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EUROPEAN CENTRE FOR DISEASE PREVENTION AND CONTROL

ASSESSMENT

Future challenges for infectious disease prevention and control

A strategic foresight approach to enhance European public health preparedness and resilience

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This report of the European Centre for Disease Prevention and Control (ECDC) was coordinated by Gerjon Ikink through a collective and collaborative process with everyone listed in Annex 1.

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Acknowledgements
Please see the list of acknowledgements in Annex 1.

Suggested citation: European Centre for Disease Prevention and Control. Future challenges for infectious disease prevention and control. Stockholm: ECDC; 2025.

Stockholm, April 2025

ISBN 978-92-9498-795-2
doi: 10.2900/4488147
Catalogue number TQ-01-25-025-EN-N

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Abbreviations

AI	Artificial intelligence
AMR	Antimicrobial resistance
EU/EEA	European Union/European Economic Area
FEAM	Federation of European Academies of Medicine
JRC	European Commission's Joint Research Centre
WHO	World Health Organization

Executive summary

The European Centre for Disease Prevention and Control (ECDC) initiated an elaborate multi-method strategic foresight process in early 2022 to consider and prepare for a broad array of potential future scenarios, in order to improve ECDC's preparedness and resilience to future threats. This was in recognition of the volatility and complexity of the dynamic systems surrounding public health. By identifying priorities for public health preparedness, research, training and workforce development, the project intends to inform long-term public health planning within ECDC itself, within the EU public health policy arena and by other stakeholders.

This process started by horizon scanning for important global trends relevant for public health ('megatrends') and assessing their underlying driving forces ('drivers of change'). It then interpreted the impact, uncertainties and implications of possible alternative pathways of change towards 2040 ('driver trajectories') to develop images of different possible futures from the resulting operational conditions, as well as their associated challenges for infectious disease prevention and control ('threat scenarios'). Finally, it concluded with imagining what a robust future organisation would look like under such conditions, to assess what actions should be taken in the meantime ('back-casting') and stress-testing these actions under the range of plausible operational conditions (wind-tunnelling). While the conditions in each threat scenario are different, five clusters of common challenges were identified:

- Climate change persists or worsens in all scenarios. It aggravates infectious diseases through various mechanisms, such as higher risks of vector-borne diseases and zoonotic diseases, higher incidence of food and water borne diseases, and the emergence of novel pathogens, highlighting the importance of One Health approaches.
- Challenges for implementing disease prevention, including vaccination, health communication and other preventative measures would be amplified in the future with lower public trust, higher societal fragmentation, or profit-seeking actors who may deprioritise prevention activities. The proliferation of misinformation further exacerbates these difficulties.
- Demographic shifts, social inequities and reduced access to healthcare may be compounded by increased pressure on existing health systems, cumulatively impacting the conditions in which infectious diseases take root. Ageing populations, people who are socially disadvantaged and people with mental health issues will grow in number, size and diversity.
- Data, digitalisation, and new technologies impact disease surveillance, access to healthcare services, and information ecosystems. Futures in which data quantities continue to increase present unique difficulties, while futures where data becomes less accessible could also create new challenges for disease surveillance operations. Closely linked to data issues is the emergence of Artificial Intelligence (AI) which could create opportunities and risks for disease prevention and control.
- Future changes of governance at global, EU, national and even community level create broad uncertainty for public health. The different directions in which EU governance may develop (e.g. greater fragmentation, harmonisation or unification) could directly impact the existence and relevance of public health authorities, including ECDC.

In preparation for these threats that are shared across the wide range of possible future operational conditions, the foresight process presented here ultimately yielded a collection of robust future-proofed actions for operational, strategic and policy consideration. These actions centre around several strategic focus areas that should:

- Strengthen external communications and outreach capabilities to foster public trust and preserve legitimacy, while developing messaging strategies to relay critical information to a spectrum of communities and groups.
- Further develop data expertise and best practice to ensure preparedness for a breadth of potential data availability and accessibility scenarios.
- Budget for and create working groups and teams in areas like climate change, health economics, behavioural and other social sciences, data modelling, and AI.
- Engage with local populations who are more exposed to the threats outlined in this document or encourage prioritisation of this type of engagement to build trust, access data, and provide advice that will be more readily received and followed.
- Value international institutional cooperation as a mode of providing mutual assistance to peer organisations (such as WHO and other CDCs), thereby improving European readiness and building responsive action networks in preparation for outbreaks.

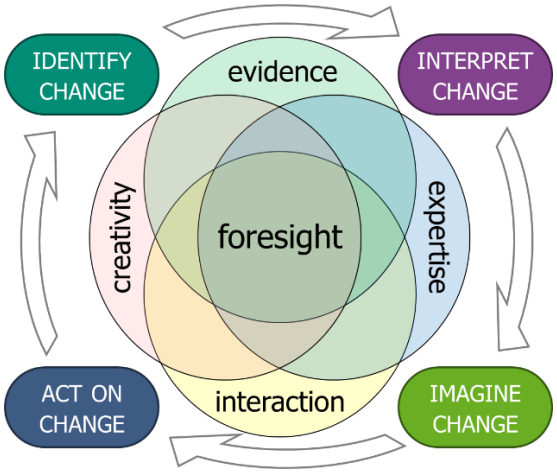
1. Background

The COVID-19 pandemic underlined how disease prevention and control is strongly influenced by a wide range of factors in addition to science and technology. The challenges experienced in responding to the pandemic highlighted blind spots in public health systems that affect their preparedness and resilience. It became clear that public health institutions need to look wider outside their direct area of work and further ahead in time to be ready for serious cross-border threats to health. Indeed, the importance of developments in, for example, geopolitics and governing structures, climate and biodiversity, societal polarisation and inequalities, for the effective prevention and control of emerging and established infectious diseases was highlighted by the challenges faced during the pandemic and in responding to other threats over the past decades.

Building on these lessons learnt, the mandate of ECDC was amended in 2022 and requires bolstering anticipation capacity and consideration of other factors– including social, economic, climatic and environmental factors (Regulation 2022/2370). Recognising the value of using strategic foresight for this, ECDC initiated the foresight process in 2022, which is summarised in this report.

Strategic foresight is about exploring different possible futures in a structured and functional way, typically combining several forward-looking approaches, systems thinking and interdisciplinary intelligence-gathering. It systematically connects diverse sources of evidence and expertise with creativity and interaction [1] to bring together different perspectives about the future, thereby reducing blind spots. Strategic foresight is done to anticipate change and its implications, imagine resulting possible futures to enable preparatory actions in the present (Figure 1)

Figure 1. Strategic foresight cycle



The foresight work published in this report forms part of a cross-cutting strategic foresight programme aimed to make European public health systems – including ECDC itself – better prepared and resilient to future health threats and other relevant developments, by:

- assessing the implications for EU/EEA public health systems of large-scale changes and their indirect impact to the operating environment.
- understanding the inter-relationships between different drivers of the future infectious disease threat landscape, as well as key developments impacting public health, including environmental, demographic and socio-economic factors.
- identifying priorities for public health system resilience, preparedness, policy, research, training and workforce development to inform strategic decisions and policymaking.
- improving futures literacy and building foresight capacity in ECDC and its partners in the Member States.

The outcomes from the work summarised in this report are mainly intended for internal use to inform ECDC's strategic direction going forward. However, the main high-level insights that arose from it can hopefully be used by ECDC's external partners and stakeholders for inspiration, information and action.

2. Methods

The foresight process presented in this report employed multiple methods for exploring relevant developments and the future threat landscape for infectious diseases prevention and control, to develop robust strategic actions based on different possible future scenarios. Reflecting the participatory practice of strategic foresight, at least 245 experts and stakeholders were consulted during the process.

The process started in February 2022 with an analysis of the European Commission Joint Research Centre's (JRC) Megatrends Hub[i] through **desk research**. The focus of these horizon scanning exercises was to identify components of each megatrend that could drive infectious disease threats, i.e. **macro-drivers research**, based on the descriptions provided by the JRC or via connected literature. Simultaneously, **micro-driver research** was done by field-specific experts identified by the Federation of European Academies of Medicine (FEAM). This desk research fed into further identification, justification and prioritisation of relevant macro- and micro-drivers of change through **online expert focus groups** (during April and May 2022) and an **online real-time Delphi-survey** (live from June to October 2022). Experts were given multiple opportunities to contribute additional macro-drivers, suggest the merging of macro-drivers from the initial list, and refine the wording or phrasing of the macro-drivers and their descriptions.

The **focus groups on drivers of change**, which included 34 ECDC's scientific staff members and seven FEAM-experts, were intended to: a) enable a more detailed analysis of the presented drivers; b) critically think about the impact they might have within their public health work; and c) contribute additional micro-drivers in view of their expert experience. Six separate focus groups covered a wide range of technical specialisations, specifically: emerging, vector-borne, and food and water-borne diseases; coronavirus and influenza; antimicrobial resistance and healthcare-associated infections; sexually transmitted infections, blood-borne viruses and tuberculosis; vaccine-preventable diseases and immunisation; surveillance and data, digital transformation, scientific methods and standards, preparedness and response, epidemic intelligence, and public health training.

The **Delphi-survey on macro-drivers** complemented the focus groups, and 77 ECDC's staff members from across the agency assessed the macro-drivers in greater detail. The self-paced survey included the ability for respondents to submit arguments and statements for their assessment of each macro-driver's uncertainty and possible future impact on the prevention and control of infectious diseases. As per the Delphi-survey process [2] responses were anonymised and could be read by other survey respondents in real-time once they had completed the survey. Participants could revisit the survey several times over a period of over four months.

Based on the combined prioritisation outcomes of the focus groups and Delphi-survey, the top 10 macro-drivers (both highly uncertain and potentially impactful with respect to the ECDC operational environment) were taken as key drivers of change for further analysis. Assessing possible driver trajectories towards 2040, as well as relationships between drivers, was done in an **in-person expert workshop** (20-21 October 2022) and three subsequent **online review meetings** (14, 17 and 22 November 2022).

The **expert workshop on macro-driver trajectories and connections** brought together 25 ECDC scientific staff members and 22 external experts from various scientific backgrounds relevant to the key drivers, who were nominated by ECDC's cross-agency foresight task force and the foresight project partners. Through multiple structured activities, the participants outlined how individual drivers could potentially develop over time, the implications of those alternative developments, and the interconnections between drivers in shaping future change.

In the following **review meetings**, the synthesised outcomes of the workshop were reviewed by 36 experts, of which 10 were experts external to ECDC. Half of the participants had not participated in the workshop, which allowed for an independent peer-review on whether the expected driver developments were lacking important assumptions or were too broad. Review meeting participants were also invited to suggest narrative elements for the strongest driver connections, to feed into the scenario development process.

Next, narrative threat scenarios for 2040 were developed through **desk research** following an adapted 'intuitive logics' approach [3]. Many draft contextual narratives – based on logically coherent sets of strong macro-driver interactions – were iteratively merged to six scenarios based on similarities in situational consequences, i.e. the impact of the contextual narrative on the operational conditions for ECDC. Relevant identified micro-drivers and governance implications were integrated into the situational narratives of the final scenarios. The six scenarios were then vetted in another **in-person expert workshop** (23-24 February 2023), during which the vetted scenarios were also used for back-casting to identify strategic mitigation and preparedness steps to take. This was followed by **three rounds of peer-review** (from March to May 2023).

[i] https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en#explore The JRC Megatrends are continuously updated to reflect emergent changes and influences. To account for this within this project, the megatrends were periodically revisited, but this did not result in significant changes to the macro-drivers of interest to ECDC.

The **scenario vetting and back-casting workshop** activities focused on three primary tasks: 1) a review and refinement of the content of the scenarios and their infectious disease prevention and control threats; 2) having vetted the scenarios, outlining a future ECDC optimised for each scenario, including its mode of working and partnerships; and 3) using these optimised future attributes back-cast necessary steps and actions to take from the present to get to each future-optimised ECDC. The 24 ECDC experts and 17 external experts participating in this workshop were nominated by the project partners and ECDC's foresight taskforce to cover the expertise required for assessing the threats and challenges identified in each scenario. Of these 41 participants, 23 had not participated in previous parts of this foresight work. The processed results of the workshop[3] were **peer-reviewed** by ECDC's Advisory Forum, by the EU Agencies Network on Scientific Advice (– Futures Cluster), and by the ECDC foresight task force.

From the back-casting process, strategic options were developed, prioritised and refined through further **desk research**, an **online scoping survey** (live from November 2023 to January 2024), **in-depth interviews** with key experts and stakeholders (between January and April 2024), and scenario wind-tunnelling exercises for stress-testing during two additional **expert workshops** (on 5 and 18 March 2024).

The **scoping survey on the strategic actions** was open to all ECDC staff, to members of ECDC's Management Board and Advisory Forum, as well as to the Directors and National Coordinators of the Coordinating Competent Bodies (CCBs) in the Member States. The 67 contributors who completed the survey assessed and ranked the 98 actions in the (collective) context of the threat scenarios for 2040. For each action, the survey asked, 'How much attention should the proposed action be given, taking the identified threats into consideration?', with the answer ranging from 'Not at all' to 'Thoroughly'.

From the survey, 43 shortlisted actions were selected for **in-depth interviews**, divided over five thematic threat clusters. In total, 14 ECDC experts and 19 experts and stakeholders external to ECDC – representing public authorities, academic and research centres, civil society organisations and international organisations – were engaged in 30 in-depth interviews that each covered one threat cluster. The interviewees assessed the actions against their relevance, effectiveness and efficiency, following the European Commission's Better Regulation practice. Based on insights from the interviews, the actions were further refined and prioritised to a shortlist of 27 strategic actions for wind-tunnelling.

In two independent **scenario wind-tunnelling workshops**, the robustness of the 27 proposed strategic actions was assessed in groups for each threat cluster against all six scenarios, to identify the actions most likely to foster organisational resilience. Participant workgroups were arranged to ensure that diverse perspectives were represented within each group, and that relevant expertise was brought to bear on the thematic cluster area at hand. An in-person workshop brought together 23 members of ECDC's Advisory Forum with 20 ECDC senior and middle managers. A subsequent virtual workshop was open to all other ECDC staff and had 81 active participants, ranging from junior to senior staff (including trainees), and with a wide range of profiles covering all Units in the agency.

All results from the entire foresight process were finally reviewed in an **internal review meeting** (on 3 June 2024) and through a **written feedback period** (until the end of June 2024). Over the rest of 2024, the internal documentation of the process and outcomes of the project were finalised, and the current public summarising report was drafted and reviewed for publication.

3. Key drivers of change

'Drivers of change', or simply 'drivers', are issues, topics, trends and other developments that effect change. Here, the scope was change that affects the risk landscape for infectious diseases in the EU/EEA, and relevant developments beyond the EU/EEA, as well as change impacting the mission and operations of ECDC and partner organisations. Although 'micro-drivers' were also explored – i.e. issues or trends emerging from research and innovation to study, monitor, diagnose, treat or otherwise prevent or control infectious diseases, with distinct ramifications on ECDC's work – the focus of this work was on 'macro-drivers'. Macro-drivers are social, technological, ecological, economic and political issues and trends that are national, international, or global in scale. Based on the 14 global megatrends[ii] defined by the Joint Research Centre of the European Commission (JRC), 36 underlying macro-drivers were identified (see Table 1).

Table 1. Megatrends with their identified macro-drivers

Megatrend (JRC)	Associated macro-drivers	Megatrend (JRC)	Associated macro-drivers
Widening inequalities	Widening inequalities in access to healthcare.	Accelerating technological change and hyperconnectivity	Personalised digital data – ownership, access, utility.
	Growing territorial inequalities – local, state, international.		Data collection, security, analysis and AI.
	Inequalities based on demographic categories (e.g. gender).		Transforming mobility and transportation systems.
Climate change and environmental degradation	Changing climate patterns and ecosystem habitations.	Changing nature of work	Platformisation[iii] and digitalisation of work.
	Developing climate change mitigation policies.		Non-standard forms of employment on the rise.
	Increasing pollution of air, waterways, soil.	Diversification of education and learning	Context-sensitive learning pedagogies and technologies.
Increasing significance of migration	International migration continues to rise.		Support new learning needs of young generations.
	The EU remains an attractive primary destination.	Shifting health challenges	Multifactorial health linked to the environment is increasingly recognised.
Growing consumption	Sustainable consumption policy impact (e.g. supply chains).		People-centric approach to health.
	Increasingly consumer-centric markets integrating personalised data.		Looming mental health and wellness issues.
Aggravating resource scarcity	Pressure increased on natural resources and ecologies.		Increasing antimicrobial resistance.
	Evolving resource management and exploitation of deposit.	Continuing urbanisation	Growing urbanisation globally and in the EU
Increasing demographic imbalances	Age structures becoming more uneven.		Increasing urban environmental degradation and new challenges in land use management.
	Impact of ageing are growing.		Changing urban mobility and services provision.
Expanding influence of East and South	Regional growth potential in Africa.		
	China and India – re-entering global economic forces.		
	New forms and leaders in international governance.		

A wide range of experts within and external to ECDC assessed and prioritised these drivers before synthesising and vetting them. They then shortlisted those with the highest uncertainties that will likely have a high impact on future infectious disease threats or ECDC's mission and operations otherwise. Of the ten prioritised key drivers, different possible development pathways – termed trajectories – were examined.

[ii] Major changes with global impact that are observable now, will probably continue in the same trajectory, and will most likely have a significant influence on the future. See JRC Megatrends Hub: https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en#explore

'Platform work is a form of employment in which organisations or individuals use an online platform to access other organisations or individuals to solve specific problems, or to provide specific services in exchange for payment.'

EU rules on platform work - Consilium

Experts defined the 'dominant' trajectory each of these key drivers would most likely take towards the year 2040, as well as alternative plausible trajectories which should also be considered.

A summary of the identified key drivers and their possible trajectories is provided below. These can be used to explore the implications of such future developments on public health institutions dealing with infectious diseases, informing anticipatory interventions to ensure better preparedness and resilience.

3.1 Inequalities in access to healthcare

Differences in healthcare systems, funding schema, and payment responsibilities lead to disparities in access to quality healthcare. Inequalities can emerge between groups within the same society and are usually rooted in 'dimensions of inequality', such as socioeconomic status, occupation, gender, age, ethnicity, religion, level of education, place of residence, or migration status [4]. Inequalities are also noted when comparing societies, such as the 'between-country' health inequalities that can be monitored based on national averages. A recent World Health Organization (WHO) report on global strategies to address HIV, tuberculosis, and malaria, showed that in many areas inequalities have not narrowed, and in some cases have worsened – impacting chronically disadvantaged populations who are among the 'poorest and least educated, living in rural and remote areas' [5]. In an increasingly digital and data-driven world, differences in access to data, information and technology is becoming an important new dimension of inequality [6]. Also the impact of climate change on health systems, coupled with its disproportionate effects on population groups who are vulnerable to these changes further widen health inequities [7].

Trajectory a: Inequalities in access to healthcare deepens both within and between countries.

Trajectory b: More complexity in access to healthcare with shift in inequalities (e.g. private vs. public).

Trajectory c: Access to healthcare more equal both across and within countries, less under-served groups.

Trajectory d: Universal healthcare coverage with strongly reduced inequalities in access to healthcare.

International migration and travel

According to the latest estimates, a record high of 281 million people were living outside their country of birth in 2020, accounting for 3.6% of the world's population [8]. In recent years, involuntary migration has risen strongly, with 117.3 million people worldwide forcefully displaced in 2023 (e.g. due to persecution or conflict), including 43.4 million refugees – more than three times the number as in 2013 [9]. Climate change is predicted to cause the forced movement of 216 million people by 2050 [10]. As the total number of both displaced people and international migrants continue to rise around the world, this places new pressure on systems and services in the places where they settle. Additionally, despite global inflation and heightened fuel prices, international travel has nearly recovered to pre-pandemic levels and is projected to reach 1.8-2 billion international arrivals by 2030 [11] which could lead to an increased risk of endemic infectious diseases from other countries being imported into Europe.

Trajectory a: International travel surpasses pre-pandemic times; migration remains on the same level.

Trajectory b: International migration and displaced populations rise further; travel as pre-pandemic.

Trajectory c: Less migration and travel to the EU (e.g., due to anti-immigration and/or environmental policies).

Climate change

Even if all human-produced greenhouse gas emissions would be stopped now, the climate would continue to change with Earth's surface temperature remaining elevated for decades. However, there is strong scientific consensus that without profound climate change mitigation that ends greenhouse gas emissions, the negative effects will be more severe and widespread. Those living in low-income regions and groups disproportionally vulnerable to severe outcomes of infectious diseases could be directly impacted by extreme weather events including heatwaves, rising sea levels, floods, extreme precipitation, droughts, and increasingly frequent and powerful storms[12-13]. Additionally, climate change creates conditions for infectious diseases to change their geographical distribution, as plant and animals change their geographical ranges, along with their respective pathogens [14]. Lastly, other environmental factors such as air pollution [15] and micro-plastics [16] can also impact health and healthcare systems across Europe.

Trajectory a: Climate change adaptation and mitigation measures remain too little and too late.

Trajectory b: Countries take diverging and disjointed approaches individually or in blocs.

Trajectory c: Strong transformation towards adapting and preparing for climate change effects.

Trajectory d: Full-blown, radical green transition with a strong focus on climate change mitigation.

New distribution of wealth and influence

Economic power is shifting towards emerging economies in the East and South, with Asia – mainly China and India – projected to provide over half the global economic output by 2050. The global scale of China's economic and soft power, combined with India's current development, may increasingly shift the centre of international influence to South and East Asia [17-18]. At the same time, the African continent is experiencing an economic and social transformation and will play an increasingly prominent role in the world economy. With its current growth rate, Africa's population will reach 1.1 billion people by 2040, comprised of more young people than other parts of the world. The African Union as an emergent global power led by an ethos of inclusive and sustainable development [19] may have different prospects for global health governance in the future, as may already be noted [20-21]. Further shifts in political directions in countries, emerging powerful non-governmental actors and private entities, and the redistribution of power between governance levels, adds complexity to global power dynamics.

Trajectory a: Multi-polar global order with influence shifts from 'the West' to China, India and certain African countries.

Trajectory b: Authoritarianism on the rise in countries across the world, including in the EU.

Trajectory c: Private actors and multinational companies increasingly take over government services.

Trajectory d: Power shifts from global/national to regional/urban levels.

Impact of ageing populations

Around the world, people are living longer and most people alive today can expect to become over 60 years old. While this population ageing trend was initially limited to high-income countries, today, the proportion and size of older populations is growing in every country. By 2050, the world's population of people over 60 years old is expected to double to 2.1 billion, of which those over 80 years old are expected to triple to 426 million, compared to 2020 [22]. In the EU, the number of people of working age for each older person (>65 years old) will have shrunk from roughly three in 2019 to two by 2025, while the number of very old people (>85 years old) is projected to more than double, and centenarians (>100 years old) to increase more than five-fold [23]. This demographic shift has a significant impact on health systems, and will be challenging for countries to ensure the healthy ageing of older people. As well as the structural challenges described above, healthy ageing is also hindered by discrimination of older people and other forms of agism.

Trajectory a: Higher proportion of older people in EU populations (progression of current trend).

Trajectory b: EU population ageing slowdown (e.g. due to baby-booms, migration, pandemics).

Trajectory c: EU population ageing acceleration (e.g. due to medical advances, war/disease events).

New modes of learning and communication

New generations of learners who are growing up under different socio-technological conditions will require fluency in skills and powerful technological platforms, and face new challenges in the labour market. The growing influence of digital media, including mis- and disinformation campaigns, radically reshapes the field of communication through dynamics of the attention economy and behavioural algorithms, and impacts how people learn about topics such as infectious diseases and trust the information they receive [24-25]. The social, political, and economic impact of digital platforms have made digital technologies some of the most powerful and influential forces in societies around the world [26]. Learning new forms of digital literacy and fluency within new media ecologies is becoming a more important skill for people of all ages – though it remains a significant challenge given digital divides between and within societies [27]. New modes of teaching and learning may be required to better equip individuals and institutions to defend

against and actively combat misinformation and prepare for some of the cyber security threats that digital hyperconnectivity have enabled [28].

Trajectory a: The EU has a well-informed population and well-developed communication channels.

Trajectory b: Polarised societies with fragmented and isolated communication bubbles.

Trajectory c: Highly digitalised and hyper-connected, virtual cross-interacting society.

Data collection, security, analysis and artificial intelligence

Public sector digitalisation can improve transparency by contributing to open government and facilitate interaction between governments and citizens. The digitalisation of government and public services also faces challenges – in particular a growing attack-surface for security issues, and in ensuring all data operations abide by protection policy. As data collection methods expand to include new sensor arrays [29], monitoring equipment [30], and data storage capacities, increasing the size and granularity of data sources enable new modes of data analysis via artificial intelligence or machine learning technologies [31]. These automated analysis systems also present challenges, particularly with data security and privacy [32-33] ensuring transparency around decision-making [34] and being able to account for any biases in training datasets [35] .

Trajectory a: Continued adoption of digital technologies and accelerated technological development.

Trajectory b: Big tech companies consolidate power to collect, store, analyse and use data.

Trajectory c: Data minimalism is the operating ethos of digitalisation (e.g., due to high energy consumption).

Trajectory d: Strong integration of public and private data streams and uses.

Urbanisation globally and in the EU

Urbanisation is at a historical peak, with over half the world's population currently living in urban areas, which is expected to increase to five billion by 2030 [36], bringing about significant economic, environmental and social transformations. Cities are the site of high concentrations of various inequalities [37], including poverty and exposure to the environmental and health impact of urbanisation such as air pollution mortality [38] [39]. Urban growth will mainly occur in Africa and Asia, but EU urbanisation also remains on an upwards trajectory and susceptible to all of the epidemiological risks involved [40], even as those risks become more uncertain [41].

Trajectory a: Continued urbanisation varying from well-managed growth to uncontrolled sprawls.

Trajectory b: De-urbanisation due to economic factors (policy-designed or otherwise).

Trajectory c: De-urbanisation due to ideological and/or changing lifestyle reasons.

Pressure on natural resources and ecologies

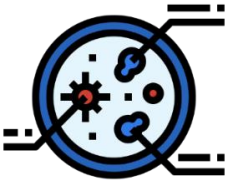
Human influence on natural ecosystems, and the services they provide, continues to rise alongside the demand for resources [42] [43]. Even localised ecosystem-collapse can have important social and economic implications. Greater levels of extraction and exploitation of resources increases the contact points between human and natural ecologies and may increase the threat of exposure to (re)emerging diseases. The disruption of natural habitats and ecological systems is further aggravated by pollution of air, soil and waterways [44]. For those systems that are providing human services – for example, potable water sources, or lands supporting agriculture [45]– the overexploitation of natural resources and ecological degradation will have significant negative impacts on people and societies globally. Policies meant to safeguard ecosystems, and services they provide, are prone to socio-political dynamics and forces [46].

Trajectory a: Accelerating depletion of natural resources with much of nature and biodiversity lost.

Trajectory b: Strong global collaborations and joint efforts in One Health limit exploitation.

Trajectory c: Transformational movement restoring nature and biodiversity.

Antimicrobial resistance



Health is challenged by the emergence and spread of bacterial pathogens that are resistant to antimicrobial agents, mainly driven by the abuse and misuse of antimicrobials in veterinary and human medicine [47]. This fuels the need for new types of treatments given that antimicrobial resistance (AMR) increases morbidity, mortality and the risk of developing serious health issues. Healthcare costs dramatically increase as AMR grows and the loss of effective, affordable antibiotic treatments may disproportionately affect those populations that cannot pay for alternatives [48-49]. There is a real risk that we enter a post-antibiotic era, where combatting previously unproblematic bacterial infections will be impossible, also meaning that simple surgical treatments can no longer be performed safely. For this reason, antimicrobial resistant infections may become the leading cause of death globally by 2050 [50].

Trajectory a: Red map scenario: high AMR prominence in all regions.

Trajectory b: Strict rules, implementation and compliance in EU and globally limit the increase of AMR.

Trajectory c: Research and innovation advancements limit the impacts of AMR.

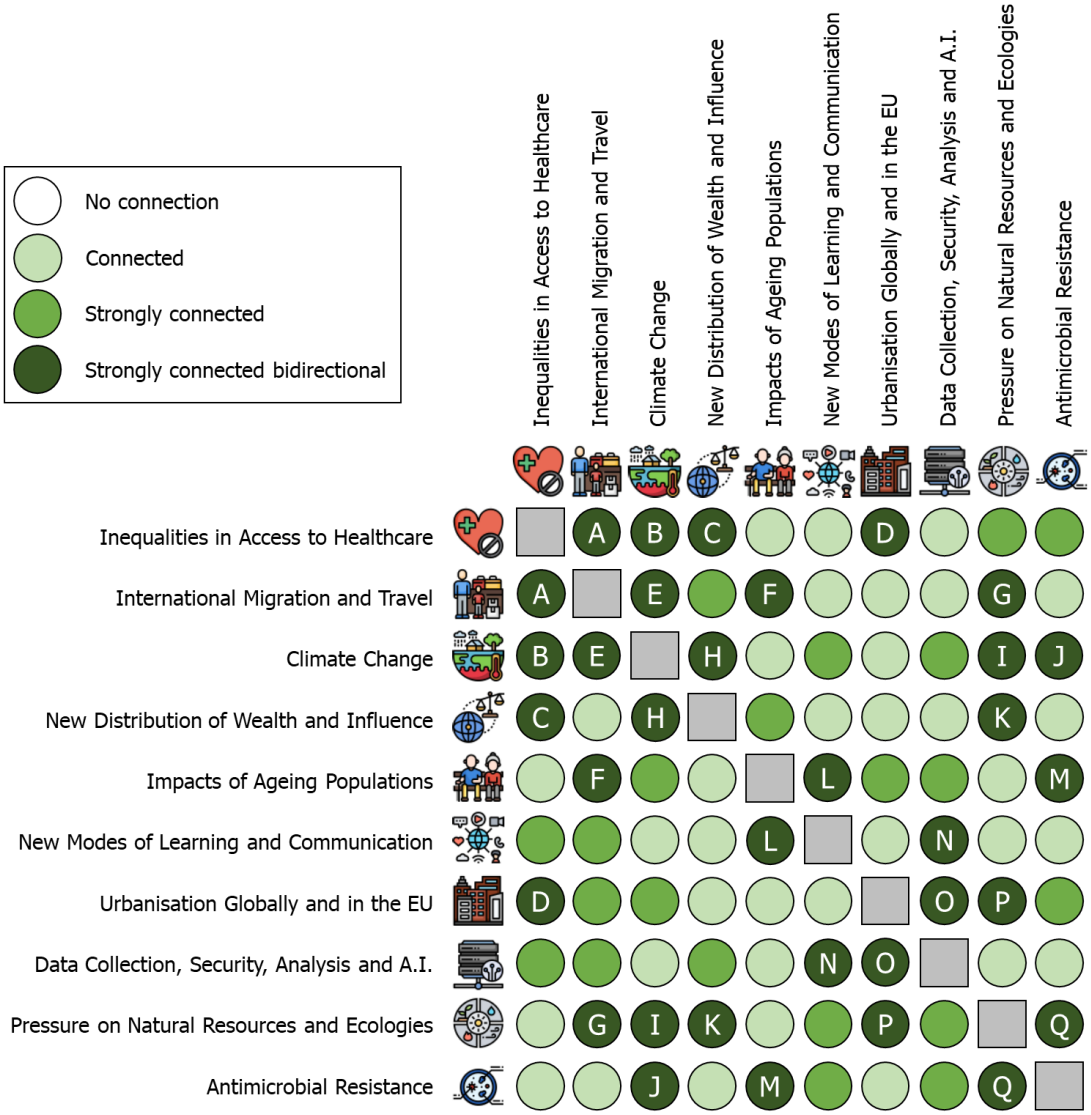
4. Interactions between key drivers

Assessing how different driver trajectories will individually impact the future threat landscape and public health organisations can contribute to forward-looking operational and policy considerations. At the same time, systemic complexity is fundamental to shaping future outcomes, and drivers of change do not effect change in isolation. As interactions between drivers can significantly shift the condition of possible futures, it is important to build an understanding of how developments in one driver may impact the trajectories of other drivers.

Diverse groups of experts helped map the relationships between drivers on an extended time-horizon, assessing either no connection, some connection or a strong connection between two drivers along any of their possible trajectories. To further qualify these assessments, the experts had to account for their interpretation of the cumulative impact on infectious disease threats, as well as on the operations of public health institutions like ECDC, when making their assessments.

Each possible driver combination was assessed from both perspectives, i.e. in separate two-way evaluations. The key drivers show a high level of interconnectivity, with no driver combination that was not considered notably connected, highlighting the high complexity of the operational environment of public health institutions. Figure 2 presents the aggregate results of the driver connections assessments, with summaries of the 17 bidirectionally identified strong interconnections below. A mapping of driver trajectory interactions shows 'climate change' and 'pressure on natural resources and ecologies', as well as 'international migration and travel' and 'inequalities in access to healthcare', as central nodes in the network of driver interactions (Figure 3). This means that developments in these areas will have the strongest impact on changes in the whole public health system.

Figure 2. Interconnections between key drivers of change



A. Many types of inequality can be drivers for migration, including in health. Inequalities in access to healthcare can also lead to more 'medical tourism' or be a motivation for migration. At the same time, migrants often face inequalities in access to healthcare, including social, cultural and language barriers. Experts also noted that both migration and travel increase the complexity of healthcare that needs to be provided, impacting access.

B. The impact of climate change is more significant for people with lower incomes who are often part of population groups that already experience inequality, meaning these developments can reinforce existing inequalities. Collaborative responses to climate change might include efforts to reduce multiple inequities, including in access to healthcare, and support social resilience.

C. Newly wealthy state actors do not default to reducing healthcare access inequality, and a tendency for authoritarian regimes to actively cultivate and exploit inequalities to cement their power was noted by experts. However, the adage 'increased wealth means increased health' was mentioned multiple times by experts. The 'most likely' result of this connection was that increased wealth would result in increased healthcare access complexity.

D. Urbanisation offers many opportunities to facilitate access to health services. However, experts noted that unplanned urban growth (sprawl) may increase inequalities in healthcare access and outcomes. Responsible urban expansion holds the potential to greatly reduce inequalities, improve the health of vulnerable groups, and change prevention and response strategies for infectious disease.

E. Expected climate change developments are likely to continue to drive population displacement and international migration. Isolationist responses to climate change are likely to result in increased conflict and refugees, who are typically more vulnerable to infectious diseases because of exposure to infections, lack of access to healthcare and poor living conditions during the migration process. Travel is likely to become less socially acceptable or more expensive as climate change worsens.

F. Changes in social age structures can result in behavioural shifts, such as new migration and travel patterns. Experts noted that as Europe is aging it may want to attract younger skilled workers, particularly in the healthcare sector and provide incentives for them to move to Europe. With these incentives they may be better positioned in the labour market than their European peers. In regions where natural resources become scarce or where ecosystem services destabilise, conditions may provoke internal and international migration. Migration, in particular following disasters, could create temporary new pressures on localised ecologies and resources. On the other hand, experts mentioned that international travel might be reduced under sustainability schema, decreasing pressure on natural ecologies.

G. Although experts noted that by 2040 climate change will have inevitably worsened no matter what is done now, the speed, the scale and the impact will depend very much on wealth and influence distributions. International cooperation, as well as actions by nations, regions, cities and private actors can significantly improve both climate change mitigation and adaptation. In contrast, nationalism and isolationism, profit-maximalisation and consumerism, and disjointed approaches will have negative impacts. The severity and timing of climate change impact will be unevenly distributed globally, which will likely influence power and wealth dynamics.

H. While it has largely been the exploitation of natural resources that has driven climate change, there remain optimistic paths to address both drivers. Climate change mitigation and restoring biodiversity and ecosystems work synergistically. Collaborative climate change mitigation efforts are likely to include reduced resource exploitation. Conversely, disjointed and isolationist climate change responses are likely to accelerate depletion of (local) resources and increased pressure on ecologies.

I. Climate change will alter local ecologies and can lead to changing seasonality of pathogens, shifting breeding times and migration for their hosts and reservoirs. Climate change-induced vulnerability of populations and pressures on food supplies can impact antimicrobial consumption and stewardship. This increases the possibility for resistant pathogens to emerge or spread to new regions.

J. Shifting wealth has the tendency to accelerate resource depletion activities (extractive measures) and increase pressure on ecologies (land use practices). While experts noted that shifts toward more localised power might go in the direction of encouraging a 'One Health' policy agenda, these systems can also accelerate localised resource exploitation. Inversely, local resource depletion or collapse of ecosystem services will also negatively impact local wealth and authority.

K. Digital services and communications may address some of the increased demands for healthcare that ageing populations imply (e.g. telemedicine). However, raising digital literacy skills within ageing user groups, and making new digital tools intuitive for them, will require increased attention.

L. Older adults tend to be more vulnerable to infection, including due to weakened immune systems, and can also be more exposed to healthcare-associated infections due to more visits to health centres, making them more at risk from AMR. As AMR-strains are difficult to remove from healthcare facilities, and ageing populations are likely to increase pressure on these facilities, AMR may also have a greater opportunity to thrive and spread, according to the experts.

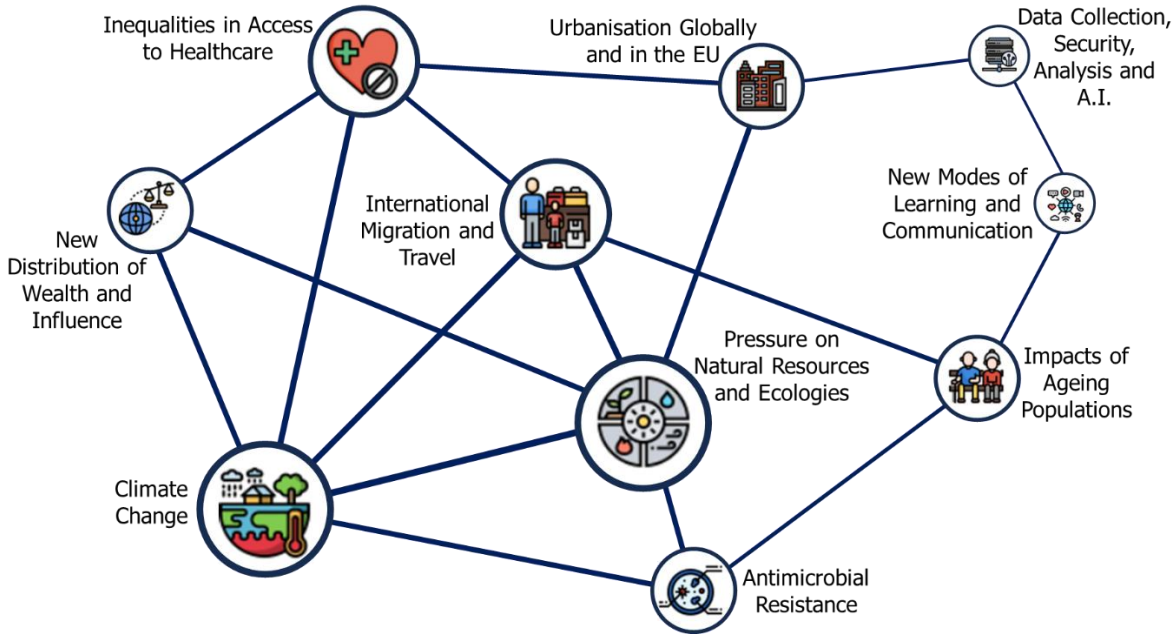
M. New digital tools and modes of communicating are data-rich resources for a variety of data collection and analysis purposes, including public health concerns. However, digital literacy, ethics and basic safety is necessary to maintain data privacy and security. Ownership and usage rights of the data could remain a contested issue.

N. Urbanisation implies highly concentrated populations that can produce large amounts of granular data, including individual and community health data for surveillance and monitoring. This can lead to more timely and focused interventions if data analysis can be optimised (perhaps using A.I).

O. While urbanisation can ultimately increase the efficient use of resources in the aggregate, it can also increase pressure on local ecologies due to encroachment. This can create more opportunities for human-animal contact along urban peripheries, increasing the potential for spill-over of zoonoses.

P. The environment is a key component to antimicrobial resistance. In some regions, practices like industrial agriculture can simultaneously increase pressure on ecologies and raise the risk of contributing to AMR. Experts noted that food security concerns have the tendency to increase the use of pesticide and antibiotics, whereas 'One Health' approaches have the potential to reduce AMR risks.

Figure 3. Mapping of driver trajectory interactions



5. Exploring future threat scenarios

As highlighted by the complexity of the strongly interconnected drivers of change, and the range of their possible trajectories, the conditions in which public health institutions are required to operate in 2040 are highly uncertain. In the practice of strategic foresight, making sense of complexity and uncertainty is mainly done through the development of 'scenarios'. A strategic foresight scenario is an image of a possible future that can subsequently be 'explored' to assess implications, monitor and prepare for threats, adjust operations and collaborations, upskill staff, and future-proof policies or strategies.

A suite of six future threat scenarios that covers the range of driver trajectories was developed and iteratively refined and developed based on diverse experts' insights. These threat scenarios for 2040 are not developed or intended as predictions or normative visions[iv], but as instruments to navigate the uncertainties about future conditions in European public health more holistically. The context of each scenario is provided by logically coherent, interrelated clusters of future development trajectories, encompassing all key drivers of change (Table 2). Context-dependent implications on the threat landscape of infectious diseases and operational conditions for public health institutions were integrated into the scenarios. In addition, assessments of potential technological and scientific developments (micro-drivers) were also considered, where relevant.

Table 2. Macro-driver trajectories and scenarios

Macro-driver	Driver trajectories	A united EU in a polycrisis world	Building back nature	Divide and prejudice	Public health in private hands	Urban dominion and digital society	A patchwork society
1. Inequalities in access to healthcare	a: Inequalities in access to healthcare deepens both within and between countries	I		III	IV		
	b: More complexity in access to healthcare with shift in inequalities (e.g., private vs public)				IV		VI
	c: Access to healthcare more equal both across and within countries, less under-served groups		II			V	
	d: Universal healthcare coverage with strongly reduced inequalities in access to healthcare						
2. International migration and travel	a: International travel surpasses pre-pandemic times; migration remains on the same level		II				
	b: International migration and displaced populations rise further; travel as pre-pandemic	I			IV		
	c: Less migration and travel to the EU (e.g. due to anti-immigration and/or environmental policies)	I	II	III		V	
3. Climate change	a: Climate change adaptation and mitigation measures remain too little and too late	I		III		V	VI
	b: Countries take diverging and disjointed approaches individually or in blocs	I		III		V	VI
	c: Strong transformation towards adapting and preparing for climate change effects				IV		VI
	d: Full-blown, radical green transition with a strong focus on climate change mitigation		II				
4. New distributions of wealth and influence	a: Multi-polar global order with influence shifts from 'the West' to China, India and Africa	I	II				
	b: Authoritarianism on the rise in countries across the world, including in the EU			III			
	c: Private actors and multinational companies increasingly take over government services				IV		

[iv] Both external experts and ECDC staff contributed to this process, providing their individual expert views, rather than those of their respective country, organisation, or other affiliated entity. The threat scenarios are not meant to be predictive and do not reflect preferred directions or an official position of ECDC otherwise. The statements and views expressed in the scenarios and analyses do not necessarily reflect those of ECDC.

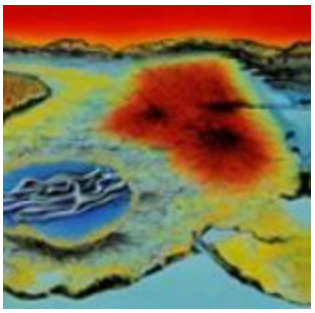
Macro-driver	Driver trajectories	A united EU in a polycrisis world	Building back nature	Divide and prejudice	Public health in private hands	Urban dominion and digital society	A patchwork society
	d: Power shifts from global/national to regional/urban levels					V	VI
5. Impacts of ageing population	a: Higher proportion of older people in EU populations (progression of current trend)	I	II				
	b: EU population ageing slowdown (e.g. due to baby-booms, migration, pandemics)			III			
	c: EU population ageing acceleration (e.g. due to medical advances, war/disease events)					V	
6. New modes of learning and communication	a: The EU has a well-informed population and well-developed communication channels	I					
	b: Polarised societies with fragmented and isolated communication bubbles			III		V	VI
	c: Highly digitalised and hyper-connected, virtual cross-interacting society		II		IV	V	
7. Data collection, security, analysis, and A.I.	a: Continued adoption of digital technologies and accelerated technological development	I		III		V	VI
	b: Big tech companies consolidate power to collect, store, analyse and use data				IV		VI
	c: Data minimalism is the operating ethos of digitalisation (e.g., due to high energy consumption)		II			V	VI
	d: Strong integration of public and private data streams and uses				IV	V	
8. Urbanisation globally and in the EU	a: Continued urbanisation varying from well-managed growth to uncontrolled sprawls	I		III		V	
	b: De-urbanisation due to economic factors (policy-designed or otherwise)				IV		
	c: De-urbanisation due to ideological and/or changing lifestyle reasons		II				VI
9. Pressure on natural resources and ecologies	a: Accelerating depletion of natural resources with much of nature and biodiversity lost	I		III	IV		VI
	b: Strong global collaborations and joint efforts in One Health limit exploitation		II				
	c: Transformational movement restoring nature and biodiversity		II			V	
10. Antimicrobial resistance	a: Red map scenario: high AMR prominence in all regions	I		III	IV	V	
	b: Strict rules, implementation and compliance in EU and globally limit the increase of AMR		II				
	c: Research and innovation advancements limit the impacts of AMR		II				

Previous outbreaks of infectious diseases have highlighted the importance of public health global-, EU-, national-, and local-level governing systems, which was emphasised in the peer-review of initial scenario drafts. Indeed, the dynamics of socio-political power, though not always directly tied to institutional strategy, can shift strategic orientation with respect to partnerships, external decision makers, and resource allocation. Hence, possible changes to public health governance and their implications were added as an additional layer of opportunities and challenges for public health institutions to consider.

Each resulting scenario describes a cohesive world in which social, economic, technological, political, and ecological forces and pressures have significantly, but plausibly, changed the operating environment for public health

professionals of Europe in 2040[v]. As images of possible futures, the scenario narratives describe key aspects of the driver trajectories and outlines threats and challenges that arise under these new conditions (summarised below). In this way, the six scenarios broaden the scope of possible futures under consideration to help the European public health system bolster its resilience and preparedness for future threats.

Scenario I – A united EU in a polycrisis world



In a world defined by systemic, socioeconomic and environmental crises, the EU draws closer together to forge forward.

Main characteristics: EU autonomy and solidarity in the face of multiple crises; lack of global governance with blocs having disjointed strategies and uncoordinated actions.

By 2040, a series of economic and environmental crises have led to a multipolar world, with power-blocs forming and calcifying based on pre-existing regional arrangements and resource availability. The EU fortifies its borders with non-EU countries. It has taken up policies that widely limit and restrict migrants to gain entrance, though it remains a prime destination for many undocumented migrants. It also remains a prime destination for illicit goods. Meanwhile internally, EU Member States reinforce their solidarity and cohesion to jointly address the constant crises. The EU and its Member States have met or surpassed many of their climate-related goals thanks to their energy sovereignty.

Globally, most of the power-blocs have failed to enact effective policies to address climate change. The world continues to warm, and climate change becomes more severe. Fragmented climate mitigation and adaptation across the globe has led to a variety of uncoordinated geoengineering projects addressing localised climate change, with unintended consequences – including higher infectious disease risks. Around the world, many food and water systems have degraded substantially, encouraging increased exploitation of still productive land and waters and intense agricultural techniques that rely on antibiotics. Degraded ecosystems and climate impact have increased pressure on fragile ecosystems that provide essential natural resources and services.

Challenges for infectious disease prevention and control in scenario I:

- Changing human-animal interfaces and interactions because of climate change effects;
- Increased vulnerability for populations in post-disaster conditions;
- Higher incidence of food-borne diseases due to production and supply chain issues;
- Increased risk of water-borne diseases due to floods/droughts and water system disruptions;
- More use of antimicrobials to combat diseases and increase food-yield;
- High pressure on and shortages in healthcare personnel;
- Unintended effects of geoengineering;
- Late detection of (illegally) imported contaminated food, disease vectors, migratory animal disease reservoirs, etc. from outside the EU;
- Lack of data availability of cross-border health threats;
- Disrupted global supply chains impacts development, production and supply of medicines;
- Complexity due to the diversity in crisis conditions requires more tailoring (e.g. communication).

[v] The scenarios are meant as a tool to explore a wide range of relevant changes: they are not meant as predictions and do not reflect preferred directions or an official position of ECDC otherwise. The statements and views expressed in the scenarios and analyses do not necessarily reflect those of ECDC.

Scenario II – Building back nature

A global movement to align human activities with planetary health is underway, but there are emergent challenges, and the EU is more a follower than leader due to anti-Western sentiments globally.

Main characteristics: complex socio-ecological transformation towards sustainability and sufficiency; global decision-making power outside the EU.

Guided by international cooperation, new trans-border protection reserves for wildlife flourish, offering ecosystems the chance to rejuvenate and fortify themselves without human intervention. Instead of accumulating material wealth, people and governments are putting nature as a top priority. Change is being led by non-Western powers, particularly those that have been hardest hit by the lingering effects of climate change. Climate change-induced environmental events fuel anti-Western sentiment and the idea gains popularity that the West should be paying for costs related to transforming societies and for the effects of the disrupted climate.

Regarding technological development, the EU has taken steps to establish strategic autonomy in green and digital technologies through its various Research and Innovation funding schemes. Many communities grow their own products locally and turn away from reliance on exploitation-based agro-industrial complexes. Nature-based solutions to address the tenacious challenge of vector-borne diseases and antimicrobial resistance (AMR) are a top Research and Innovation priority and global rules to curb AMR have been put in place. Environmental sensors are globally deployed to measure the progress of biodiversity and sustainability across the natural world.

Challenges for infectious disease prevention and control in scenario II:

- Increased human-animal contact with livestock, peri-domesticated animals and wildlife;
- Novel pathogen emergence and disease reservoirs (due to e.g., rewilding, wildlife reintroduction);
- Possible spread of infectious disease vectors due to city greening and rewilding;
- Possible increased risk for food- and waterborne diseases;
- Nature-based focus could lead to vaccine and medicine hesitancy;
- Consequences of changes in economic model for EU/local public health financing;
- Anti-globalisation could lead to medicine, vaccine and other biologicals production and supply issues.

Scenario III – Divide and prejudice

As societies continue to polarise and fragment, trust and accountability evaporate. Can public health operate if the public trust is so shattered?

Main characteristics: increasing authoritarian and nationalistic tendencies; lack of international cooperation and solidarity.

In the year 2040, the world grapples with the reversal of globalisation. Nations turn inward, prioritising self-reliance, and the repercussions ripple through fractured supply chains, heightened conflicts and diverging social values. Many nations have looked to gains in wealth and geopolitical influence of big authoritarian states as evidence for the success of authoritarianism – using strong national sentiments as powerful social levers guided through media messaging and surveillance. Weakened governing checks and balances and corruption is a rising problem.

European societies are characterised by polarisation and mistrust. Conspiracy theories and misinformation are widespread, partly fuelled by online attacks from competing interest groups who may operate in secret or otherwise have hidden motives, such as troll farms, or particular lobby organisations. Intergenerational tensions are aggravated by a rapidly ageing European population that can no longer rely on a young l migrant workforce to

address labour needs. In many countries, both inequality and poverty are on the rise. People with certain diseases such as HIV and TB are increasingly stigmatised. Migration is severely restricted in many countries. Access to healthcare is highly diverse across the EU and within many countries, some rely on private actors to provide vital services. Rising prices and restricted cooperation limit the availability of many medical countermeasures and slow technological development. Population mental health is suffering, particularly among younger generations.

Challenges for infectious disease prevention and control in scenario III:

- Polarisation and mistrust impeding health information, risk communication and healthcare access;
- Weakening EU institutions facing more complex coordination challenges;
- Poor quality and limited availability of health data;
- Staff shortages across all levels of healthcare systems;
- Inequality and poverty deteriorate health in population;
- Increasing health risks and vulnerabilities due to unabated climate change;
- Increased risk for food safety and AMR issues.

Scenario IV – Public health in private hands

The private sector is dominating decisions, services and data, with a mainly privatised healthcare sector and market forces in control, where profit is prioritised above health.

Main characteristics: private actors and market forces are increasingly directing policies and controlling data and information; high inequality.

Around the globe, financialisation (financial markets, institutions, and elites gaining greater influence over economic policy) has grown to exert an outsized impact on public policy in 2040. A rift occurs in approaches to climate policy. More specifically, the EU and a few populous nations pursue green growth initiatives by using financial incentives for biodiversity, while the major blocks in the Global South have sought to build capital reserves by extracting higher costs for resource exploitation and reforming their intellectual property law. The dissonance between approaches puts a strain on international relations with growing tensions and more frequent conflicts. Increasingly volatile global economic conditions – due in part to regional conflicts and climate-induced disasters – continue to favour the responsiveness of the private sector over the slower reaction of public actors. With private stakeholders funnelling money to influence regulation, unchecked economic growth remains the dominant vision for society and the health sector, causing greater inequities.

With respect to data collection and analysis, the most useful and applicable data pools for public health and infectious disease monitoring are developed and controlled by the private sector. Healthcare systems across the EU are increasingly reliant on costly personnel, communication, and management services provided by the private sector, each of them amplifying unequal access to care. The profit motive also drives the global research agenda, with weaker guarantees for the public to share in the bounty of resulting innovations.

Challenges for infectious disease prevention and control in scenario IV:

- Risk of losing access to key data for surveillance and monitoring;
- Expansion of the digital divide, also between the private sector and public institutions;
- Widening inequalities create more vulnerabilities in (sub)populations;
- Unequal and profit-based access to healthcare impacts diagnosis, treatment, and prevention activities;
- Increased contact and mobility for commerce and trade increases transmission rates;
- Encroachment increases risk of pathogen (re)emergence and spill-over;
- Market failures impact R&D for e.g., paediatric medicine, rare diseases, antibiotics;
- Human resources shortages in less profitable healthcare sectors;
- Late or undetected threats due to free cross-border movement of goods and people;
- Unethical use of Artificial Intelligence tools.

Scenario V – Urban dominion and digital society

People find refuge in the engineered safety and security of cities, where a global youth-driven and high-tech culture thrives, but not all can keep up.

Main characteristics: technological advanced, highly digitalised and urbanised societies; power lies with cities and younger parts of populations.

With continued climate change, urbanisation has been a key response to maximising land allocation for highly industrialised agricultural production in 2040. Cities have become central powers in nations as they provide relatively stable access to digital infrastructures, food supply and materials. There is great diversity within and between city identities. Digital connectivity and platform literacy are strong social and economic forces within and between cities and have become a development priority for many nations. Monitoring of urban services and resources is built on networks of multi-modal sensors, with data maximisation and automated analyses. Personal health data, no longer private, is one data stream amongst many to manage the safety and security of the hyper-urban world. Many countries invest in e-health and home-based care.

The younger populations face lower medical treatment exposure, and benefit from entanglement with the urban surveillance networks. The young have been more successful at adapting to the highly digitised spaces and risen to political prominence. They are setting governance and funding priorities to benefit their generation in the immediate term, like geoengineering and urban climate change mitigation.

Challenges for infectious disease prevention and control in scenario V:

- Higher disease transmission rates due to higher density and mobility of people;
- Antimicrobial resistance due to high pressure on urban healthcare centres and food-production;
- Urban sprawling and greening increases human-animal contact (vectors, pests, zoonoses);
- Access to healthcare issues due to hospital-associated and acquired infections and AMR;
- Higher population vulnerabilities due to lower physical activity;
- Tech-solutions like telemedicine, e-health, remote work, etc. are not accessible to all;
- Possible increasing interactions between wild and (peri-)domesticated animals;
- Unintended consequences of gene editing (e.g. of gene-drive, gene therapy, species hybrids).

Scenario VI – A patchwork society

Exhausted and intimidated by creeping governance, many try to break free and create their own isolated utopias, but can so many diverse self-organised communities thrive?

Main characteristics: many self-organised communities with high diversity; societal trust in central national and international authorities is low.

In 2040, the consequences of climate change, several pandemics and other crises that put a lot of pressure on urban life generated frustration with the 'mainstream' way of living and lowered societal trust in authorities. Though cities continue to be the dominant location of residence around the world, an increasing number of people gather in new isolated communities with shared beliefs, policy preferences, and ideologies different from mainstream society.

These sub-societies are very diverse in their fundamental principles, material resources and needs, their constitutions and their political orientation. Some are globally networked with other communities, some are disconnected, even xenophobic, and others are open to and encourage change and experimentation with new types of socio-political identities. In some communities, large private companies have entered through the backdoor, providing services and gaining power gradually. This high level of differentiation poses new problems for traditional governance institutions.

For instance, it is more difficult to conduct disease surveillance or to provide prevention and control of infectious diseases. At the same time, some highly organised communities have established their own health provision and monitoring systems.

Challenges for infectious disease prevention and control in scenario VI:

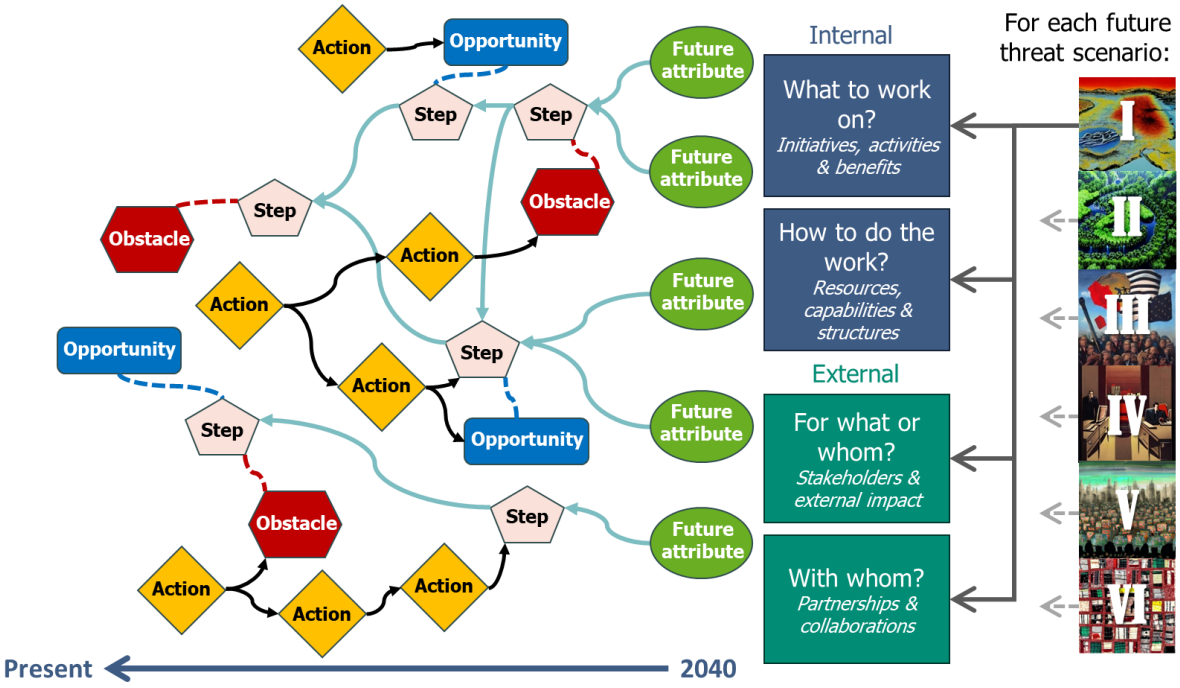
- Access to healthcare is highly differentiated, affecting disease risks and vulnerabilities;
- Fragmented/absent disease surveillance and monitoring activities across and within sub-communities;
- Difficulties in prevention and treatment of diseases with disjointed approaches and isolated groups;
- High diversity in values and beliefs impede collaboration, consensus, trust and governance;
- Low accountability and coordination during outbreaks or other serious events.

6. Back-casting for actions to take

Exploring the individual scenarios – mentally time-travelling into the conditions of a possible future – can help reduce blind-spots and biases in our awareness of future threats, opportunities and uncertainties. However, strategic foresight is especially useful to organisations if such explorations contribute to innovation and preparedness. This means identifying critical strategic or operational adaptations, particularly those with a long lead-time, or flagging developments to monitor closely to intervene when required. Of course, with limited resources one cannot fully prepare for every possible future, so the key is to identify attributes and actions that will address challenges across multiple future scenario conditions.

To this end, the collective intelligence of a diverse groups of experts was employed to outline how a public health institution like ECDC can be optimised for each scenario. This entailed articulating essential features of the future organisation that would enable it to successfully fulfil its mission and be effective under the conditions of each scenario. These 'future attributes' described internal and external aspects, such as how ECDC should be organised and who ECDC should collaborate with, respectively. From the resulting optimised future attributes in 2040, the experts moved their way back to the present through a structured process of 'back-casting'. In the back-casting, steps and conditions necessary to attain the future attributes for each scenario were identified, as well as the barriers and enablers of those steps, leading to the articulation of specific actions ECDC should take (Figure 4).

Figure 4. Back-casting process for each threat scenario



Across the six scenarios, 26 common threats were noted under five thematic clusters, highlighting several action areas and even specific types of action to take as critical waypoints towards a future-ready ECDC. From this process, 98 strategic actions were formulated that would contribute to steps, address obstacles, and/or enable opportunities in several scenarios, as defined in the back-casting (Figure 4). Some of these actions were already in progress or under preparation by ECDC, but there were also very new insights and suggestions. A prioritisation by experts of which of these common waypoints between the present and a future ECDC are the most important, formed the basis of the following recommendations grouped under the five thematic clusters:

A. One Health and climate change:

- Enhance monitoring of climate-sensitive diseases;
- Adopt a systematic, pro-active approach to climate change;
- Promote knowledge and public awareness;
- Mitigate communicable disease risks related to urban greening and geoengineering;
- Address the cross-sectoral dimensions of AMR risks;
- Support AMR diagnostics and surveillance;
- Contribute to strengthen the EU's commitment and framework on AMR;
- Promote knowledge and public awareness of AMR;
- Support global actions on AMR.

B. Health services and risk mitigation:

- Enhance the visibility of ECDC with regards to disease prevention;
- Address challenges related to potential disinvestment/fragmentation of public health services;
- Prepare for the growing acceptance of 'alternative' medicine;
- Contribute to addressing potential shortages in the public health workforce;
- Address potential gaps in disease surveillance;
- Support the removal of financial, structural and cognitive barriers to healthcare;
- Contribute to ensuring the availability of critical medical countermeasures (through advising the Health Emergency Preparedness and Response Authority).

C. Demographics and social determinants of health:

- Promote disease prevention and control for international travellers and migrants;
- Contribute to mitigating disease vulnerability associated with overcrowding;
- Mitigate infectious disease risks associated with ageing;
- Enhance knowledge on gender and infectious diseases;
- Collaborate with partners on measures related to mental health issues associated with disease outbreaks;
- Promote education of young people about health behaviours.

D. Data, digitalisation and new technologies:

- Ensure good quality of epidemiological data;
- Enhance access to data in case of fragmented or privatised data collection;
- Build trust and willingness to share data;
- Identify data gaps for certain population groups;
- Address gaps in digital health literacy;
- Use novel technologies for disease surveillance;
- Support remote care delivery and disease surveillance;
- Monitor the misuse of technologies impacting public health;
- Track technological developments relevant to ECDC’s work;
- Keep up with innovations in the private sector.

E. Governance and collaborations:

- Maintain ECDC's relevance and resilience towards potential futures that have a weaker EU, increased isolationism or fragmented communities;
- Be pro-active to potentially reduced cross-border cooperation in health and increased power of private actors over governments;
- Contribute to enhancing public trust in governments and supranational entities;
- Prepare and respond to decreased public spending on health.

7. Wind-tunnelling of strategic actions

Out of the 98 actions, 42 were shortlisted through a scoping survey and then assessed against their relevance, effectiveness and efficiency by ECDC staff and key external experts, decision-makers and stakeholders. An action was considered 'relevant' if it is closely connected to ECDC's work and to the emerging needs in the scenarios; 'effective' if deemed to help ECDC meet its objectives associated with the threats emerging from the scenarios; and 'efficient' if the benefit-cost ratio (in terms of resources and impact) was proportionately high, as assessed by expert elicitation. This led to a further prioritisation of 27 strategic actions (Table 3), which were further refined and elaborated through in-depth interviews and then reviewed against different scenario conditions in 'wind-tunnelling' exercises.

Wind-tunnelling, also referred to as 'stress-testing', is done to assure the robustness of actions, processes and policies in a dynamic operating environment. It entails testing their performance and potential against different plausible futures. Wind-tunnelling facilitates the identification of strategic actions that are robust against several scenarios and are thus more likely to foster organisational resilience. In the wind-tunnelling exercises, diverse groups of ECDC staff, management and members of ECDC's Advisory Forum examined the plausibility and utility of the strategic actions in creating a more resilient ECDC under the collective future social, technological, economic, ecological, and political conditions of the scenarios (see 'Robust' column in Table 3). Robust actions are generally considered 'no-regret' actions to take, as these will be beneficial in a wide range of possible futures. Actions that are contingent on the relevant scenario's conditions arising require the monitoring of changes towards these conditions, after which the action may be taken.

Table 3. Summary of the assessments of the strategic actions

Strategic actions	Relevant	Effective	Efficient	Robust
Cluster A: One health and climate change				
A1. Identify regions and populations at risk	+	+	++	Yes
A2. Promote alternative surveillance methods and approaches	++	+	+	Partly
A3. Reinforce the use of climate data in disease monitoring	+/++	+	+	Partly
A4. Establish an ECDC climate change team	++	++	++	Yes
A5. Jointly (with other EU agencies) propose guidance to Member States on control of disease vectors	+	+	+	Yes/Partly
A6. Contribute to a coordination mechanism for cross-sectoral monitoring of AMR and antimicrobials consumption (under the One Health approach)	++	++	++	Partly
Cluster B: Health services and risk mitigation				
B1. Strengthen ECDC's communication on disease prevention to different audiences, leveraging diverse channels and innovative technologies	++	++	++	Yes
B2. Develop capacity and expertise (health economics, behavioural and other social sciences, data modelling, AI) to support public health advocacy and tailored risk management	++	++	+	Yes
B3. Leverage sociodemographic and spatial data to identify economically disadvantaged populations and the blind spots of passive disease surveillance	++	+	+	Partly
B4. Enhance engagement of local communities g under-served by health services in disease surveillance and tailored recommendations	++	++	++	Yes/Partly
B5. Provide evidence, analysis and forecasting to predict demand for critical medical countermeasures and identify priority Research and Development areas	++	++	+	Yes/Partly
Cluster C: Demographics and social determinants of health				
C1. Create further guidelines on health screening and vaccination for migrants in EU countries	+	0/+	++	Partly
C2. Advocate to remove migrants' barriers to health services	0/+	+	++	Partly
C3. Promote support for disadvantaged communities when health crises require physical distancing and restricted working hours	0/+	+	+	Yes/Partly
C4. Further develop and promote ECDC's guidelines on protecting older adults	++	+	+	Yes
C5. Working with partners, ensure integration of mental health policies in EU-national preparedness and response planning	+	+	0/+	Partly
C6. Promote education of young people about health behaviours	++	+	+	Yes/Partly

Strategic actions	Relevant	Effective	Efficient	Robust
Cluster D: Data, digitalisation, and new technologies				
D1. Improve quality of epidemiological data via training to national authorities and other stakeholders	++	+	+/++	Yes
D2. Strengthen working group on the European Health Data Space to identify useful datasets	+/++	+	+	Partly
D3. Research and develop an effective counter-misinformation strategy	++	+	o/+	Yes
D4. Open a dedicated team on data analytics	++	+	+	Partly
D5. Strengthen in-house expertise and establish practices for continuous disease signal scanning using AI	++	+/++	+/++	Yes
Cluster E: Governance and collaborations				
E1. Provide disaster readiness exercises and certificates to governments and other stakeholders	+	0/+	0	Yes/Partly
E2. Support ECDC staff in building interpersonal, informal networks	+	++	+	Contingent
E3. Explore ways to keep up international health dialogues in case formal cooperation breaks down	+	0/+	+	Yes
E4. Enhance ECDC's external communication strategy towards the public	+	+	++	Partly
E5. Pre-emptively review the ECDC budget, including prioritising tasks and consider diversifying funding sources	++	+	+	Yes/Partly

Note: the score '0' depicts that the action was deemed not relevant/effective/efficient, '+' moderately relevant/effective/efficient action, and '++' highly relevant/effective/efficient. Robustness assessments shown summarise two independent expert workshop results, where robustness was assessed according to the following assessment rubric (assessment scores are not shown): very promising in this scenario (++); suitable for this scenario (+); neutral in this scenario (0); causes problems in this scenario (–); not possible in this scenario (– –). Strategic actions are considered robust (depicted by 'Yes' under 'Robust') when receiving positive assessments in the majority of scenarios, 'partly' robust when assessments varied based on scenario differences, and 'contingent' if scored to be very promising in only specific scenario conditions.

8. Conclusions and potential implications

This foresight process enhanced the awareness of the wide range of threats and challenges that ECDC and other public health organisations may be faced with in the future. It also provided more clarity about the complexity of the operating environment of public health systems in Europe. The drivers of change and the threat scenarios identified and developed in this foresight work provide useful tools to enhance preparedness and resilience of ECDC and our partner organisations going forward. Five thematic action areas were suggested to mitigate or prepare for common threats across the scenarios:

A. **One Health and climate change**, including changes in seasonality and habitats, extreme weather, and effects of adaptation measures, as well as aspects related to AMR
B. **Health services and risk mitigation**, covering challenges to prevent and treat infectious diseases, and unequal access to health
C. **Demographics and social determinants of health**, in relation to travel and migration, population density, ageing, gender, and mental health
D. **Data, digitalisation and new technologies**, including quality and access to data, use of AI, misinformation, and emerging health technologies
E. **Governance and collaborations**, both within and beyond the EU/EEA, including at the global level, covering the public and private sectors, for- and non-profit

Taken in aggregate, the initial results point towards several strong strategic focus areas that should be robust across most future possible conditions that ECDC is likely be operating in. These strategic focus areas are strengthening external communications and outreach; further development of data expertise and best practices; budgeting for and creating cross-organisation working groups and teams; engaging with localised vulnerable communities; and valuing international institutional cooperation. The conclusions of this report will be, and already are being used to inform ECDC's strategic direction going forward.

Strengthening external communications and outreach

Proposed actions focused on ECDC external communication capacities were assessed as robust across the scenario sets and across thematic clusters. These include capacities to utilise different communication channels (e.g. broadcast, social media, physical media) and working with partners that can help with regional or localised messaging and targeting specific vulnerable groups. Sharpening ECDC capacities for outreach activities to older, younger and marginalised groups could require building new media literacies internally and/or collaborating with organisations that have the expertise to reach these groups. Raising the public profile of ECDC through communication strategies can have the added benefit of fostering public trust in the institution – an aspect that was viewed as critical for ECDC to remain effective (even in scenarios where public trust had eroded for other governing institutions). Public trust is an essential component to contend with mis- and disinformation, which were identified as increasingly difficult challenges in multiple scenarios.

Related (partly) robust actions:

- Enhance ECDC's external communication strategy towards the public (Cluster E)
- Strengthen ECDC's communication on disease prevention to different audiences, leveraging diverse channels and innovative technologies (Cluster B)
- Develop capacity and expertise (health economics, behavioural and other social sciences, data modelling, AI) to support public health advocacy and tailored risk management (Cluster B)
- Research and develop an effective counter-misinformation strategy (Cluster D)
- Enhance outreach of ECDC's guidelines on protecting older adults (Cluster C)
- Promote education of young people about health behaviours (Cluster C)

Further development of data expertise and best practice

Insights from this foresight process very strongly underline that for ECDC to continue to fulfil its mandate, the organisation should continue to bolster both its internal expertise in data collection and analysis, and its ability to partner and work with trusted data sources (particularly public institutions). Additionally, ECDC training and guidance related to best practices in data collection, organisation and analysis could be developed as a resource for national and regional public health actors. Helping to develop standards and best practice for public health surveillance data can foster future coordination. Moreover, it allows ECDC to more effectively inform the European Commission, Parliament, and Member States, if called upon to do so. This might also mean the development of new types of data literacies and analytic capacities internally, to reinforce partnerships with other EU agencies, and to work effectively for and with national level public health institutions.

Related robust actions:

- Improve quality of epidemiological data via training to national authorities and other stakeholders (Cluster D)
- Strengthen in-house expertise and establish practices for continuous disease signal scanning using AI (Cluster D)
- Jointly (with other EU agencies) propose guidance to Member States on control of disease vectors (Cluster A)
- Identify regions and populations at risk of climate-sensitive infectious diseases (Cluster A)
- Provide evidence, analysis and forecasting to predict demand for critical medical countermeasures and identify priority Research and Development areas (Cluster B)

Budgeting for and creating cross-organisation working groups and teams

A proactive approach to the ECDC budget was deemed a robust action area, particularly considering actions proposed to create cross-sectional working groups on topics important for future resilience. Such cross-organisational teams included a climate change preparedness and response coordination group – viewed as a promising and suitable action within conditions across multiple scenarios. Additional cross-organisational teams that were assessed as promising and suitable across some (though not all) of the scenarios included an 'institutional vision' team dedicated to Big Data and Analytics, and a strengthened working group on the European Health Data Space.

Related robust actions:

- Pre-emptively review ECDC's budget, including prioritising tasks and considering diversifying funding sources (Cluster E)
- Establish an ECDC Climate Change team (Cluster A).

Engaging with localised priority populations

Increasing ECDC involvement at a more localised level (in collaboration with the Coordinating Competent Bodies), either in partnership with national actors or civil society organisations, surfaced as an important activity for increasing ECDC efficacy across the thematic clusters. These efforts might be combined with targeted communications to promote institutional trust among marginalised populations and address mis- and disinformation. Importantly, staff viewed this as a robust activity for ECDC with respect to future resilience and operational efficacy (acknowledging the possible resource implications).

Related robust actions:

- Enhance engagement of local communities and disadvantaged groups in disease surveillance and tailored recommendations (Cluster B)
- Promote support for disadvantaged communities when health crises require physical distancing and restricted working hours (Cluster C)
- Identify regions and populations at risk of climate-sensitive infectious diseases (Cluster A).

Valuing international institutional cooperation

Maintaining open channels for international cooperation was highly valued to increase ECDC resilience even when faced with more fragmented geopolitics. This valuation was particularly strong among staff, which might reflect a position shaped by experience of preceding public health emergencies.

Related robust action:

- Explore ways to keep up international health dialogues in case formal cooperation breaks down (Cluster E)

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Annex 1. Acknowledgements

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of the European Union