stages. As described above, AB undertook full searches, de-duplicated the list and removed obviously non-relevant articles. Targeted searches were then conducted to identify topics that were poorly covered in the reviews. This involved extending the search to primary research articles. In the second stage, JE examined the titles and abstracts of each article to determine their relevance and, in the third stage, assessed the full text of each article to determine its relevance. In the fourth stage, JE completed a uniquely designed meta-data form that listed the broad topics covered by each article, categorized them into type (e.g. systematic review, narrative review, primary research), and provided a brief summary of each article, including the main topic and its usefulness for the literature review. The form includes a hyperlink, the American Psychological Association style citation, the abstract of each article and a brief assessment of confidence in each article by categorization as very good, good, moderate or low and a statement of the reasoning for the assessment. JE provided a reason for exclusion of each article that was deemed irrelevant at full-text examination.

In 2021, 122 articles were considered relevant after full text reading (Table 2), comprising 111 reviews and 11 primary research articles. At that time, we were unable to obtain the full texts of two reviews considered potentially relevant from their title and abstract:

- Jyoti, Bhattacharya B. Impact of COVID-19 in food industries and potential innovations in

---

2.3 Screening

<table>
<thead>
<tr>
<th>Relevant topic or outcome</th>
<th>Topics listed in section 2.5</th>
<th>Topics not listed in section 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant review type</td>
<td>Systematic review</td>
<td>Non-systematic reviews (of topics already well-covered in included reviews)</td>
</tr>
<tr>
<td></td>
<td>Scoping review</td>
<td>Primary research</td>
</tr>
<tr>
<td></td>
<td>Semi-systematic review (containing some elements of systematic review methods)</td>
<td>Editorials and overviews</td>
</tr>
<tr>
<td></td>
<td>Non-systematic review (eligible only if the topic was not covered in any other included review of the above type)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>In English</td>
<td>In a language other than English</td>
</tr>
<tr>
<td></td>
<td>Duplicates</td>
<td>Duplicates</td>
</tr>
<tr>
<td></td>
<td>Reports superseded by newer, more comprehensive or more complete reports</td>
<td></td>
</tr>
</tbody>
</table>

During the 2023 update, the full texts of these two reviews were retrieved, and the articles were excluded. The numbers and types of articles that were found relevant after review of the full text in 2021 are listed in Table 2.

Table 2. Numbers of articles retained after the first “sift” and found to be relevant at full-text review in 2021

<table>
<thead>
<tr>
<th></th>
<th>No. retained after the first “sift”</th>
<th>No. considered relevant at full-text reading</th>
<th>No. of full-text articles not found</th>
</tr>
</thead>
<tbody>
<tr>
<td>List 1</td>
<td>56</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>List 2</td>
<td>61</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>List 3</td>
<td>43</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>Targeted searches</td>
<td>119</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>279</td>
<td>122</td>
<td>2</td>
</tr>
</tbody>
</table>

Articles that had passed the full-text review in 2021 were passed to SB to assess the evidence and the relevance to the topic. After discussion and agreement with GM, some reviews were excluded, either because subsequent (i.e. later published) reviews covered the same area in greater depth or the reviews only provided guidelines on issues such as waste segregation and disposal for certain countries. The findings of 86 reviews were thus processed in 2021 for inclusion in this review of reviews. SB and GM subsequently agreed not to include primary research articles identified in the targeted search. This report is therefore confined to a rapid review of reviews and one briefing from the Centers for Disease Control and Prevention in the USA.

Given the wide-ranging nature of the topic, the reviews were authored by researchers in a range of academic disciplines, each with their view on what constitutes evidence and on what constitutes a review.

2.3.2 Updated review screening (2023)

To update the review of reviews, the articles retrieved in new searches were reviewed in March and April 2023. An initial “sift” of reviews was undertaken by AB to remove reviews that were obviously not relevant. The screening consultant, JE, then conducted the remainder of the screening and relevance assessment using the inclusion and exclusion criteria listed above. JE had undertaken the original review of reviews and was therefore experienced in making decisions for this assessment. In the first stage, each article was screened for relevance on the basis of the title and abstract. An article
2 Methods

was deemed either potentially relevant or not relevant.

The full text of each article deemed potentially relevant was obtained and assessed for relevance. For articles that were deemed not relevant, a reason for exclusion was given. For reviews deemed to be relevant on the basis of the full text, meta-data were extracted, which included the category and topic(s) covered in the review, the review type and a brief summary of its scope.

A confidence assessment was made for each review, comprising categorization as very good, good, moderate or low. The reason for providing a confidence assessment was included. The categorizations are based on broad categories of the risk for bias in systematic review; for non-systematic, semi-systematic and scoping reviews, the categorizations were adjusted to reflect the review type. For example, a systematic review with a confidence rating of “good” had a lower risk of bias (and was given more weight in the synthesis) than a semi-systematic review with the same confidence rating. A semi-systematic review with a confidence rating of “very good” had a lower risk of bias (and was given more weight in the synthesis) than a systematic review with a confidence rating of “low”.

2.4 Synthesis

The synthesis of the reviews includes the evidence used to prioritize the most recent, most comprehensive evidence after account was taken of the risk of bias (confidence) and the type of review. A Grading of Recommendations, Assessment, Development and Evaluation (GRADE) (3) evidence profile not appropriate for this review of reviews, first, because the evidence was derived from reviews rather than studies, which is not the intended use of the GRADE profile, and, secondly, the reviews did not provide information about imprecision, indirectness, inconsistency or publication bias. We therefore provide a narrative review of the reviews, on the basis of the factors recorded on the meta-data sheet and the authors’ assessment of the evidence base.

In the updated review of reviews in 2023, the titles and abstracts of 545 articles were screened. Of these, 100 were deemed potentially relevant, and the full text article of each was retrieved and assessed for relevance. Of these, 51 were deemed to be not relevant and 49 relevant, from which meta-data were extracted. These, with the 86 reviews from the original review of reviews, resulted in 136 reviews for this updated review of reviews. Articles for inclusion were passed to SC to incorporate into an updated review of reviews and were discussed with JE and GM. After discussion and agreement, four of the reviews were excluded, either because other reviews covered the same area in greater depth or because they were found to be insufficiently relevant or useful. In total, therefore, 132 reviews were included in this updated review of reviews.

2.5 Outcomes selected

The categories and topics (which may be considered “selected outcomes”) listed in Table 3 were chosen in consultation with WHO during the original review of reviews.
Table 3. Categories and topics related to COVID-19 and environmental health

<table>
<thead>
<tr>
<th>Category</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>Transmission of SARS-CoV-2 in ambient aerosol</td>
</tr>
<tr>
<td></td>
<td>Indoor transmission (domestic, occupational)</td>
</tr>
<tr>
<td></td>
<td>Transmission of SARS-CoV-2 on transport systems</td>
</tr>
<tr>
<td></td>
<td>Emergence of SARS-CoV-2 (e.g. markets)</td>
</tr>
<tr>
<td></td>
<td>Transmission of SARS-CoV-2 via waste</td>
</tr>
<tr>
<td></td>
<td>Impact of built environment on transmission of SARS-CoV-2 (new in 2023)</td>
</tr>
<tr>
<td>Air quality</td>
<td>Ambient air quality and pollution (changes in traffic and public transport)</td>
</tr>
<tr>
<td></td>
<td>Indoor air quality: increased ventilation (domestic, occupational)</td>
</tr>
<tr>
<td></td>
<td>Hazardous chemicals in aerosols</td>
</tr>
<tr>
<td></td>
<td>Working from home (increase)</td>
</tr>
<tr>
<td></td>
<td>Indoor ventilation (increase)</td>
</tr>
<tr>
<td></td>
<td>Exposure to tobacco smoke (increase)</td>
</tr>
<tr>
<td></td>
<td>Management and monitoring of air systems and their quality</td>
</tr>
<tr>
<td></td>
<td>Ambient air quality and pollution (increased risk for noncommunicable diseases, which in turn increases the risk of severe COVID-19)</td>
</tr>
<tr>
<td>Water, sanitation and hygiene (WASH) and water</td>
<td>Demand for washing (increase), altered patterns of water use</td>
</tr>
<tr>
<td></td>
<td>Demand and use of sanitizer and disinfectant (increase)</td>
</tr>
<tr>
<td></td>
<td>Exposure to hazardous chemicals (in early life), potential replacements</td>
</tr>
<tr>
<td></td>
<td>Access to safe drinking-water, WASH, sanitation</td>
</tr>
<tr>
<td></td>
<td>Environmental surveillance of SARS-CoV-2 in wastewater</td>
</tr>
<tr>
<td></td>
<td>Management, monitoring of water systems, quality and pollution</td>
</tr>
<tr>
<td></td>
<td>Pressure on water provisioning (general)</td>
</tr>
<tr>
<td>Waste management</td>
<td>Rapid increase in demand for and use of disposables, personal protective equipment (PPE) (increase), masks, plastics, United Nations guidance</td>
</tr>
<tr>
<td></td>
<td>Illegal waste disposal and trafficking</td>
</tr>
<tr>
<td></td>
<td>Hazardous waste exposure, contaminated soil, soil quality</td>
</tr>
<tr>
<td></td>
<td>Management and monitoring of waste systems, quality, pollution</td>
</tr>
<tr>
<td>Urban environment (home, transport, public space)</td>
<td>Reduced access to green and blue spaces (during lockdowns)</td>
</tr>
<tr>
<td></td>
<td>Change in demand for housing type, ventilation (access to outdoor spaces), including demand for local spaces for exercise</td>
</tr>
<tr>
<td></td>
<td>Increase in active mobility</td>
</tr>
<tr>
<td></td>
<td>New urban agenda</td>
</tr>
<tr>
<td></td>
<td>Emphasis on “cities of proximity”</td>
</tr>
<tr>
<td></td>
<td>Urban resilience, urban recovery, green recovery</td>
</tr>
<tr>
<td></td>
<td>Noise reduction during lockdowns</td>
</tr>
<tr>
<td></td>
<td>Disruption of food supply chain</td>
</tr>
<tr>
<td></td>
<td>Food security, safety, support systems for isolation, reduced mobility</td>
</tr>
<tr>
<td></td>
<td>Change in public and private transport use, increased active transport</td>
</tr>
<tr>
<td></td>
<td>Negative interaction of urban environment with mental and physical health, domestic violence (lockdowns, working at home)</td>
</tr>
<tr>
<td>Health systems</td>
<td>Infectious disease awareness, loss of complacency</td>
</tr>
<tr>
<td></td>
<td>Extreme pressure on health systems</td>
</tr>
<tr>
<td></td>
<td>Antimicrobial and antibiotic resistance (AMR)</td>
</tr>
<tr>
<td></td>
<td>Energy efficiency of health systems</td>
</tr>
<tr>
<td></td>
<td>Space requirements for distancing, temporary health-care centres</td>
</tr>
<tr>
<td></td>
<td>Health-care medicine and waste management (including clinical waste)</td>
</tr>
<tr>
<td></td>
<td>Quality improvement, efficiency of health systems [new in 2023]</td>
</tr>
<tr>
<td>Environmental services</td>
<td>Access to nature, natural space</td>
</tr>
<tr>
<td></td>
<td>Use of, appreciation of nature, natural space</td>
</tr>
<tr>
<td></td>
<td>Environments for child outdoor activity, physical activity</td>
</tr>
</tbody>
</table>
### 2 Methods

#### Nexus of equity and well-being
- Energy poverty (lockdowns, working at home)
- Domestic violence (lockdowns, working at home)
- Physical activity (lockdowns, working at home)
- Negative interaction between social inequity and mental health (lockdowns, working at home)
- Housing, crowded, ventilation, heating

#### Nexus with environmental impacts
- Change in greenhouse gases and air pollution emissions (transport, working at home)
- Change in modal shares distribution (more – temporary? attention to active mobility, including shared active mobility)
- Potential for floods and droughts
- Strengthening of One Health
- Waterway, sea pollution from WASH
- Biodiversity protection (to prevent future pandemics)
- Plastic pollution, production, disposal
- Pollution, runoff to land and sea
- Landfill pressure
- Impacts on flora and fauna
- Energy efficiency of health systems
- Health-care waste pollution
- Pressure on natural environments
- Weather changes (extreme events due to climate change)
- Circular economy, recycling

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Table 3. contd.
3 Results
The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram is shown in Fig. 1, presenting the flow of articles through this updated review of reviews.

**Fig. 1.** PRISMA 2020 flow diagram for updated systematic reviews, which included searches of databases and registers

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The synthesized findings from the included reviews are summarized below, in subsections. The origins of COVID-19 are discussed in section 3.1, followed by findings from reviews about its transmission in the environment in section 3.2. The relevance of indoor settings to the spread of COVID-19 and action to reduce such transmission are discussed in section 3.3. Sections 3.4 and 3.5 describe COVID-19, WASH, waste and waste management. The relation between COVID-19 and ambient air quality is discussed in section 3.6, and the impacts of and on food supply chains and food security are explored in section 3.7. The effects of COVID-19 on public places, public activities and health and the health sector are covered in sections 3.8 and 3.9. The impact of and on wider global concerns (climate change and biodiversity) are discussed in Section 3.10.
3.1 Origins of COVID-19 and zoonotic disease

COVID-19 has been classified as a zoonotic disease caused by the SARS-CoV-2 virus, which was originally a pathogen in bats (5,6). It is one of an increasing number of pathogens that are considered to have originated in wildlife and that subsequently infected humans, either through direct contact with infected wildlife or through intermediaries such as domesticated animals or vectors (such as biting insects) (7–9). It has been reported that, between 1940 and 2004, 335 new human pathogens were described, 60% of which were from zoonotic sources and 71% of which originated from wildlife (10).

Several factors increase the interface and interaction between humans and wild reservoirs of infection and thus enable zoonotic spill-over. These are described below, in section 4.9.

3.1.1 The environment

Human activities directly impact wildlife habitats, through deforestation (5,8,11), intensification of agriculture (5,10,12,13), livestock farming (5,11) and urbanization (5,7,13). These activities contribute to housing and feeding the growing global human population (14). Humans have an impact on habitats indirectly through their role in biodiversity loss (7,9,10,13,14) and climate change (5,9,10,14,15). It has been argued that biodiversity can provide alternative hosts for pathogens, thus reducing the risk of transmission to humans (9). Climate change can result in changes to environments that may encourage animal hosts such as bats to leave, for example, forest habitats and move to agricultural land, extending their habitat range (5). All of the above result in loss or fragmentation of habitats (9,13,15) and bring wildlife into closer contact with humans, creating opportunities for interspecies transmission.

3.1.2 Wildlife

Bats are known to harbour a range of coronaviruses, apparently with little pathogenic effect (12). They have been identified as the primary host of SARS-CoV-2 (8), with evidence of genetic homology (6). Bats may shed viruses when they are stressed, opening the possibility of transmission to humans (9,12). Human activities and behaviour such as noise and light pollution have been implicated in causing stress in wildlife, affecting their feeding behaviour and resulting in viral shedding (12). It has been suggested that these environmental stressors may affect a wide range of species, further adding to the risk of spill-over of zoonotic diseases (12).

3.1.3 Humans

Humans bring themselves into contact with wildlife by encroaching on their habitats through hunting, poaching (8,12), the (now international) trade in wild meat (11,13) and farming in wildlife habitats. The wildlife trade provides income for some of the poorest sectors of society and generates revenue nationally (8).

In China, where COVID-19 is thought to have originated, recent economic development has opened up the country through railway and road construction, leading to economic prosperity and increasing tourism (5). It has been argued that this has driven the demand for both wild and domesticated meat (8). “Wet markets” have been implicated in both the genesis of the COVID-19 outbreak and other recent viral crossovers (5). In wet markets, live animals and meat are brought from various places into towns and cities and sold in areas that often have no running water for cleaning. They have been identified as a primary source of meat purchases throughout Africa and Asia (5).
One of the determinants of interspecies transmission of SARS-CoV-2 to humans is interaction between its spike protein and the angiotensin-converting enzyme 2 (ACE-2) receptor in the epithelial lining of the human respiratory system (11).

3.2 Transmission of SARS-CoV-2 in the environment

SARS-CoV-2-infected people can produce virus-containing aerosols by coughing, sneezing or exhalation (11,16,17–19). These are either inhaled directly (usually within 2 m) (18), or the aerosol droplets fall onto and contaminate surfaces (16,17,19,20), where they can be picked up on the hands of uninfected people and thus transported to their nose, mouth or eyes and initiate infection (17,21). Transmission can also occur by physical contact between infected and uninfected individuals (16,17).

The reviewers showed that overcrowding, use of public transport, proximity to public spaces, the numbers of health and service workers, degree of poverty and the proportions of minorities and vulnerable populations are all major predictors of the spread of the disease (22). With respect to the impact of the built environment and human factors on the spread of SARS-CoV-2, the driving forces of transmission can be divided into seven categories: density, land use, transport and mobility, housing conditions, demographic factors, socioeconomic factors and health-related factors (22). Indoor spaces with constrained space and inability to maintain social distancing are thus important areas for transmission of the virus. One review (18) included four studies that provided convincing evidence for long-distance (> 2 m) airborne transmission, based on a combination of detailed epidemiological investigations and genomic sequencing. The conclusion was that airborne transmission of SARS-CoV-2 from an infectious individual to others located > 2 m away can occur in various indoor non-health-care settings and from people who are asymptomatic or pre-symptomatic.

It was reported that, under laboratory conditions, viruses can remain viable for 3–4 h in aerosols (17), in artificially generated aerosols for up to 16 h (18), and on inanimate surfaces for periods ranging from a few hours to up to 9 days, depending on the composition of the surface (16,17). The length of viability may be much shorter in the less conducive environments outside a laboratory (23). It was further reported that the stability and viability of the virus depend on environmental factors such as temperature, humidity, exposure to sunlight (18) and levels of air pollution (24).

The relation between weather and transmission patterns was explored in several reviews (25–27). Atmospheric conditions such as temperature and relative humidity may influence the time the virus remains viable outside a host (19,20), but temperature is the only significant meteorological indicator significantly correlated with the spread of SARS-CoV-2 (27). One review (19) described the survival time with respect to relative humidity as “U”-shaped, the shortest survival reported at 50–70% relative humidity. Virus survival decreases with increasing temperature, inactivation generally occurring at 25–30 °C (19). The virus can be deactivated by disinfection (20,28).

The interaction between air pollution and the severity of COVID-19 has been explored. One study showed that particulate matter (PM) in polluted air can reach the bloodstream via
the lungs, causing inflammatory responses that exacerbate respiratory diseases, including COVID-19, and potential antagonization of coronavirus receptor ACE-2. Pollutants such as nitrogen oxides (NO\textsubscript{x}), ozone (O\textsubscript{3}), sulfur dioxide (SO\textsubscript{2}) and carbon monoxide (CO) can negatively impact lung health and function (24). Section 3.6 describes the findings of the review on air pollution during the pandemic.

There is currently no evidence that human coronaviruses are present in surface water or groundwater or are transmitted through contaminated drinking-water (29). In that review, potential contamination of groundwater with SARS-CoV-2 from burial sites was considered, and it was proposed that contamination of groundwater by surviving viruses could occur in the case of mass burials in warmer climates, highlighting the importance of proper siting, design and management of burial sites according to recommended guidelines, when the likelihood of transmission would be low.

Social, economic, environmental, genetic and behavioural factors may make some parts of the population more susceptible to infection and more vulnerable to severe disease, as the impacts of health inequality (9). Population density (5) and crowded housing create conditions for person-to-person transmission (particularly in the early days of a pandemic), and national and international travel (5) leads to wider transmission (10). People living in crowded conditions have been found to be at greater risk of infection, including those living or working in places where they congregate, such as prisons and long-term care institutions (30,31), homeless shelters (32), refugee camps (7), slum areas and crowded households (5,30,33).

Public transport vehicles have also been identified as presenting a high risk for transmission (34,35). SARS-CoV-2 RNA has been identified in air samples from public transport vehicles (32), although no evidence was found that virus was viable and infectious. One review (34) on transport and mobility, comprehensively addressed the issue of transmission in various forms of transport and proposed strategies and policies for collaboration among policy-makers, transport fleet operators, the vehicle manufacturing industry and users of public transport to develop more sustainable mobility patterns (34).

### 3.3 The home environment and other indoor settings

This section addresses the contribution of indoor settings to the spread of the SARS-CoV-2 virus and and severity of COVID-19 and the effectiveness of action to reduce such transmission (e.g. lockdowns, self-isolation, working at home, education at home) on indoor air quality, quality of life, social issues, inequality, health, mental health and well-being.

In view of the routes of transmission of the SARS-CoV-2 virus (see above), airtight buildings with little or no ventilation are conducive to viral transmission (18,36,37). It has been proposed that proper ventilation with increased filter efficiency could contain the spread of SARS-CoV-2 (36,37); however, it has also been suggested that too much ventilation during winter in some regions could result in cold, dry conditions in buildings, which would allow the virus to survive for longer outside their host, thus increasing the risk of transmission (19). The authors of one systematic review of viral survival recommended maintaining indoor temperatures at 18–20 °C and a relative humidity...
of 50% (19). Others have proposed maintaining a high temperature and high humidity (33,38) to reduce viral transmission, noting that the occupants’ comfort should be considered (33).

3.3.1 Domestic settings

Indoor air quality depends on: local outdoor levels of ambient air pollutants; people’s activities in the home (such as moving about, cooking, cleaning and burning fossil and other fuels) (38,39); emissions from building and furnishing materials; and the level of ventilation (37). There is evidence that actions to reduce SARS-CoV-2 transmission have affected ambient air quality (generally improving it, see section 3.6), and such actions have also impacted the activities of occupants and increased their exposure to indoor air (36,38–40). One review cited the finding of one study that pollution of indoor air was four to five times that outdoors (33). Another included a small number of studies which suggested that people who stay indoors in polluted air experience more severe COVID-19 symptoms (36).

Lockdowns, travel bans and closure of workplaces and places of education have resulted in people and families spending more time in their own homes (40,41). It has been suggested that working at home is associated with poorer indoor air quality (7) and that stay-at-home policies have resulted in increased emissions of PM and volatile organic compounds (VOC) due to more domestic cooking, cleaning and indoor tobacco smoking (36,39). Domestic infection control measures have included more frequent cleaning with stronger chemicals and detergents (36,39), which also affects indoor air quality. One review reported the findings of a study in Madrid, Spain, which found a 12% increase in indoor levels of PM$_{2.5}$ (particulate matter measuring ≤ 2.5 µm) during lockdown (39).

3.3.2 Occupational settings

SARS-CoV-2 RNA was reported to have been detected in air samples from hospitals, crowded government offices and public transport vehicles (34,35). One review reported “mixed results” for the use of ventilation to reduce transmission in hospitals (17). A more recent review (18) suggested that long-distance airborne transmission of SARS-CoV-2 may occur in indoor settings such as restaurants, workplaces and venues for choirs and identified factors such as insufficient air replacement that probably contribute to transmission. The authors proposed that mitigation measures be strengthened in indoor settings, particularly to ensure adequate ventilation (18). Mechanical ventilation systems and air purifiers have been reported to improve ventilation and air quality and to reduce transmission (18,33,37,42), although, if such systems are not installed and maintained appropriately, they could be sources of transmission (33).

In one review, it was reported that labourers, retail staff, agricultural workers, health-care workers and people working in congregate settings (such as shelters, prisons and meat processing facilities) are at higher risk of infection than other occupational groups. It was also noted that people on low incomes are more likely to work in essential sales and services and to live in crowded housing and are thus at increased risk of exposure to the virus and of virus transmission (29).

Public transport is another area of concern for risks of infection for both workers and the people using public transport. Mitigation measures such as separation of drivers from the public and temporary barriers and floor markings have been described (8,34).

Workers in municipal solid waste (MSW) disposal have been identified as at increased risk of infection, as they come into contact with waste materials that could be contaminated
with the virus (16,43) (see section 3.5). As a result, there have been calls for better training of the workforce in hygiene and safety (44) and for protection of workers in the sewage industry (45).

### 3.3.3 Impacts of COVID-19 on health and social interactions

Policies to control COVID-19 have reduced human mobility and contributed to better environmental conditions (22). Fear and anxiety about the pandemic (46) and the mitigation strategies to minimize viral transmission adopted in many places have been associated with negative mental and physical health and well-being (31,47–51), including more cases of depression, anxiety, frustration, isolation, anger, post-traumatic stress disorder and hostility (9,46,48,50). Such conditions can lead to more harmful behaviour, such as self-harm, suicide and thoughts of suicide (46). In contrast, one review provided evidence of a psychophysiological benefit: a substantial decrease in adverse cardiovascular events due to the reduction in aircraft noise during the pandemic (52).

#### Effects of mitigation strategies on the economic health of people and families

The pandemic and its mitigation strategies resulted in a severe contraction of economic activity throughout the world, with decreased industrial activity and a sharp reduction in employment (49), resulting in increasing economic inequality (40). Loss of work or working hours, job security and income (47–49,53–55) have increased poverty, including food (56) and fuel poverty (55), and housing insecurity (30,53,54,57). Domestic energy consumption remained increased after easing of restrictions, with displacement of the energy usually consumed on business premises (58), which may further increase fuel poverty. Food poverty has been associated with more undernourishment (13,56), and it has been argued that the pandemic has reversed progress towards attainment of Sustainable Development Goal 1, to end poverty (53). Loss of work and income have been associated with poorer mental and psychological health (47,48,56). In contrast, one review based on qualitative questioning reported that nearly 90% of the participants expressed elements of post-traumatic growth in the aftermath of facing great adversity during the pandemic (51).

#### Lockdowns and stay-at-home orders resulting in social isolation and loss of support

The reviews found that mitigation measures have led to feelings of isolation (31,53) and increased stress, which were closely related to education level, gender, income and housing conditions (50,51). People’s experience of the lockdowns depended on their situation before the pandemic (51). Thus, ethnic minorities, people living in deprived conditions and young people in particular struggled much more with distress, isolation or overcrowding and other problems than people who were socioeconomically better off (22,51). The reviewers called for longitudinal cross-disciplinary research on social, contextual and protective factors as well as on mechanisms of action and public engagement (51). A number of reviews called for “building back fairer” in response to the experiences of the COVID-19 pandemic.

One review (51) noted that pandemic mitigation measures have been associated with increases in mental health disorders, such as anxiety, depression and post-traumatic stress; however, the authors advocated for caution in reporting such associations until more longitudinal studies are available in which potential biases are factored into the screening tools. The same review, however, included one study in the USA that reported that the prevalence of symptoms of depression was increased three times during the COVID-19 pandemic, predominantly and
disproportionately among people who were already at increased risk due to socioeconomic factors. The authors suggested that people with previous mental health problems were particularly vulnerable to further mental health problems during the pandemic. Other findings indicate that overall well-being was reduced during the pandemic and that parenting stress increased (59). Secondary stressors in people’s life circumstances have had profound effects on the risk of symptoms of mental disorders, and those stressors were exacerbated by events associated with the pandemic (51).

**Impacts of orders and guidelines to work from home**

The ability to work from home allowed workers to avoid the risk of infection (60), reduced use of transport and thus improved environmental quality (60,61), and reduced noise (31,60,62), particularly in urban areas. Educational attainment, formal employment status and household wealth have been positively associated with the possibility of working from home (40), thus avoiding the risks of infection inherent to close contact with others.

It has been reported that numerous businesses and public organizations improved their information technology systems and encouraged staff to work from home (63). One reviewer proposed that cities improve their information technology networks to support mitigation (64), as was done in Milan, Italy (65). In a study in New York City, USA (quoted in reference 55), between March and April 2020, commercial use of energy decreased by 7% while domestic use rose by 23% in March and 10% in April. The authors of the review (55) concluded that this increased the financial burden on families. They identified three countries in which electricity bills were waived for specified periods, two that provided price reductions and two that deferred electricity bills.

People living in crowded conditions may have difficulty in social distancing (33,47), which may be compounded by working at home (33); this has also been associated with unhelpful blurring of the line between work and home life (53,66). One review of studies on the psychosocial risk of teleworking (working remotely by using the Internet, e-mail and a telephone) concluded that there were increased emotional demands on full-time remote workers, with blurring of the home–work boundary, but that, in the longer term, part-time or flexible remote working might have a positive impact on psychosocial risk factors such as work–home balance, social relationships and communication (67).

The shift to working at home placed some professionals who did not usually work at a desk in an unfamiliar setting. Two reviews (66,68) analysed studies of musculoskeletal pain symptoms associated with working from home during the COVID-19 pandemic. They reported that the findings suggested that people who work from home reported more musculoskeletal pain (66) and that 86.3% of participants who worked from home due to the pandemic had experienced musculoskeletal issues, in particular in the neck (a 20% increase) and lower back (a 30% increase) (59,68). The three factors associated with an increase in lower back pain during lockdowns were prolonged sitting, stress and decreased physical inactivity (66,68).

One review stated that office workers who worked at home had a greater decrease in physical activity and increased sedentary behaviour than the general population and the unemployed (59). This is an important distinction, as it is known that unemployed people have poorer physical and mental health and a shorter life expectancy because of less physical activity (59).
**Lockdowns and physical activity levels**

The pandemic has been associated with restrictions in the physical activity levels of children (69) and of adults (70,71). Physical activity at all levels of intensity decreased: by 17% for all physical activity, by 26% for light physical activity and by 20% for moderate-to-vigorous physical activity (59), while sedentary behaviour increased by 16% during the COVID-19 pandemic lockdowns (59,70).

Children living in detached houses or houses with gardens or with garages tended to have smaller reductions in physical activity than others (69,72). One review of studies of school closures as part of social lockdown measures found adverse mental health symptoms and detrimental physical activity and health behaviour among children and adolescents (72), although the associations between school closures and health outcomes could not be clearly separated from associations with broader lockdown measures.

A review of studies of the impacts of COVID-19 restrictions on various physical activity domains in children and adolescents included reduced movement, and being sedentary; changes in sleep patterns, play behaviour, independent mobility, and nutrition and eating habits; poorer mental health, social connections; stress; increased social media use and screen time; and poorer quality of life (73). The reviewers found that loss of physical activity in organized sport and structured activities disrupted meaningful routines and reduced opportunities for energy expenditure, training and socialization, with negative impacts on mental health and social connection. It was found, however, that pandemic-associated restrictions created not only challenges but also opportunities for engagement in unstructured physical activity, often in free play, or with family members, facilitated familial social connection, supported mental wellness and reduce boredom and improved movement, although it isolated many children and young people from their peers (73).

In a study in Italy (71), adults were disadvantaged if they did not have access to a garden, terrace or balcony when confined to home. A study of adults in the United Kingdom (80) found reduced physical activity (commuting and recreational activities) and a significant increase in sedentary behaviour (including sitting, reclining and using screen-based devices), such that the overall prevalence of physical activity was much lower than before the pandemic. In the same study, three potential determinants of the frequency of physical activity during the pandemic were identified: physical opportunity (access to gyms, parks, gardens), social environment (social cues, social support from friends and family, norms) and reflective motivation (willingness, drive). Other studies found socioeconomic differences in the likelihood of physical activity by older adults, higher socioeconomic status and sociability resulting in more activity (59,70,74).

Another review found that the studies showed a greater decrease in physical activity among females than males and a significantly greater increase in sitting time for women than for men (59).

The authors of one review, considering the beneficial physiological and psychological benefits of physical activity, invited researchers and policy-makers to devise interventions to reduce sedentary behaviour and promote physical activity in future instances of restrictions in public life (70).

**Changes in the way people use their homes**

It has been argued (53,60) that stay-at-home measures and lockdowns have changed the traditional ways in which homes are used. People confined to small apartments (especially families with young children) changed their use of rooms. Thus, kitchens were no longer used only for cooking and bedrooms no longer only for resting (60). One review found an association between increased depressive symptoms and
living in small apartments or housing with scarce air and poor lighting (7). Another found that using the home for teleworking impacted social relationships and emotional stability (67).

**Impacts on social health**

The closure of schools and other educational institutions has resulted in a loss of or diminished access to education for children and young people (47,53), exacerbating educational inequality (54).

COVID-19 mitigation strategies have also been associated with increased gender inequity (47,49) and more family violence (31,47,49). The increase in family violence has been linked with confinement of abusers and abused together in their homes (46). Transgender people may face higher risks of harassment and physical violence if, as a result of the pandemic, they return to less-accepting communities and families (46).

Some countries have reported more calls to helplines for domestic violence than before the pandemic (46,60), and the authors of one review (46) quoted an estimate by the United Nations Population Fund of an additional 31 million cases of gender-based violence in the first 6 months of lockdown. Loss of services for people suffering from domestic abuse, conversion of shelters for use for COVID-19 isolation, and loss of access to contraception services and services to counter female genital mutilation have all been described (46).

### 3.4 COVID-19, water, sanitation, and hygiene (WASH) and wastewater management

Issues for the WASH sector related to COVID-19 identified in the reviews included the role of a supply of clean water for hand-washing and cleaning surfaces to control the spread of the infection; the possibility of viral contamination of sewage and wastewater systems (and the possibility of a role in surveillance) and contamination of systems with larger quantities of disinfectant and drugs that pose a risk to ecosystems. Concern about microplastic leachates is discussed in section 3.5.

**3.4.1 Water supply to accommodate hand-washing and surface cleaning to mitigate transmission**

It has been estimated that 11% of the population of Europe is at risk of water scarcity, 48 million people in the region do not have access to piped water to their homes, and 31 million people do not have access to basic sanitation (76). The SARS-CoV-2 virus is transmitted in aerosols, droplets and contamination of surfaces, followed by hand-to-mucosal membrane contact (21). Guidelines for preventing infection included cleaning surfaces and frequent hand-washing under running water. Thus, provision of water has been identified as central to controlling the spread of the virus (21,40,76–78). Lockdowns and social isolation have increased the demand for domestic water in some areas of Europe, and the situation was compounded by low rainfall in some areas during 2020 (74).

One review described alternative methods for cleaning and decontamination where water is scarce and some families struggle to balance
the need for hand hygiene and the need for water for drinking, cooking and for livestock (21). The reviewers, noting that hand sanitizers are expensive and not visibly effective in cleaning soiled hands, identified four alternative decontamination strategies: use of salt scrubs; use of sand, soil or ash to clean hands; use of soda ash powder and other alkaline materials for cleaning; and exposure of contaminated clothing and other domestic materials to sunshine. None of these was considered as effective as use of soap and water, and there is little evidence either of their effectiveness or of any adverse effects of their use (21).

Some population groups are particularly vulnerable to lack of access to water and sanitation, including people who are homeless, migrant workers and people designated as stateless (57). Specific issues have been described in detention centres and refugee camps. The review included a case study of a refugee camp where 1300 people shared one water tap and no soap, with poor or no sewage systems. Another review noted that women and girls are at particular risk in regions where they are responsible for collecting water when this involves waiting in queues (40).

3.4.2 Possible contamination of water systems by SARS-Cov-2 and surveillance

The possibility of contamination of sewage systems and hence natural water systems by the SARS-CoV-2 virus was considered in several reviews and is the subject of current research. Reviews cited evidence of the shedding of viral RNA fragments in the faeces of infected people (11, 20, 62, 79) and detection of fragments at various stages of sewage collection and treatment (62, 79, 80). At the time of the reviews, little or no evidence had been found of viable SARS-CoV-2 in such systems, nor epidemiological evidence of transmission via this route (45, 62, 79, 80); however, detection of viral fragments has led to calls for improved sewage treatment (20, 62, 77, 80) and protection of workers in this industry (45, 79). The additional risks in areas not connected to centralized sewage systems, such as rural areas where septic tanks are used, have been discussed (62).

For safe management of hospital wastewater, WHO guidelines propose that 40–60 L/day of water per inpatient are necessary in hospitals for proper functioning (78). Depending on the intensity and nature of the disease or treatment, the requirement can vary from 100 to 400 L/day per patient in operating theatres and isolation wards (78). Consumption at these levels generates equally high levels of wastewater. Studies have shown pharmaceuticals at various levels in wastewater, reflecting their consumption during the pandemic (78). Some authors have proposed surveillance of sewage and wastewater systems for detecting and monitoring the presence of SARS-CoV-2 (17, 59, 76, 78).

3.4.3 Contamination of sewage, wastewater and natural water systems with disinfectants and medications used in the treatment of COVID-19

Chlorine has been considered the most economical option for disinfecting wastewater. One review (80), however, included a study in China that found that the levels required for complete disinfection resulted in high levels of by-products such as tri-chloromethane, tribromomethane and dibromochloromethane, which were described as posing substantial environmental risks.

In some countries at the start of the pandemic, streets were disinfected with chlorine (61), which damaged green areas, polluted local waterways and posed a risk to biodiversity (8). Furthermore, the practice was described as of unknown effectiveness for disease control (8).
Increased use of pharmaceuticals, including antibiotics on prescription and by self-medication, has been reported (62,78,82). Reports described use of antibiotics in hospitals as a precaution for people on ventilation (see section 3.9). Bio-active forms of antimicrobials can be secreted by patients and thus enter sewage and waste water systems, where they can disrupt treatment and enter natural ecosystems, increasing the risk of spreading AMR (62,78,82). A study of wastewater in Athens, Greece, showed a 387% increase in the consumption of hydroxychloroquine, 36.3% more azithromycin, 198% more paracetamol, 170% more antiviral drugs and 57% more antibiotics (81). The potential impacts of entry of these pharmaceuticals in wastewater into marine and aquatic environments are yet to be studied. In Australia, researchers observed the presence of SARS-CoV-2 in wastewater (81); however, its survival in aquatic environments depends on factors including temperature, concentration of organic matter and alkalinity (81).

### 3.4.4 Additional pressures on the WASH industry

To support people affected economically by the closure of commerce and industries deemed “unessential” during lockdowns, a number of municipalities and countries suspended or reduced water charges (76). This resulted in loss of income to the industry at a time when it faced increased absenteeism and labour costs, increased cost of procurement of PPE for staff, and limited supplies of the chemicals required for water treatment (76).

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### 3.5 COVID-19, waste and waste management

The COVID-19 pandemic resulted in increasing amounts of clinical waste (20,43,83), representing a possible infection hazard. The additional waste included plastics and other waste associated with the diagnosis and treatment of COVID-19, disposable and single-use PPE, and clinical packaging. Other changes in the volume and composition of solid waste have been reported as a result of lockdowns and stay-at-home orders. The changing composition and contribution to total waste and pressures on services have presented major challenges to the MSW sector (44). Solid waste management systems before the pandemic tended to be designed for steady-state operations for average waste flow rates and compositions, with only moderate variation (44). In Europe, governments were reported to have difficulty in retaining waste management staff, maintaining a safe environment for workers, and creating additional space for the waste produced by the pandemic (84).

#### 3.5.1 Contaminated and potentially contaminated waste from clinical and non-clinical settings

In many countries, the pandemic resulted in a rapid increase in hospitalizations and thus a rapid increase in the amount of waste generated (84). Significant increases in the amounts of waste that might be contaminated with SARS-CoV-2 from both clinical and non-clinical settings have been reported (43,82–85). A review of studies conducted in Australia (82) reported that a single COVID-19 patient can generate an average of about 3.4 kg of medical waste per day, and one local council reported a 35% increase. The authors of one review (85) called for guidelines to minimize use of storage areas, increased incineration capacity, co-processing with other wastes or mobilizing other facilities. Another review (16) noted that infectious waste should be disinfected, sorted and stored, potentially for 9 days.
The highly infectious nature of the virus and the fact that infected individuals may be asymptomatic, or experience mild disease, has meant that many infectious individuals remain at home; therefore, potentially infectious domestic waste should also be separated (61). WHO has provided guidelines on segregation of clinical waste in yellow bags, including waste from the homes of infected people (16,82). Concern has been expressed that materials that would not previously have been considered a risk for infection might now be considered to be so, greatly increasing the amount of potentially contaminated waste (84).

The increase in waste from clinical settings includes plastics (see below) and other waste associated with COVID-19 diagnosis, treatment and vaccination, such as glass vials, empty disinfectant bottles and vaccine containers (16,82). It was estimated that, during the pandemic, an infected patient generated 3.4 kg of health-care waste per day (84). In Hubei, China, a 600% increase in the amount of clinical waste overwhelmed their disposal systems. France and Netherlands (Kingdom of the) reported smaller increases of 40–50% (84).

3.5.2 Single-use plastics and plastic waste

Plastic production had already increased by 20 times in the 60 years before the pandemic, reaching 364 million tonnes in 2019 (83); the pandemic has increased the demand for plastic, for both PPE and in the diagnosis and treatment of the disease. Plastics persist for a long time in the environment, and this, in combination with improper waste disposal had led to the accumulation of plastic debris and microplastics in many environments, including water, soil, air and living organisms (83,86). The pandemic has led to large increases in the amounts of plastic waste in MSW (85). In Romania, for example, the waste level increased by a factor of 10 between late February and early June 2020, which was considered to be the result mainly of additional use of PPE (85). Furthermore, some of the controls on single-use plastics in place before the start of the pandemic have been lightened (85), which has nullified the considerable efforts made for plastic recycling in recent years (43).

Plastics have also been central to public health work to contain the virus (44). It has been estimated, for instance, that each polymerase chain reaction COVID-19 test generated about 37 g of plastic waste (87), which contributed to the large increases in the amounts of plastic waste observed globally (43,44,87). PPE such as face masks, gloves and face shields, as well as wet wipes, prevent transmission (88), and most PPE contains plastics (88). Use of plastic PPE by front-line clinical staff, other workers at risk of infection and the general public has increased exponentially (16,44,62). WHO has estimated that nearly 129 billion face masks are used globally each month (44,88). It is therefore important that waste PPE be disposed of appropriately throughout the world (44), as, once released into the environment, it undergoes continuous weathering and mechanical stress. Furthermore, PPE such as face masks leach heavy metals, and each mask releases millions of microplastic particles (83,86).

3.5.3 Impact of lockdowns and similar mitigation measures on MSW

Many countries saw decreases in the levels of industrial waste during lockdowns (43), while the levels of domestic waste varied (43), some studies reporting increases (associated with more on-line purchasing) and others reporting an overall decrease in the amount of domestic waste (43,89). It has been suggested that decreased income and higher food prices have improved domestic food management and reduced overall food waste (89,90). For instance, one study in the United Kingdom found a decrease in the amount of waste of essential food items such as bread, milk, chicken and
potatoes, from 24% in November 2019 to 14% in April 2020 (90).

Decreases in the levels of waste associated with public events and public areas have also been observed (43). At the start of the pandemic, during early lockdowns, the total amount of MSW decreased in some cities, particularly those with extensive tourism, including a 27.5% decrease in Milan, Italy, and a decrease of 25.05% in Barcelona, Spain (85). With the resumption of tourism, there have been calls for stricter regulation of PPE disposal, such as installation of waste bins (83,88). Specific bins for disposal of PPE have been installed to encourage safe disposal of used face masks in Montreal, Canada, and Guimaraes, Portugal (85).

An increase in packaging waste, both plastics (16,43) and paper (16), has also been observed as a result of lockdowns and stay-at-home regulations. Limited over-the-counter shopping has resulted in increased packaging for online purchases (16,44) and for take-away food services (44).

Socio-demographic, psychological and economic variables impact the generation of food waste (89). The factors associated with food waste during the pandemic included age, gender, educational level, income (and relative change in income), employment and number of household members (89). Consumers generally reported behavioural changes during the pandemic and claimed to have adopted more sustainable practices to reduce food waste (89). It was observed, however, that strategies to prevent food waste were motivated mainly by socioeconomic factors related to the pandemic rather than environmental concerns (89). On a larger scale, the pandemic disrupted the entire food supply chain, leading to waste at all stages of the chain, from farming and production to retailing and consumption. Studies on food redistribution as a means of reducing MSW and promoting food security found interrelated effects of the pandemic on the food system, such as input and labour shortages, demand peaks due to lockdown measures, panic buying, and increased online grocery shopping and delivery, all of which interact with overall food waste (89).

The recovery and recycling sector has been reported to be experiencing a decrease (43) linked to a sharp global decrease in plastic recycling (44). In a case study in the USA described in one review (44), closure of municipality-run recycling centres was reported to be due to a reduction in funding and staff shortages (44). Most European countries have banned infected residents from sorting their own waste (43), and less informal recycling has been reported (44). It has been suggested that a fall in oil prices at the start of the pandemic made use of recycled plastics less economically viable (44).

The pandemic has resulted in increasing use of landfill (43,85), and some sites may have become overloaded (852). In the long run, this could lead to crushed space, illegal dumping and the release of toxic pollutants (44,85). There have been calls for improving landfill sites to ensure the collection, purification and subsequent use of biogas and removal of microplastic leachates and plastic waste (85). It has been suggested that the increased pressure on landfills may compromise progress towards meeting the Sustainable Development Goals (85).

Some countries have reported increasing reliance on incineration because of concern about the safety of people dealing with waste (43). Unprecedented levels of waste have overwhelmed capacity in some countries (44,85), and concern has been raised about toxic emissions, such as dioxins and furans, and thus for appropriate air pollution controls (44). Germany and Sweden, however, dealt effectively with the increased load of potentially infected waste items associated with COVID-19 because they had well-developed and distributed incineration (waste-to-energy) facilities, using landfills only to bury the ashes generated (<1%) (85).
3.5.4 Illegal dumping, littering and open burning

Concern has been raised that the large volumes of plastic and other waste could overwhelm systems, resulting in increased illegal dumping, littering and open burning, which pose risks of transmission (80) to terrestrial and marine ecosystems (16,44,85). In 2020, the prevalence of illegal plastic waste disposal worldwide increased by 280% (85). In addition, stay-at-home policies have resulted in more home clearances and do-it-yourself home improvements, which, with the closure of facilities, have been linked to increased illegal dumping (90).

Surveys of environmental and aquatic sites have identified a variety of discarded PPE items (88), half of which were face masks and disinfectant wipes. Seasonal variation was observed on one beach, the levels being highest during the tourist season.

3.5.5 Wider environmental impacts of pressure on the MSW sector

The current pandemic may require more landfill sites and thus increasing demand for land and further encroachment on natural environments (85). One review showed that soil pollution was exacerbated by the massive amount of MSW and medical waste generated during the pandemic (82,86), and authorities were called upon to establish stronger management measures for solid and medical waste during crises (86).

Plastic litter can collect in sewage drainage systems and may be washed into natural waterways and the sea as a result of wind, storms and water run-off (87). PPE litter can impact aquatic environments and wildlife by entanglement and ingestion (88). Natural environments such as beaches, rivers and seas, which had less waste at the start of the pandemic (due to the reduction in tourism), later had increasing waste, such as PPE items (85). Improperly discarded face masks are a significant source of secondary microplastics, particularly micro- and nano-fibres, and it has been suggested that these will increase (88). Microplastics damage marine organisms and soil biota (86,87).

3.6 COVID-19 and ambient air

Air quality depends on the levels of its constituents from natural and anthropogenic sources. Measures of air quality include the levels of primary pollutants such as NOx (in most of the studies cited in the reviews nitrogen dioxide (NO2) was measured); carbon dioxide (CO2), a greenhouse gas that contributes to climate change; CO; black carbon; SO2; O3; and VOCs. The physical characteristics of the quality of air can also be measured by filtering and measuring airborne PM, which is differentiated by the size of the particles collected: PM10 (particulate matter measuring ≥ 10 µm) and PM2.5 (particulate matter measuring ≤ 2.5 µm). The latter are considered to penetrate deeper into the respiratory system. PM can consist of various elements, depending on its source. Air quality is also based on secondary pollutants, such as some PM (36) and O3, which results from photo-chemical reactions between NOx and VOC (36) and is associated with smog. Prevailing weather conditions can affect the quality of air (36), as can proximity to sources of pollution (24) such as industrial plants, transport,
domestic heating, cooking, as well as wildfires and volcanic eruptions.

Two main issues have been explored with respect to ambient air quality and the COVID-19 pandemic: the impact of global lockdowns and travel restrictions and the role of air pollution in determining the spread and severity of COVID-19 infection. In the initial review of reviews (November 2021), we noted some limitations in consideration the second topic. At that time, much of the evidence was from ecological studies, which were retrospective, cross-sectional, included few or no controls for potential confounding, addressed only one pollutant at a time with no detail of individual exposure, and uncertainty about how the numbers of cases and deaths were calculated when little testing was conducted. In addition, the reviewers identified lack of controls in studies that reported that infections occur in clusters and difficulty in identifying a possible mechanism for any associations observed. Association does not prove cause and effect, and most of the evidence cited in the available reviews had been collected in 2020 or very early in 2021, so that there was limited coverage of the pandemic at the time of the first draft. The field has since moved rapidly, and while some limitations remain, more focused studies address several pollutants, with managed controls and better data on the numbers of cases and deaths.

3.6.1 Relation between COVID-19 mitigation policies and air quality

Different countries (and in some cases, regions within countries) instituted different mitigation policies, such as quarantine, self-isolation requirements, stay-at-home and work-from-home orders, closure of industries and commerce considered to be non-essential, lockdowns, travel restrictions, and closure of borders. The timing of such policies also differed (91). Wide-scale changes in air quality were observed when such mitigation policies were in place in most parts of the world. Some reviews reported geographical and temporal differences from wider trends. As both different spatial and temporal phases of lockdowns and prevailing weather patterns can affect air pollution levels, variations in trends would be expected and were observed (36,92). In general, the reductions in pollutants were greater when lockdowns were more severe (58,93,94) and when baseline pollutant levels were higher, such as at lower elevations and in more densely populated areas. During lockdowns, substantial reductions were observed in NO\textsubscript{2}, NO, CO, CO\textsubscript{2}, PM\textsubscript{2.5}, PM\textsubscript{10}, benzene and the air quality index (27,58,74,93,94).

There were relative reductions in industrial activity (7,20,36,68,95–97) and economic activity (95,96,98) and less road transport (20,31,34,95,98). One review reported that human movement was reduced by as much as 90%, mainly as a result of air travel restrictions (8,27). Another reported that road transport was 50% lower than in the same month in the previous year (95). International and domestic flights were cancelled during lockdowns (8,96), reducing the number of flights, reported variously as a 75% decrease in the number of flights in the early phase of the pandemic (March 2020) (95) and a 90% decrease in air traffic in the European Union (96), including a 53% decrease in air cargo (95).

These reductions in flights were associated with an overall improvement in air quality (20,27,37,94) and reductions in a number of air pollutants (37,86,95), although air pollution was not totally eliminated (27,98). The pollutants studied included PM\textsubscript{10} (36,93), PM\textsubscript{2.5} (36,93,95), NO\textsubscript{2} (31,36,93,95), CO (36,93), CO\textsubscript{2} (93), SO\textsubscript{2} (36,93), O\textsubscript{3} (93), NO (93), PM\textsubscript{10} (93) and NH\textsubscript{3} (93). The most common sources of emission of NO\textsubscript{2} are 90% from on-road and non-road combustion and biomass burning; the remaining 10% is due primarily to chemical production at power plants (94). Instigation of stay-at-home orders reduced the traffic on roads (58,94) and the closure of many factories, resulting in a decrease
in NO₂ (94). One review noted that most of the studies they reviewed reported changes in PM and NO₂; only a few reported no change, and none reported increases in either of the pollutants (95). In another review, none of the studies reported increases in NO₂ and reported decreases of 12–96%, depending on the country and the size of the study (99). A recent review reported that the air pollutant for which the decrease was the strongest was NO₂, for which 83 of 89 studies reported reductions (93). One review (99) included eight studies with reports on PM₁₀ levels, of which six reported decreased levels of PM₁₀. This was corroborated by other reviews (93,94), which reported large reductions in PM₂.₅ and PM₁₀, in 75% of the studies included, one of which reported reductions of ≤ 71% between 11 March and 10 April 2020. Reduced vehicular emissions were attributed to significant reductions in CO, CO₂, VOCs, NOₓ and PM pollutants (58,93,94).

In one review (93), O₃, SO₂ and NH₃ in air were found to have null or worsened associations with lockdowns. In studies of O₃, the concentrations increased by up to 7.6% and were associated with reductions in NO emissions (27,93) and attributed to the nonlinear photochemical reaction between NOₓ, VOC and sunlight (94). Increases in SO₂ were linked in several studies to industrial activity, and one study in the review indicated that the increases were directly related to increased power generation during lockdowns, providing a rationale for increasing sustainable energy sources (93). The findings for NH₃ were mixed, with either stasis or increases reported associated no change or increases in agricultural activity, respectively (93). The reviewers (93) also commented that the emissions of factories and industrial plants decreased as they were shut down during lockdowns, which were strongly linked to PM, O₃, NO₂ and NO pollutants (24).

In some areas, ground-level O₃ levels increased (36,95,98) by up to 36% (98), probably as a result of variations in the levels of NOₓ and VOC and reductions in the levels of PM, which reduced haze and thus allowed more sunshine into the lower atmosphere, resulting in the generation of more O₃ (36). A number of theories have been put forward on the precise mechanism (91). Stratospheric levels of O₃ (the ozone layer) were increased (20), probably as a result of decreases in the emissions of greenhouse gases.

Overall, researchers are unequivocal about the impact of the pandemic on improving air quality and reducing emissions (100), although the results were not homogeneous among countries and areas because of differences in the restrictions (100). The long-term benefits are, however, threatened by differences among countries in economic prosperity and responses to climate change (100). With the end of lockdowns and overall resumption of normal activities, emissions of pollutants have rebounded in some regions, and air pollution has gradually returned to near pre-COVID-19 levels (27,86,100).

### 3.6.2 Relation between air quality and transmission and the incidence and severity of COVID-19

Research and evidence on the relation between air quality and COVID-19 is based on observations that the regions with the highest caseload of COVID-19 were also areas with poor air quality (33,101,102). Research was then undertaken to establish the timing of such an association, including progression to infection and any underlying biological mechanism that might provide additional evidence of a possible effect.

**Relation between air quality and the incidence of COVID-19**

Several reviews have included studies that found positive associations between air pollution levels and the numbers of new cases of COVID-19 (7,24,101,102). One review found
significant positive associations between the levels of PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$ and CO and the risk of COVID-19 infection, noting that the association was strongest for PM$_{2.5}$ (103).

Two possible mechanisms have been explored – that PM act as a nucleus of infective droplets (7,9,58,101,103) and that exposure to air pollutants increases susceptibility to infection by enhancing the ability of viruses to invade epithelial cells (9,103–105). It is difficult to distinguish the aerosol theory from the susceptibility theory, but it is an important distinction, as, if the former is true, it would provide evidence that poor environmental quality plays a direct role in COVID-19 transmission (9).

Theories have also been put forward for how exposure to air pollutants might increase vulnerability to infection. These include the idea that prolonged exposure to PM$_{2.5}$ results in over-expression of alveolar ACE-2, thus providing the virus with more anchorage to allow it to enter cells (24,101,107). A second theory is that air pollutants increase mucosal permeability (101,104). A third is an impact on the ability of macrophages to phagocytose (104).

Evidence for the aerosol theory is provided by a study from the north of Italy in which samples of PM tested positive for SAR-CoV-2 gene markers (24,97). One review suggested that a spike in air pollution could result in a spike in virus mutation rates, increasing the risks of future waves of infection (107).

A systematic review with a meta-analysis reported “moderately certain evidence” of an association between PM$_{2.5}$ and COVID-19 incidence, and a moderate correlation with NO$_2$ levels (106). The authors further concluded that, although the evidence could not be considered “quite solid”, the review supported the view that air quality adversely influenced the burden of COVID-19, short- and long-term exposure to PM$_{2.5}$ and long-term exposure to NO$_2$ being most consistently associated with epidemiological and clinical data on COVID-19 worldwide (106). A recent review with good confidence levels reported that PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$ and CO are most frequently associated with the spread and with cases of COVID-19. The review found that the evidence was less consistent for deaths, in that PM$_{2.5}$ and NO$_2$ are most frequently associated with more deaths; however, most of the associations for PM$_{10}$ and O$_3$ are null, and evaluations of CO indicated no difference in the numbers of positive and nonsignificant relations with deaths. For SO$_2$ and NO$_x$, no clear conclusions could be drawn, as there were too few studies (24).

**Relation between air quality and the severity of COVID-19**

Epidemiological evidence has been provided of an association between the level of air pollution, the severity of infections (24,38,101,102) and mortality rates (20,24).

A systematic review and meta-analysis found a strong positive association between PM$_{2.5}$ and the risk for hospitalization in a single study in Netherlands (Kingdom of the) in which the review authors considered the overall risk of bias to be low (106). A systematic review and meta-analysis provided evidence of an association between long-term exposure to PM$_{2.5}$ and mortality, with a “high certainty of being positive”, and the level of NO$_2$ was positively associated with mortality from COVID-19 with a “high degree of certainty” (106).

In a recent systematic review and meta-analysis, more than half of the studies showed that the spread and incidence of COVID-19 increased with higher levels of air pollution; however, the evidence of a link between air pollution, hospitalization and deaths was mixed and was based on relatively few studies (24). A review published in 2022 found positive relations between an increased air pollution index (CO, NO$_2$, SO$_2$, O$_3$, and PM$_{2.5}$) and mortality from COVID-19 and possible associations between...
3 Results

Theories about the mechanism of any causal relationship include the idea that exposure to air pollutants affects the function of the respiratory and cardiovascular systems, resulting in diseases that increase the risk of more severe COVID-19 (36,101,103,105). A number of underlying health conditions have been associated with the risk of death from COVID-19 (106), including cardiac disease, immune and metabolic disorders, respiratory diseases, cerebrovascular diseases and cancer (101,103,106). Some are also associated with socio-demographic differences in a population (101). These theories should be tested, with careful control of confounding.

Other theories of how exposure to air pollutants might result in more severe disease include aggravation of respiratory symptoms by inhibition of inflammatory mediators (7,103) associated with long-term exposure to PM$_{2.5}$ (104). It has also been suggested that exposure to PM aggravates neurological symptoms (103).

One review of studies on the relation between air quality, COVID-19-related mortality and all-cause mortality did not find that the number of COVID-19 deaths was in excess of all-cause mortality. The authors noted that context is important in epidemiology. They considered that the correct interpretation of any observed association is that, even if COVID-19 is found to be more severe in areas with high concentrations of airborne PM, it cannot be assumed that ambient air quality was responsible for the outcome (39).

3.7 COVID-19 and food

Increasing demand for food to feed a growing global population and greater demand for meat as a result of rising economic prosperity have been identified as drivers of the increasing occurrence of zoonotic diseases over the past 80 years, of which COVID-19 is but one (see section 3.1). COVID-19 mitigation strategies have been reported to have had profound effects on local and global food supply chains and on food security.

3.7.1 The food supply chain

The COVID-19 pandemic and the mitigation strategies and policies have highlighted weaknesses in current food systems, which are characterized by complex global interdependence (60). There is also evidence of shocks to the supply chain (56,108). The pandemic has disrupted the global food supply chain in a number of ways, including shortages of farm and factory workers, limited access to food, restrictions on the transport of farm commodities, changes in consumer demand, closure of food production facilities, uncertainty about food quality and safety, restriction of food trade, and delays in transportation of food products (108). Industrialized food systems are highly vulnerable to global crises such as the COVID-19 pandemic as a result of their poor resilience and flexibility (13). In low- and middle-income countries, one of the greatest impacts on agriculture and food systems was loss of income due to the pandemic, which affected the purchasing power of all participants in food supply chains (56).

Production: agriculture and fisheries

Most European countries had decreased agricultural product trading during the
lockdowns, with the exception of Switzerland, which had an 18% increase (109).

Workers in agriculture, food production and sales were generally exempt from lockdown restrictions (56); however, the sector has been greatly affected by the pandemic because of shortages of essential materials (109), such as seeds and grains (13,110,111), fertilizers (13,111) and other chemicals (111). The shortages were due to disruption of international trade (111) and travel restrictions (13) and resulted in raised prices (13). As China is one of the world’s primary producers of fertilizer, the industry was seriously impacted by the country’s lockdowns (111).

Labour shortages of up to 25% can affect supply chains (109). Restrictions placed on the movement of the agricultural labour force resulted in a decrease in labour productivity in the first few weeks of the pandemic and higher labour costs (112). The issues included the loss of migrant workers (13,40), loss of job security (112), travel restrictions (47,110,112) and loss of earnings and workers due to illness (112), all of which impacted the agricultural sector (112) and increased costs (110). In some places, quarantine restrictions overlapped with the harvest season, and farmers and farm workers were stopped from travelling to their fields, with an impact further down the food supply chain (47).

**Transport**

Some countries instituted export and trade restrictions during the pandemic to protect national food security, which affected those that usually import their food (13). Transport restrictions led to rising costs in some countries (112). Restrictions on movement and transport bans were a particular issue in long supply chains and resulted in large amounts of waste for producers (13). In some countries, this compounded shortages in cold storage, which increased waste at both farm and retail levels (90).

**Fluctuations in the pattern of demand**

Food consumption outside the home (the hospitality sector) was severely affected by lockdown policies globally (111,112), resulting in acute cash flow problems, staff redundancy (112) and widespread closures (112). The extent to which this affected the producers who serviced this sector depended on how quickly they could change from restaurant to home delivery (112). Local marketing channels and short food supply chains in Italy were more resilient and saw a significant increase during lockdown (112). Closures of schools and cafes were reported to have resulted in a decreased demand for milk and dumping of excess supplies (90). A significant switch to online sales was observed during the pandemic (55,112), further marginalizing groups who lived in areas (often rural) with little or no Internet access (112).

Increased consumer anxiety may have triggered behaviour such as hoarding and panic buying (13,56,113). This occurred in the first few weeks of lockdown in many places and resulted in disruption of local supply chains (13,56). Changes in consumer preferences have also been reported, some people reporting that they had had a less healthy diet because of unaffordability and due to eating “comfort food” (110).

The effects of the pandemic on rice production and demand led to shortages and price increases, which affected food security in some countries. A fall in international demand for fish led to increased work by inland fisheries to provide a local source of protein (40).

Changes in consumer preferences has affected the structure of demand (89,112). Spending long periods at home as a result of lockdown policies made the public more aware of the importance of buying non-perishable, conservable food items. This, combined with an increase in new hobbies such as cooking (13,83), resulted in a fall in demand for highly processed foods (109). Industrial and household food waste was greatly reduced during the pandemic (89) (see section 3.5).
Fluctuations in the pattern of access

As a result of COVID-19 mitigation policies, local food and farmer markets were closed in some countries (13,111), while supermarkets remained open (13). This increased demand from shops (111) and affected food availability everywhere (113). Online shopping became common (13,90,113), further changing the ways in which consumers accessed food. In some rural areas, emergency food relief was provided, while elsewhere emergency food relief agencies shut down entirely (113), adding to lack of confidence in food availability.

3.7.2 Food security

Threats to food security globally during the pandemic were considered to be due to mitigation policies that disrupted food supply chains and income (56,114), especially for vulnerable groups such as families with low or unstable incomes (110,113). Loss of income and rising food prices resulted in more food poverty (13,110) and increased use of food banks (13) but may also have improved food management and reduced domestic food waste (90).

Schools (13,111) and social assistance and food shelters (13) were closed in some countries during the pandemic, preventing access to food by the most vulnerable groups in society. In one review, 71% of studies that included rural–urban comparisons found that food insecurity was significantly higher in rural areas (113). This information might be useful in designing strategies to decrease the impact of future global events on food security.

Food insecurity in high-income countries was associated with hoarding of supplies and panic buying (47,113), resulting in loss of food diversity (46), while in low-income countries food insecurity can manifest as starvation and famine (47). It was estimated that the number of people living in severe food insecurity globally could more than double by the end of 2020, from 130 million to 265 million people (54). It has been suggested that, in low- and middle-income countries, most food insecurity is due to two reinforcing factors: structural issues (such as transport routes, water and power) and shocks and stresses such as the COVID-19 pandemic and the effects of climate change (56). One review included two surveys that found that most respondents considered that governments should provide food, shelter and other basic needs for quarantined individuals (47).

Achieving food security in the context of sustainable development and the pandemic requires integrated, inclusive policy-making across disciplines and changing conventional, siloed ways of working. A coherent approach to food security will also require a systematic approach to stakeholder involvement at local, national, regional and international levels (114).

3.8 COVID-19 and public places

Public places and the neighbourhoods in which people live, learn, work and take leisure are where they experience environmental benefits and are exposed to environmental challenges. The exposure includes a combination of physical, social and economic factors, which together influence physical and mental health and well-being. This section presents the changes due to the COVID-19 pandemic on public places and local neighbourhoods associated with travel restrictions and work-from-home policies on the provision and accessibility of workplaces, goods and services and on the broader structure and function of
urban areas, with related impacts on rural areas. The role of increasing urbanization throughout the world in the genesis of zoonotic diseases is discussed in section 3.1.

3.8.1 Impacts of travel restrictions and requirements for social distancing

At the end of March 2020, global road transport was 50% of that reported for March 2019 (95). This resulted in better air quality (31, 61, 91, 94, 96) (see section 3.6), fewer road traffic accidents (31, 96) and less congestion in a number of European cities (96). It also contributed to less noise pollution (52, 60–62). One review of the impact on soundscapes reported a significant reduction in physical noise due to external anthropogenic sources such as roads, aircraft, seaports, construction and human outdoor activity (52).

Use of public transport decreased during lockdowns (31, 95, 96). COVID-19 mitigation strategies in some countries included bans on public transit and limits on who could use such services. It was reported that use of public transport fell by 80% in Europe (96). One review (91) cited mobility indexes published by Google and Apple that showed decreased use of public transport hubs (such as rail, bus and metro stations) of 30% in Spain, 12% in Italy and 8% in France.

As a result of changes in the use of public transport, services were reduced and reconfigured (63), and revenue dropped (31). In addition, the infrastructure was changed to protect staff and users from infection with SARS-CoV-2 (8). Concern has been raised that, after release from lockdowns, there may be a modal shift from use of public transport to increased use of private motorized transport due to concern about infection (53, 60, 63). One review included a study in China that found that use of private cars nearly doubled at the end of a lockdown (60); another (63) reported that a city in China had created an app to reserve places on the metro to reduce queuing. Concern has been raised that, without government support, public transport systems may go into bankruptcy (60).

The authors of a review on studies of COVID-19-related actions to promote walking, cycling and use of e-bikes, scooters and e-scooters expressed hope that such actions could be used as pilot projects or as a basis for more profound changes (63), including reductions in speed limits. Another described the concept of “tactical urbanism” in response to COVID-19, consisting of the provision of low-cost, scalable interventions in urban environments such as additional bicycle lanes with temporary signalling and low-cost barriers (31). More journeys were reported to have been made by bicycle during the pandemic (31).

Two case study reviews, one of cities in Italy (65) and another of cities throughout Europe (64), proposed a taxonomy for urban policy to address the pandemic. In terms of physical infrastructure, actions were described to encourage more active forms of transport, by extending cycling lanes to reduce pressure on crowded public transport systems, reduce the risk of infection and reduce dependence on private motorized transport. The reviewer noted that Milan, Naples and Rome had all adopted such policies. The taxonomy included improved walking paths and extended pedestrian areas to encourage active forms of transport, as had been done in Milan.

3.8.2 Work-from-home policies

Policies to encourage working from home were put in place to limit social mixing and enable social distancing during the pandemic (see section 3.3). It has been reported that this also resulted in reductions in commuting and traffic pollution, without harming the economy (58, 94, 96). Travel distance and mode of transport were found to be significant factors in
determining the magnitude of the benefits for reducing pollution (58).

3.8.3 Inequality

It has been reported that inequality was exacerbated by the pandemic (30,40,54) within and among countries (40). One review (60) cited geospatial data that showed that lower-income workers continued to move around during pandemic, while higher-income workers were more likely to be able to work from home (40,60), which could in turn influence who used public spaces and further exacerbate social divisions and inequality (60). Closure or reduction in public transport systems was also more likely to affect low-income communities, the elderly and key workers (31). A move to working from home, if sustained after the pandemic, could change the patterns of demand for real estate, with an exodus from city centres (63).

3.8.4 Impacts on access to services

Education (47,71,96), sports facilities (69,71,96) and spiritual institutions (96) were closed as part of COVID-19 mitigation strategies, and social gatherings were restricted and citizens advised to stay at home (71,96). It has been reported that the effects on the education sector (closure of school, colleges and universities with a move to online learning) have resulted in widespread exacerbation of inequality in education and social vulnerability (54). Less access to health care has also been reported (47). One review reported a 30% reduction in access to public buildings and commerce (63).

3.8.5 Access to and use of green spaces

Living in neighbourhoods with green spaces was associated with less anxiety in people living through lockdowns and quarantine (7,71,115). The authors of one review (7) included a study in which participants being treated for anxiety were given audio-video stimuli, which were more effective when forest environments were shown. This observation adds to growing evidence of a relation between green spaces and physical and mental health and health inequality more generally. The two reviews of cities in Italy and Europe (64,65) noted that extension of green spaces and their function as part of the infrastructure response to the COVID-19 pandemic had been crucial for encouraging physical exercise and as a source of well-being. The author commented that extension of such areas, as in Milan, would make a valuable contribution to city sustainability.

Mitigation policies varied between and within countries and changed to address changing levels of transmission and the incidence and severity of infection over time. It was reported that, in some places, mitigation resulted in loss of access to public and green spaces (47,71,115). It was noted (71) that this resulted in fewer opportunities for physical activity, more isolation and effects on mental health (31,70,115,116). The impact on behaviour might have been associated with physical activity level and aspirations before the start of the pandemic (71). One review (31) included a study based on Google maps, which showed a 48% reduction in visits to parks in 131 countries in April 2020 as compared with 3 January–3 February of the same year. A review based on mobility index data from Google and Apple reported 28–82% more trips to parks and other places for outings in France, Italy and Spain (91).

It has been reported that the social pattern of the groups that were able to take advantage of opportunities to work from home to minimize their risk of infection may have been more likely to have more use of parks, promenades and green spaces, while those who continued to go to work may have been more exposed to public spaces and streets (61). Some people who lived through severe lockdowns might have had a heightened appreciation of local parks.
and plazas, while others did not (60,117). The provision and maintenance of neighbourhood green spaces were thus considered to be an issue of inequality (60,115,116). Public spaces were often the only outdoor spaces for recreation for people on low incomes living in crowded conditions (60). Green spaces in low-income neighbourhoods in the global North were reported to be often smaller, fewer and less well maintained than those in wealthier neighbourhoods (47,60,115,117).

The pandemic may change society’s requirement for green spaces, with greater demand for smaller local or neighbourhood parks that could provide a refuge from loud, bustling cities (60,115,116). One review of studies on the impact of lockdowns on soundscapes reported that the benefits of enhanced natural sounds were their restorative quality and better perceived health (52). In some areas, fields for team sports were used for individual exercise (60). New expectations in terms of accommodating social distancing may result in new or extended infrastructure (60,117); however, concern about biodiversity would create pressure to provide networks of green spaces and nature-based solutions in urban areas (115,115,118), perhaps with larger parks as important hubs (60).

Three reviews described the benefits of guaranteeing access to neighbourhood green areas to encourage outdoor activities (115–118). One review (117) concluded that parks and green infrastructure provide a variety of benefits for physical health, including better cardiovascular health, lower incidences of respiratory illnesses and allergies and better pregnancy and birth outcomes. Spending time in green infrastructure reduces sedentary behaviour and decreases the risk of ill health. Use of green infrastructure increased during the pandemic, as did the appreciation of users, and use of local green spaces increased. Any decrease in use was usually due to COVID-19 lockdown restrictions and fear of viral transmission.

3.8.6 Physical activity

COVID-19-related mitigation strategies were linked to reduced physical activity (31,70,71) and less exercise (50,70), although the results were mixed (see section 3.3.3). Among children, reduced physical activity was greater among those living in urban areas, which was linked to closure of sports facilities (69).

3.8.7 Mental health

It has been reported that the pandemic and its mitigation measures were associated with psychological distress (47), and depressive symptoms were associated with living in poor housing and small apartments (7). One study found evidence of a strong association between stopping work and poorer mental health as compared with people who continued to work (7). Restrictions on public life resulted in a three-fold increase in markers of risk for depression (51,70) and a higher prevalence of anxiety, stress, stigma and post-traumatic stress disorder during lockdowns.

A review of studies of the effects of school closures and social lockdown on children and adolescents in 11 countries found an association with adverse mental health symptoms such as distress, anxiety and unhealthy behaviour such as increased screen time and less physical activity (41).
3 Results

3.9 COVID-19 and the health sector

In countries and regions with high rates of COVID-19 transmission, the numbers of admissions to hospital increased massively (84), with high demand for intensive care beds to ventilate the most seriously ill patients. This threatened to overwhelm health systems, and concern about the impacts on health services was one of the reasons for subsequent mitigation policies. The economic impact of the pandemic on health systems included various effects on costs and human resources (100). Critical factors in dealing with the virus were immunity and comorbidity. In various countries, higher rates of lung cancer, Alzheimer disease, diabetes and obesity were associated with higher rates of mortality from COVID-19, indicating that the health of the population was a key factor, as measured by the proportions of people with chronic illness, diabetes, obesity, depression, and other mental and physical diseases (22). Vaccination reduced the proportion of infected patients who required hospitalization and intensive care.

Another factor in the spread of COVID-19 was the distribution of health infrastructures and services. One review noted that the state of the health-care system in a country was strongly related to the mortality rate, even in the countries with low rates of infection. In general, locations with better health services, such as more hospital beds, doctors, intensive care beds and primary medical services, had lower rates of mortality (22).

Diagnosis and treatment of COVID-19-infected patients in health-care facilities, in care facilities and in their own homes and the fact that many people can be infectious but asymptomatic required strict infection control policies (78). These included isolation or separation of patients who were considered to be infected and PPE for staff, carers and key workers in contact with the general public, albeit to different degrees. The demand for PPE led to sharp increases in the amount of potentially SARS-CoV-2-contaminated waste and of plastic waste (see section 3.4).

Increasing COVID-19 caseloads affected the ability of health-care systems to maintain the levels of diagnosis, treatment and care that they usually achieved (78), including routine services for infectious diseases other than COVID-19 (vaccination services, antibiotic treatment, laboratory services, infectious disease control and surveillance). A WHO study was reviewed (78), in which the number of people receiving care for tuberculosis during the pandemic was reduced by 21%, corresponding to 1.4 million fewer people than in 2019. Use of telemedicine has increased in many countries (78) to limit mixing of patients and health providers (78).

3.9.1 Antimicrobial resistance

Antimicrobial resistance (AMR) was increasing before the COVID-19 pandemic, as a result of widespread use of antibiotics in food systems (78) and overuse of antibiotics in health systems. The authors of two reviews (75,119) reported that, during the first 18 months of the pandemic, COVID-19 patients had a high prevalence of AMR. The prevalence varied by hospital and geography, with substantial heterogeneity; however, more resistant infections were seen in intensive care patients that in those not in intensive care (75).

Particularly during the early stages of the pandemic, when testing capacity was limited and treatment had not been optimized, antibiotics were widely used to treat confirmed and suspected bacterial or fungal co-infections of the respiratory tract (120,121). In one review, it was reported that up to 15% of COVID-19 patients had secondary bacterial infections, more than half of whom died (120). Studies
included in a more recent review reported that 2.5–100% of COVID-19 patients were co-infected with either bacterial or fungal organisms (75); another reported that an average of 8% of COVID-19 patients had such co-infection, and 72% of patients admitted for COVID-19 were treated with antimicrobials (122). In another review (123), it was reported that AMR was assessed infrequently but was highly prevalent in patients with COVID-19 and bacterial co-infections; the authors noted that, although the prevalence of co-infection in COVID-19 patients was low (121), the prevalence of secondary bacterial infection was significantly higher and provided comprehensive evidence that the prevalence of AMR in bacterial infections was 60.8% (123). These findings suggest that patients presenting to a hospital with COVID-19 are unlikely to have bacterial co-infections (121,123); however, patients admitted to intensive care have a high prevalence of secondary infections, raising concern about AMR (119,123).

Some patients who presented to hospital had infection phenotypes that were similar to those of atypical bacterial pneumonia, which made it difficult to distinguish COVID-19 and led to precautionary use of antimicrobials (75,78,119,120). In some countries, antimicrobials were used as part of the package of care for hospitalized COVID-19 patients (120). One review showed that self-medication with antibiotics, administration of empirical antibiotic therapy and prescription of antibiotics by general practitioners were risk factors for high levels of AMR during COVID-19 (119,121,122,124). It has been proposed that COVID-19 has increased inappropriate prescribing of empirical antimicrobial therapy (75,78,121,122,124) and thus the risk of development of AMR (78,120,121,124), potentially increasing the number of resistant infections globally (75,122) through evolution of extremely resistant microorganisms, which seem to have worsened the status of some patients, particularly those in intensive care (122). The authors of five reviews (119,122-124) concluded that doctors who prescribe antibiotics should adhere strictly to judicious antimicrobial stewardship and the guidelines of WHO and other health authorities, especially during a pandemic. One review included studies of knowledge about implementation of antimicrobial stewardship in acute care settings and concluded that inadequate surveillance and auditing protocols at the height of the pandemic had decreased the effectiveness of stewardship, and structured education should be provided in addressing emergencies and crises (124).

Increased prescription of antimicrobials and broad-spectrum antimicrobials has also been attributed to increased use of telemedicine, for example in the United Kingdom (78). Postponement of seeking health professional advice during the pandemic delayed presentation of acute infections and increased the use of antibiotics for complex and severe infections without (or before) confirmatory laboratory testing. It was noted that people are more likely to self-prescribe antibiotics in countries where they can be obtained without prescription. Another review reported that almost 69% of COVID-19 patients stated that they had used antibiotics (typically ceftriaxone and azithromycin) before admission to hospital (122). Misinformation and inconsistent messaging may also have influenced prescription of antimicrobials. One review cited statistics from the USA showing that an estimated 32 000 prescriptions for azithromycin were issued after then-President Trump erroneously declared that this antibiotic could cure COVID-19 infection (78). In view of the increase in inappropriate prescribing and use of antimicrobials, rational prescribing should be emphasized to reduce the risk of increasing AMR (78,119,120).

A particular problem was observed in low- and middle-income countries, where antimicrobial stewardship programmes were at risk of disruption by the pandemic. In addition, limited laboratory capacity and uncontrolled access to antimicrobials resulted in a rise in AMR during the pandemic (78,119,121).
There is concern that increased use of antimicrobials and of biocides for disinfection of both health-care facilities and other indoor and outdoor settings could result in evolution of antimicrobial-resistant organisms that could be released into the environment (see section 3.4). There is also concern that global actions to halt morbidity and mortality from COVID-19 may have diverted attention from the wider problems associated with AMR, including research and the production and supply chains of antimicrobials (78). Some national plans and other initiatives to reduce AMR have been delayed, as has research on bacterial co-infections, secondary infections and the prevalence of antibiotic-resistant pathogens in outpatients and inpatients with COVID-19. The authors of several reviews (119,121–124) have called for additional research and surveillance of the effect of COVID-19 on AMR in both patients and the general population.

3.9.2 Impact on health-care staff

Health-care systems were unprepared and under-resourced to address the pandemic (51), and extreme pressure was placed on health-care providers and staff at every level. Initial waves of public solidarity and mutual support gave way to reports of fatigue and burn-out, and the strain of supporting front-line staff had an impact on mental health providers and internal support staff. A review of the impact of the pandemic on health-care staff identified both primary and secondary stressors as triggers of distress and symptoms of mental health disorders. In all of the studies included in the review, the mental health of health-care staff was assessed during the first wave of the pandemic, and all reported high levels of psychiatric symptoms. The authors of the review commented on the beneficial effects of early psychological interventions for vulnerable groups of health-care workers. They also considered reasoned approaches to caring for and supporting health-care staff. The potential interventions were increasingly focused, from supporting the well-being of each member of staff (the “well-being agenda”), to providing psychosocial interventions for struggling or distressed staff (the “psychosocial agenda”) and specialist mental health assessment and, possibly, treatment for specific conditions (the “mental health agenda”). The authors identified a number of limitations in existing research and called for well-designed, carefully executed longitudinal clinical studies to obtain a clearer picture of the longer-term impacts of the COVID-19 pandemic on health-care staff and to “determine the nature and extent of the impact on people’s mental health” (51).

3.10 COVID-19 and global systems

3.10.1 Climate change

The COVID-19 pandemic has presented an urgent, serious threat to health and to human systems. Initially, this resulted in rapid, urgent social and economic measures to limit the spread of infection and protect health-care systems from becoming overwhelmed. They included a global effort to develop, test and produce vaccines much faster than usual. Climate change is a major existential threat, and efforts have been made to reduce emissions of the greenhouse gases such as CO₂ and C₃, which are responsible for the current changes to the climate globally and which will be exacerbated in the coming decades. It has been described as having a more insidious long-term impact on global public health than that of the COVID-19 pandemic. Both climate change and COVID-19
affect vulnerable and poorer populations particularly (15,22).

This section summarizes the conclusions of the reviews on the relation between climate change and zoonotic diseases generally; the impact of COVID-19 on humanity’s ability to respond to disasters associated with climate change, such as major floods and wildfires; and the impact of COVID-19 mitigation policies on greenhouse gas emissions.

Climate change and zoonotic diseases

The potential role of climate change in the spill-over of zoonotic diseases from wildlife to humans is discussed in section 3.1 of this review. The agri-food sector has been identified as a major contributor to greenhouse gas emissions (40,109) and a direct driver of zoonotic disease (40). Climate change acts on the spatial distribution of wild species, in some cases increasing the chances of contact with humans and their infection with pathogens (10,15).

COVID-19 and natural disasters

One review listed a number of natural disasters, some of which (tornadoes, floods, bush fires and dust storms) may have been influenced by climate change, and the authors described the complexity of addressing such disasters during the pandemic (125). They cited the example of people who were at high risk of a hurricane who refused to go into shelters because of the fear of infection. The authors recommended that countries merge disaster risk reduction strategies into their COVID-19 response plans and called for clear guidelines on social distancing in shelters and self-isolation after staying in a shelter.

COVID-19 mitigation policies and greenhouse gas emissions

COVID-19 mitigation policies reduced global human mobility by 90% (8,126), due mainly to a 96% reduction in air travel (8). Greenhouse gas emissions fell during the pandemic (8,15,20,61,96,109,126–128), one review (40) citing a global fall of 8% in 2020, while another (20) reported an improvement in the Earth’s ozone layer.

The pandemic was also associated with a reduction in energy use (20,109) due to disruption of usual travel patterns (61) and closure of a number of industrial sites considered to be non-essential and also with reduced power production, resulting in a sharp fall in industrial and economic activities (96). Decreases in energy production were described across Europe (96,109), with global decreases in the consumption of coal (8%), oil (5%) and gas (2%) (96). In the longer term, intense use of landfill sites will lead to the production of biogas (a greenhouse gas comprising CO₂, methane and hydrogen) (85), which may aggravate the environmental footprint of such sites.

3.10.2 Biodiversity

Biodiversity loss has been identified as one of the reasons for the spill-over of novel zoonotic diseases (of which COVID-19 is one) from wildlife to human populations (see section 3.1). It has been suggested that biodiversity could provide alternative hosts for potential human pathogens, diluting the risk of human infection (9).

Biodiversity on land

The reduction in human activity and in noise levels may have benefitted wildlife (43. For example, more anecdotal sightings of wildlife have been reported in urban environments (126).
Lockdowns in some countries have resulted in renewed appreciation of local green spaces and natural areas (see section 3.8) and a renaissance of small neighbourhood parks (60). It has been suggested that, in order to address the needs of wildlife and thus improve or maintain biodiversity, these small parks should be linked through green networks to larger urban parks (60).

Economic downturns associated with COVID-19 mitigation policies and the collapse of international tourism during 2020 resulted in loss of funding for wildlife protection and enforcement (40). This has resulted in loss of income for some poor communities and thus an increase in hunting and foraging to feed their families (8,40). Concern has been expressed that countries’ economic recovery may include increased deforestation (40).

Plastic pollutants weather to form microplastics, which can affect soil biota (87) and thus soil health (6). General disinfection of urban streets conducted in some countries early in the pandemic resulted in chemical deposits on street greenery, residual chlorine dried on leaves and reactions with organic matter to form compounds such as trihalomethanes and halo acetic acids (61), which are toxic to many organisms.

**Biodiversity in waterways and seas**

Lockdown restrictions, travel limitations and major disruption of the tourist industry may have reduced pressure on aquatic systems (86,126) in a number of ways. Reduced emissions of NO\textsubscript{2} (see section 3.6) could reduce the levels of acid rain falling onto seas and waterways, and there have been reports of regeneration of fish stocks associated with the closure of some fisheries and increased sightings of some marine wildlife, such as marine mammals and turtles (126). One review concluded that, during lockdowns, biological oxygen demand, coliform counts and the concentrations of other pollutant decreased (836), while the levels of dissolved oxygen increased in most lakes and rivers around the world. Both positive and negative effects on the global oceans were reported, with better coastal water quality and less underwater noise; however, there were increasing amounts of COVID-19-related medical waste (e.g. PPE), which led to severe pollution and threatened the marine ecosystem and wildlife (129).

COVID-19 pandemic mitigation strategies resulted in large decreases in national and international tourism. This has resulted in cleaner beaches (20,85) and improved water quality (85,86). Biodiversity and aquatic ecosystems that have been under pressure from humans for a long time have had a chance to recover somewhat (86). The canals in Venice, Italy, became cleaner with a decrease in tourist numbers, less canal traffic and less churning of the canal waters by boats (20).

It has, however, been suggested that, while the few months of COVID-19 restrictions may have resulted in short-term improvements to waterways and seas, these will not be enough in the long term as society returns to pre-pandemic behaviour (126). One review identified a trend to deterioration after restrictions were lifted (86).

Surface water was found to have improved due to significant decreases in continuous domestic sewage, industrial effluent and agricultural wastewater discharges into catchments during lockdowns, which also reduced the risk of pollution with heavy metals and compounds. These and other benefits for ground and surface water were considered, however, also to be temporary (86).

Concern has been expressed that plastic litter (particularly PPE) collected in sewage and water run-off systems are swept into waterways (87), where they affect aquatic environments (44,88). The volume of plastic litter (associated with PPE) has been reported
to have increased on some beaches (85). PPE in waterways can affect wildlife by entangling them and by ingestion (88). In addition, plastic residues disintegrate over time into microplastics, which damage smaller marine organisms and have wider impacts on food chains (87).

There is concern that the increased use of antibiotics, biocides and disinfectants may result in release of active versions of those compounds into sewage systems (see section 3.4) and disturb natural ecosystems (8,62,78). More research is necessary to address gaps in current knowledge of the effects on ecosystems (62).
4 Building forward better
The response to the pandemic itself and the mitigation policies put in place to limit the spread of infection exerted huge pressure on health and care systems, which highlighted the lack of resilience and flexibility for most of the areas of the environment and health addressed in this review. Evidence was found that most systems were insufficiently resilient and flexible to meet the demands of the pandemic. Rapid, drastic short-term measures were used to accommodate the attendant shocks and stresses. Inequality both between and within countries and regions was exacerbated in many areas. People who are less wealthy and privileged experienced more profound impacts, leading to the view that the pandemic has increased inequality.

The authors of some reviews noted that the pandemic presented an opportunity to re-think our systems, take broader concerns into account and create more flexible, more resilient systems to meet future shocks, such as new pandemics and the impacts of climate change.

4.1 Improving the resilience of waste systems

The huge surge in the use of single-use plastics, particularly in the manufacture of PPE to control infection, resulted in a very large increase in plastic waste. This has coincided with a time when other pressures reduced funding and support for plastic recycling, leading to what one reviewer called a “plastic pandemic” (44). This is discussed more fully in section 3.5. Reviewers proposed use of the principles of the circular economy in order to address the problem (85). The circular economy approach is a model of production and consumption that includes sharing, leasing, repairing, refurbishing, reusing and recycling products and materials, thus reducing waste and the amount of waste dumped into landfills (109).

The reviewers concluded that circular economy approaches could address issues in MSW by increasing recycling and conversion (e.g. to energy) and reducing the reliance on landfills (16), including for health-care waste (84) and plastics (85). In the agri-food sector, composting waste would reduce reliance on manufactured fertilizers (109). It has been suggested that effective management of MSW during the pandemic would contribute to the circular economy, by using recycling and repurposing for a valuable purpose (e.g. energy) rather than landfill (16).

4.2 Improving the resilience of the energy sector

Energy has been significantly affected by the COVID-19 pandemic, one of the most significant effects being a change in the structure of consumption. The reviewers recognized limitations in forecasting methods used for determining supply and demand and found that current forecast models are ineffectual in crisis situations such as the pandemic, as they rely on time-based expectations, meteorological information and historical data. Real-time data on consumer behaviour and grid load during the pandemic allowed scientists to determine critical aspects of future energy systems. One author called for further research on the effect of changing energy consumer behaviour patterns to decentralize energy systems.
and establish distributed power generation. Recommendations were made for improving forecasting and strategic planning in the energy sector (100).

These reviewers also identified impacts of the pandemic on renewable energy, such as in Delhi, India, where a link was found between fewer pollution particulates and increased sunlight on solar panels (100); such data can be used in planning solar parks. The observation of improvements in overall air pollution with reduced carbon emissions during the pandemic reinforce the finding of global, economic and health benefits of changing to sustainable and renewable energy sources (20,93,100) and development of new energy projects that could withstand possible future crises while ensuring a transition to clean energy (100). It was noted that, during the COVID-19 pandemic, the demand for renewable energy increased because energy networks that have a significant share of renewable energy are more adaptable to crisis conditions and reduce the loads on centralized energy systems (93,100). It was concluded that a combination of the positive (if temporary) effects of the COVID-19 pandemic on the environment and the proven higher efficiency of decentralized energy systems with renewable energy over those based on fossil fuels has revitalized renewable energy development (100).

4.3 Improving the resilience of food supply chains

The pandemic has highlighted weaknesses inherent in global and long supply chains (40), and review authors urged greater support for local food supply chains (40,112) and recognition of the vulnerability of the highly complex, interlinked global supply chains (49). Others have described the benefit of short supply chains and use of innovative approaches such as farm networking and cooperation among producers, consumers and non-profit organizations (112), with encouragement of cooperative supply chains (109,114).

Reviewers suggested that the food and beverages sector re-frame, re-strategize and re-design food supply chains for post-COVID-19 resilience (108) and that better global food security systems can be achieved by changing priorities towards policy coherence, innovative food system governance, re-engineered market access and “nexus thinking” in food systems (114). Frameworks recommended for building more resilient global food supply chains after COVID-19 included consideration of system decentralization for flexibility, e-commerce platforms to digitize the supply chain, end-to-end visibility in the supply chain in which more agile food producers are identified to supply networks, vertical integration through artificial intelligence and new technologies (“industry 4.0”) and use of digitization and cloud-based technologies (108). Adoption of international policy instruments such as the Paris Agreement, the Sustainable Development Goals and the New Urban Agenda could improve management of extreme climate-related disasters while concurrently reducing food-related greenhouse gas emissions (114).
4.4 Improving the resilience of health systems

The scale and speed of the pandemic took many countries by surprise (10), and the global community has been urged to review its successes and mistakes and learn from its experience (27) for both health systems and wider societal and economic planning (128). With respect to access to public health, one review (118) recommended increasing the availability of services to the most vulnerable groups of inhabitants and particularly the elderly.

In one review, the challenges faced by health-care providers in the rapidly changing pandemic were highlighted, particularly adapting rapidly to an unfamiliar, stressful workplace (130). The authors proposed a three-part policy intervention to assist health-care providers in building resilience and preparing for pandemic situations: create a flexible, efficient system by modifying the roles of personnel; ensure adequate training of health-care personnel in their working conditions when treating COVID-19 patients; and create a supportive, motivating work environment.

One review (131) addressed quality improvement in public health during the COVID-19 pandemic. Factors such as strong stakeholder engagement and communication and coordination among stakeholders in decision-making were found to be crucial in a complex, multisectoral, inter-jurisdictional emergency such as the COVID-19 pandemic. The reviewers posited that organization-wide quality improvement, with use of quality improvement tools and techniques, could help to strengthen communication and coordination channels by ensuring that stakeholders and relevant partners become accustomed to collaborating towards shared goals. They further suggested that engagement in preparedness and planning will support rapid action, promote functional streamlining and reduce errors or miscommunication during a crisis. To ensure resilience in public health responses, public health agencies should integrate quality improvement into the culture of organizational management, integrate quality improvement of projects at all stages of the emergency management cycle (131), and update and integrate environmental emergency plans into those planned for health emergencies (118).

4.5 Improving the resilience of the places in which people live

The question has been raised of whether the increased possibility of working from home might result in a flight from cities and peri-urban areas to rural areas, which would affect the availability of land and housing for people already living in rural communities (60). It may be years before the extent to which the pandemic and its aftermath have affected urban planning and the design of public spaces. Although the pandemic is unlikely to affect the global economic and spatial inequality, it may result in changes in the structure and functioning of cities and suburban areas (60,72). The authors of several reviews called for use of evidence on transmission of respiratory viral infection in urban planning, legislation and policy (72). One review noted that architectural design has often played an important role in the prevention and control of infectious diseases
and could be further used to combat the spread of future viruses and variants (132).

The pandemic and its mitigation policies have challenged traditional views of city planning and organization (63). Living in large, densely populated cities may be no longer considered an advantage but a liability (22). Urban sprawl, low-density housing, rural urbanization, garden cities and individual transport were more resilient to the challenges of the pandemic (22,63). While shopping and socializing were major reasons for people to visit city centres, these have been strongly affected by the pandemic in terms of fear of infection and increased online shopping, resulting in less pedestrian traffic, jeopardizing the viability of large shopping areas and their cafes (60). With respect to greenhouse gas emissions, working from home is preferable to commuting, and travelling by train is preferable when working from home is not possible (58), transport being a crucial issue in many other categories of environmental impact, with implications for the planning and design of more resilient cities.

The role of urbanization and urban sprawl in the spill-over of zoonotic diseases, such as COVID-19, from wild animals to humans should be considered in planning land use and for public health (9). In some studies, higher population density was correlated with lower infection rates, which was posited to be due to denser neighbourhoods with more local amenities within walking distance, which resulted in less air pollution (a factor in infection), easier compliance with social distancing (72), and increased physical activity (a factor in immunity and overall health) (22,72). In one review (22), a significant negative association was found between mixed land use and COVID-19 infection rates in both Chinese cities and in London, United Kingdom. Mixed land use reduces long travel and less movement (22,72), resulting in fewer COVID-19 cases. Additionally, mixed land use neighbourhoods are more conducive to walking and cycling, which increases immunity-building physical activity and reduces the spread of the virus (22). Ensuring the walkability of cities and neighbourhoods might be considered for ensuring resilience.

Urban resilience requires the ability to adapt and respond to disturbances and changes in the system (133). To respond to the pandemic and address climate change, the authors of some reviews (50,128,133) have called for changes in urban and regional planning to build more resilient cities (133,134) by a more integrated approach to issues such as the economy, energy supplies, transport networks and food production and by integrating open spaces, water, parks and forests. They argue that this would improve public health, water management and climate adaptation and mitigation (128). The authors of one review (133) proposed that three dimensions of modern resilient cities are essential in pandemics: pandemic-related health requirements to help prevent the transmission of viruses; environmental–psychological principles to support positive mental well-being, facilitate safe social interactions, physical activity, and access to green infrastructure; and general resilience principles such as self-sufficiency, self-organization, decentralization, diversity, multifunctionality, flexibility, adaptability, connectivity and inclusiveness. The more rapidly cities are transformed to improve resilience to pandemic diseases, the more rapidly disease transmission will be controlled and the better the quality of life during pandemics (133).

Others have suggested that urban planning should consist of planning population density in urban parcels, increasing the amount of green space and bringing agricultural areas into cities (63). One review proposed various innovations to repurpose urban infrastructure and build adaptive re-use to address shortcomings in the food supply chain (9). A number of reviews concluded that the flexibility of neighbourhoods and their infrastructure should be improved (9,60,63,65,133). One reviewer (64,65) proposed that cities decentralize facilities to ensure access to
goods and services at a minimum distance from people’s homes to limit travel and interactions and therefore viral transmission. Another suggested the idea of a “20-minute neighbourhood” and the provision of flexible spaces that can be repurposed at short notice (63).

Urban greenery and green infrastructure were associated with fewer cases in studies in Poland, the United Kingdom and the USA (22). One review suggested that urban regeneration strategies for vulnerable districts should include space requirements for social distancing in future pandemics (8). Another noted that urban heat had increased during the pandemic, as lockdown measures had resulted in secondary pollution, creating additional risks for more vulnerable groups. It was suggested that planners construct a robust, resilient urban system for addressing multiple challenges (135).

It has been recommended that public spaces for pedestrians be improved by encouraging “shared streets” policies and introducing speed limits, especially in residential areas (118). Some reviewers considered that short-term interventions such as additional bicycle lanes could be considered pilot schemes (31,96) to encourage active movement more generally and contribute to reducing carbon emissions, which was considered a priority (8,86). Others reviewers suggested that reduced noise and air pollution and the return of wildlife in some places allowed residents to re-imagine their cities as places that smell better, sound more peaceful and permit better sleep (60).

### 4.6 The global economy, the social sector and the environment

A common conclusion was that the COVID-19 pandemic has shown that the most economically vulnerable industries are tourism (20,40,86,132), transport (34,53,96), health care (51,130,131) and food (89,90,108). Transport and tourism were heavily affected by the restrictions imposed on movement of the population. The health-care industry was unprepared for the huge increase in the number of patients. The food industry saw the destruction of logistics chains, which significantly affected the least well-off sections of the population. Marine tourism and the fishery industry were severely disrupted, and coastal communities experienced loss of income, unemployment, inequality and health problems (129).

A review of the ethical and economic results of attempting to address climate change during a pandemic concluded that, although the pandemic has had positive effects on the climate and contributed to energy goals, it has been too expensive in terms of lost economic activity and that international climate policy provides more cost-effective mechanisms to combat climate change than simply reducing use (100). Energy systems with a significant share of renewable energy were found to be more flexible in responding to demand, and their use was economically justified during the pandemic (20,93,100). These networks could increase the energy independence of energy-poor countries, protecting them from economic and social threats. Thus, the COVID-19 pandemic has revealed the association of energy with achievement of Sustainable Development Goals 7 (affordable and clean energy) and 13 (climate action), and also with Goal 3 (good health and well-being) (100).
4.7 COVID-19 as a tipping point for action on climate change

Some review authors suggested that the COVID-19 pandemic and its sequelae might be considered a juncture at which either opportunities were taken to consider the wider implications of plans and actions beyond perceived economic advantage, or that mankind would resume its behaviour before the pandemic, making little or no progress towards addressing existential threats such as climate change. It was noted that governments had found US$ 8 trillion in 10 weeks to respond to the COVID-19 pandemic and to set mitigation policies; the same aggressive, urgent action should be taken to address climate change (15). The international cooperation found to address the challenges of the pandemic could be used to address climate change (128); politicians and governments that have used scientific evidence to design policy could take a similar approach in addressing climate change (15). Governments could build on the environmental improvement observed during lockdowns (20,33,38). Urban planners should use experience during the pandemic to improve sustainable transport (53) and to address transport-related greenhouse gas emissions (63).

The authors of two reviews suggested that climate change could be mitigated by using the experience of the pandemic to accelerate decreases in carbon-intensive industries, technologies and practices and leverage responses to the pandemic to drive low-carbon innovations (63,86). One reviewer recommended better use of new technologies to improve air and water pollution and an international three-dimensional monitoring strategy to reduce uncertainty and facilitate understanding and prediction of air pollution (86). It was pointed out that, because emissions of harmful substances and greenhouse gases increase to the usual values when economic and industrial activity is resumed, artificial restrictions are ineffective for combatting climate change. Instead, governments and policy-makers should focus on economic incentivization to conduct business responsibly with environmentally respectful technologies (58,100).

In building forward better, it has been argued that the agri-food sector should take climate change mitigation and adaptation into account, moving towards shorter, mutually supportive supply chains that consider environmental health (109) and reduce carbon emissions (86,109). In terms of personal behaviour, trends towards more sustainable transport and remote working (96) could be sustained after the pandemic, leading to reductions in greenhouse gas emissions and air pollution (56,60,96). It has also been suggested that the pandemic has led to a more family-centred lifestyle (128).

Although greenhouse gas emissions decreased during the pandemic and early mitigation strategies, this was not sufficient to affect climate change (86,128), and there is concern that emissions will resurge once the threat of the pandemic has passed (8,15,86,128), as in the past (128). Intense use of landfill during the pandemic may result in emissions of biogas from those sites in the future (85).

It has been suggested that the response to the pandemic has marginalized climate and environmental issues, with less political will to address these issues (100,128). A number of countries either stopped or slowed action to reduce climate change, reduced investment and/or requested relaxation of carbon emission limits (e.g. Poland) (128). In addition, the pandemic may have undermined initiatives to reduce dependence on individual transport (53), as some people may prefer private transport to
avoid the risk of infection, as occurred in China after the early lockdown (40).

Plans for economic stimulus after the pandemic must include addressing climate change and considering the ecological environment for a green, low-carbon transformation of the global social economy (128). Only joint social effort and international collaboration can ensure a clean energy system built on the extensive lessons from the pandemic for environmental health (100).

### 4.8 Future action on biodiversity

It has been proposed that the risks of future zoonotic disease spill-over be considered in decisions in which economic impact was previously the major consideration, and that disease risk be considered before encroaching on natural ecosystems (7). To mitigate the risks of future pandemics, conservation of biodiversity must be improved nationally and internationally and aligned with global health (5,86). A number of authors called for wider use of the One Health approach to address these issues (8,10,14,114,136).

### 4.9 One Health

Given the increase in novel zoonotic infections, the devastating impacts of COVID-19 on global health and the social and economic sequelae of measures to control the spread of infection, it is not surprising that a number of reviewers called for greater use of the One Health approach, in which the health of people, animals and the environment are considered in a multidisciplinary, collaborative approach to manage the risks of future crises (8,10,14,136). This approach would mitigate concern that decisions on human encroachment onto wild and natural areas are often based primarily on economic considerations (10), as One Health is based on the precept that prevention and zoonotic control programmes are more effective when the wider ecological and socioeconomic determinants of health are included (22,136). One Health is also considered to be an important approach to climate change (10,14) and with respect to the contribution of the agri-food sector to increasing AMR (78).
5 Gaps in knowledge

The 132 reviews included in this review of reviews listed a number of limitations, and most proposed future research steps. The largest gap in current research is clearly the lack of longitudinal studies, which are necessary to reinforce or disprove many findings. Only time and the collation and integration of data will fill the gaps in knowledge. The policy brief (I) that is based on this literature review includes recommendations for both policy interventions and additional research.
6 Conclusions

This rapid review of reviews was conducted as a basis for the policy brief (1) to inform discussions on the impacts of COVID-19 on the environment and health, particularly in the WHO European Region. The brief also proposes future directions for environment and health in Europe.
References
References


How coronavirus disease has changed the environment and health landscape

References


References


References


References


References


The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

The WHO European Centre for Environment and Health, located in Bonn, Germany, was established in 1989 by the First European Conference on Environment and Health as an integral part of the WHO Regional Office for Europe. The Centre provides technical and scientific expertise on the impacts of the environment on health. It delivers advice on policy and tools to inform and support decisions on air quality; access to safe drinking-water, sanitation and hygiene; minimizing the adverse effects of chemicals; adaptation to and mitigation of climate change; environmental sustainability of health systems; urban health planning, including transport and mobility; and violence and injury prevention. It collaborates with partners on initiatives to address environment-related diseases. The Centre also strengthens national capacity to address environment and health challenges through training courses on environment and health, including health impact assessments.

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