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ORIGINAL ARTICLE

Creating the Dutch One Health Shared Socio-economic Pathways (SSPs)

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Abstract
The world is changing, in terms of both climate and socio-economics. These changes have the potential to have a profound impact on the health of humans, animals and the environment, often grouped together as 'One Health'. Humans, animals and the environment are closely interlinked and to determine realistic future vulnerabilities we must consider everything together. We need comprehensive scenarios which cover a broad range of variables affecting One Health. We developed a methodology to create national-level One Health scenarios based on the global Shared Socio-economic Pathways (SSPs), which we applied to the Netherlands. We identified variables which should be included in such scenarios and gathered input from existing scenarios, stakeholder consultation and current plans and commitments. This information was combined to create detailed descriptions, which were used to assess the main health risks under each scenario. All the scenarios face similar challenges, for example an aging population, introductions of infectious diseases and rising sea-levels and extreme weather events; however, in some scenarios, they deal with these challenges much better than in others. The healthiest outcome was achieved when a policy of low greenhouse gas emissions was combined with a well-functioning society which looks after both its citizens and the environment. These scenarios can be used to analyse specific health risks and to consider options for mitigation and preparedness. Because they are national-level scenarios, they allow the local context, policies and customs to be accounted for and should be a valuable tool for protecting One Health in the future.

Keywords One Health · Scenarios · Shared socio-economic pathways · The Netherlands · Climate change

Introduction

Ours is a period of rapid change, not just in terms of climate, but also of technology, land use, population and many other factors. These changes have the potential to have significant impacts on human, animal and environmental health, often grouped together as 'One Health' (The World Bank 2018). For example, changes in climate, land use and mobility have been found to contribute to the increased rate of emergence of novel infectious diseases (e.g. SARS, MERS, SARS-CoV-2), the spread of known diseases to new regions (in particular vector-borne diseases (VBDs) such as West Nile,

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Zika and dengue) and the increased prevalence of diseases which had previously been controlled (e.g. Ebola, malaria) (Mora et al. 2022; Nova et al. 2022). Human, animal and environmental health are closely interlinked with many dynamic interactions. It is therefore helpful to consider them together in a One Health approach when considering future challenges.

Future One Health challenges are many and varied. Infectious diseases (particularly zoonoses and VBDs), non-communicable diseases, antimicrobial resistance, biodiversity loss, air pollution and threats to ecosystem services have all been identified as areas of particular concern. Climate change exacerbates many health-related challenges. This is a particular problem in urbanised deltas, which face the combined pressures of high population density and sea-level rise and have been identified as especially vulnerable ecosystems (Kuenzer and Renaud 2012; Loucks 2019). Particular threats to deltas include habitat loss, salinisation, flooding and disease introductions from trade (Wardekker et al. 2010; Loucks 2019; Hill et al. 2020). The Netherlands is an example of an urbanised delta and we take it as a case study in this research. It is a generally healthy country and is ranked eleventh on both the Global Health Security Index and the Environmental Performance Index (GHS Index 2021; EPI 2022). Nevertheless, it does face certain challenges. Climate-related health risks such as sea-level rise, heat stress, allergens and air quality are all expected to worsen, as well as infectious diseases (van Alphen et al. 2022; RIVM 2023). The population is aging and it is expected that dementia cases will increase, also obesity, chronic conditions and stress are all on the rise (RIVM 2018, 2020). There are concerns that drinking water quality will deteriorate in the future as a result of the combined pressures of climate change, pollutants and salinisation (Kools et al. 2019; Van Gaalen et al. 2020). Natural areas are increasingly threatened by eutrophication as a result of nitrogen deposition and the Netherlands scores particularly poorly for biodiversity and species habitat (Bouma et al. 2020; de Jongh et al. 2021; EPI 2022). Such One Health vulnerabilities across the globe in general, and for deltas in particular, suggest it is important to have a comprehensive system view of possible changes. This requires internally consistent scenarios which cover a broad range of factors affecting One Health.

Internally consistent scenarios covering a broad range of environmental and societal factors affecting One Health risks already exist on a global scale: The Shared Socioeconomic Pathways (SSPs). These are global scenarios for future societal development. Each describes one potential future, with a set of coherent plausible changes in factors such as demographics, economics, technology, governance, energy and the environment (O'Neill et al. 2017). They do not include climate change, but instead complement separate climate scenarios (Representative Concentration Pathways (van Vuuren et al. 2011)) and can be used in combination with them. The SSPs are widely used and have the advantage of covering a wide range of variables while being internally consistent. This makes them an excellent starting point for creating One Health scenarios, even though they do not specifically include health or health risks. Sellers and Ebi (2018) considered a broad range of human health challenges under each SSP, but only at a global level. While some One Health risks may be relatively consistent between countries, others are highly dependent on the local context. Therefore, it is important to downscale the SSPs to grasp the context-dependent One Health risks. While large-scale scenarios are free to have a huge amount of variation, smaller-scale scenarios are more useful for assessing specific risks (Frame et al. 2018). They are constrained by local dependencies and context and have less uncertainty. SSPs have already been downscaled for several countries and regions, including Europe (Kok et al. 2019). However, for most European countries, they have not been further downscaled to the national level. There are large differences in the One Health challenges faced by different European countries (White et al. 2011; Medlock et al. 2012; Karanikolos et al. 2013; Di Napoli et al. 2018), and deltas have their own specific challenges. National versions of the SSPs, with a focus on those aspects that have the potential to impact One Health, would enable country-specific One Health-risk analysis, with the ability to develop solutions based on available resources and which fit within national agendas.

SSPs with a specific focus on One Health have not previously been developed. We suggest that such One Health SSPs should include those variables which have the greatest influence on the health of people, animals and the environment. Many of these variables are already part of the global SSPs (e.g. governance and land use), but some new specific variables are required (e.g. healthcare provision). Selecting appropriate variables is the first step in creating One Health scenarios. The next step is to determine how these variables will develop under each scenario. Creating national-level scenarios requires national-level information, particularly for those variables which are not included in the global SSPs. Many countries have national-level scenarios available on various topics, though they are not necessarily linked with the SSP scenarios. These are an excellent resource and in this study we propose a method for matching such national scenarios to the SSPs so that the wealth of national-level information they contain can be used for One Health scenarios.

Here, we aim to develop national One Health scenarios for a country on a delta based on the global SSPs, using the Netherlands as a case study. Studying this data-rich delta can help develop scenarios for other densely populated deltas where a sizeable fraction of the world population lives. We identified the key variables affecting One Health and considered the available national scenarios for the Netherlands. None of them specifically considered health risks and none of them covered all of our key variables, meaning that Dutch One Health SSPs would be a valuable new resource for assessing future One Health risks in the country. We considered what each of our key variables would look like in the Netherlands under each SSP scenario; this was done through a combination of stakeholder consultation and use of existing national scenarios. This is the first time downscaled SSPs have been created from existing national scenarios and this methodology could be extended to other countries/regions. These scenarios will enable researchers to examine potential future One Health challenges, the key factors which might cause these challenges, and possible mitigation measures and responses.

Methods

General approach

First, we identified the key variables that affect One Health and which should be included in our scenarios. We then reviewed what existing national scenarios were available. We engaged with a variety of expert stakeholders to obtain input on the content of the scenarios and what type of information is most valuable for users. In addition, we looked at existing plans and commitments which might be relevant. We then collated all this information to create detailed scenario descriptions. These descriptions, combined with a literature review, were used to assess possible One Health risks. Full details of all these steps are given below and an outline of the process is shown in Fig. 1. Finally, we considered an application of the scenarios to mosquito-borne disease risk.

Although our scenarios are for the Netherlands, it is not possible to consider one country in isolation. How things develop in the Netherlands will be highly dependent on what is happening in the rest of the world. For example, if the Netherlands follows a low-emission scenario but the rest of the world is emitting large amounts of greenhouse gases, then the Netherlands will still have to deal with relatively extreme climatic changes. Here we assume that most of the world will follow the same SSP pathway and for each SSP we consider the climatic changes which have

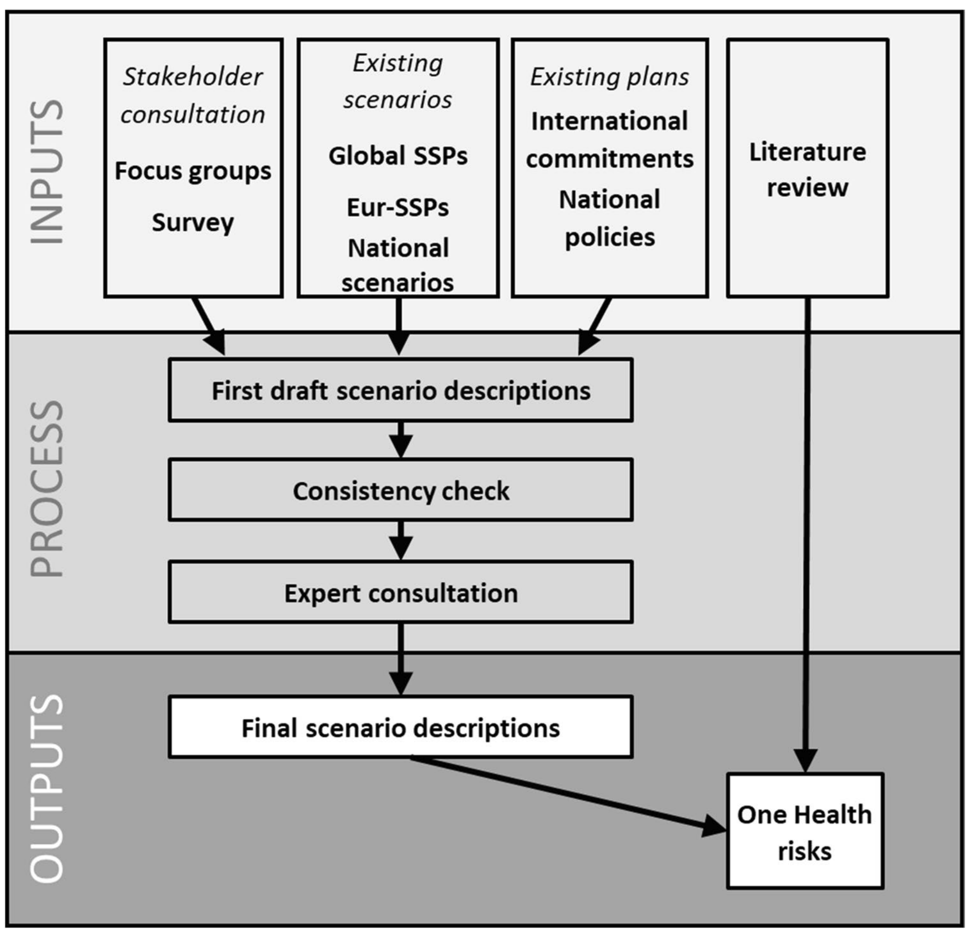


Fig. 1 Inputs, process and outputs for developing national One Health SSPs. Inputs were stakeholder consultation including focus groups and a survey, existing scenarios at global, European and national levels, existing plans including international commitments and national policies, and literature review. The stakeholder consultation, existing scenarios and existing plans were combined to create first draft scenario descriptions, followed by a consistency check and expert consultation. This led to the first output: final scenario descriptions. These, combined with the literature review, were used to assess One Health risks

been identified as most likely by the Coupled Model Intercomparison Project (CMIP6) (O'Neill et al. 2016).

Our scenarios go up to the year 2050. Looking too far into the future limits their utility, particularly when it comes to preparing for future health risks. The further ahead you consider, the more uncertainty there is. Also, many of the existing Dutch scenarios do not go beyond 2050, thus limiting the information available. When discussing possible futures with stakeholders we looked up to 2100 as we found this promoted creativity; the long-term future trends raised in these discussions are included in the detailed scenario descriptions.

Identifying key variables

One Health incorporates the states of humans, animals and the environment and the interlinkages that affect the health of all (The World Bank 2018). This covers a highly diverse range of factors and it is not possible to include absolutely everything. We took particular care to include variables which affect VBD risk since this is a highly relevant issue with linkages across the human, animal and environmental health domains, and is known to be affected by socio-economic change (Nova et al. 2022). Rapidly urbanising deltas, such as the Netherlands, have been identified as having a high risk of emerging infectious diseases and the Netherlands' water-dominated landscape and abundant wildlife make it particularly vulnerable to VBD outbreaks (Allen et al. 2017). Indeed, the Netherlands has recently experienced introductions of tick-borne encephalitis, usutu virus and West Nile virus (De Gier et al. 2017; Oude Munnink et al. 2020; Vlaskamp et al. 2020; van den Bremer and van Turnhout 2021) and it is expected that other VBDs will spread northwards from southern Europe in future (Fischer et al. 2013; Bouzid et al. 2014; Esser et al. 2020).

Identification of variables for the One Health SSPs was done in two ways: literature review and expert consultation. For the literature review, we mostly focused on studies related to VBDs (e.g. Semenza and Suk 2018; Franklinos et al. 2019; Nova et al. 2022; Power et al. 2022), but also more general sources on One Health challenges for the Netherlands (EEA 2019; RIVM 2022b). The spread of VBDs is dependent on vector populations (e.g. mosquitoes, ticks, rats), host populations (humans, wild animals and domestic animals), the environment and response efforts to combat outbreaks. Considering all the factors which affect these led to a highly diverse range of possible variables and they will be relevant to a wide range of One Health risks, not just VBDs. We summarised the list of possible variables gathered from literature and shared it with the participants in a focus group (see Stakeholder consultation). They reviewed our selection, adjusting some and making some additions. The final list of key variables is shown in Table 1. As a final check, we compared our list with Zhang et al. (2022) who proposed 57 indicators for assessing overall One Health performance, all of which are covered by at least one of the variables we have proposed.

Evaluating existing scenarios

Global level

The SSPs were published in 2017 and are used by the Intergovernmental Panel on Climate Change. They encompass five scenarios including information on a wide range of socio-economic variables. While they include some basic information at a national level (population and GDP), they are mostly concerned with broad trends at a global or regional level (O'Neill et al. 2017; Riahi et al. 2017). The authors of the global scenarios encourage researchers to downscale or extend the SSPs, focusing on their spatial regions or sectors of interest. They state that while the assumptions for such extended scenarios should be consistent with the basic SSPs, they may wish to expand the list of variables included and to provide additional quantitative information which can be used in modelling and analysis

Table 1 List of key variables included in One Health SSPs for the Netherlands

Key variables
Global context (global politics and trends)
Demographics (population, spatial distribution, age distribution)
Economy and technology
Land use
Socio-economic inequality
Environment (water management, water quality, biodiversity, climate change adaptation and mitigation measures)
Governance (priorities, organisation, effectiveness)
Agriculture (demand, livestock numbers, management practices, use of fertilisers and pesticides)
Lifestyles (Diet, time spent outdoors, travel and tourism)
Health and healthcare

(O'Neill et al. 2017). In our case, we focus on One Health in the Netherlands.

European level

SSPs 1, 3, 4 and 5 have already been downscaled to the European level (the 'Eur-SSPs'). These were based on pre-existing European scenarios (CLIMSAVE) and input from an expert workshop. They did not include SSP2 since it lacks its own 'identity' and they were concerned that since it is in the middle of the other four, users might take it as a 'best estimate' and not use the others (Kok et al. 2019). There are also the Eur-Agri-SSPs. These are downscaled SSP scenarios for Europe which focus entirely on agriculture. These were based on the SSPs and Eur-SSPs as well as multiple rounds of stakeholder engagement (Mitter et al. 2020).

National level

While downscaled national SSPs did not yet exist, there were several other existing scenarios which focused on the Netherlands. Some of these included a range of different variables (e.g. WLO2015 (CPB/PBL 2015) and the Delta Scenarios (Wolters et al. 2018)), while others focused on a single variable (e.g. demographic scenarios: NIDI Bevolking 2050 in Beeld (NIDI/CBS 2020, 2021) and agricultural scenarios: Landbouw in Nederland in 2050 (Lesschen et al. 2020)). None of the Dutch scenarios we found were designed to align with the SSPs, but they nevertheless contained a wealth of Netherlands-specific information on how the country might develop in the future. To be able to use this information, we mapped these Dutch scenarios onto the global SSPs, identifying with which SSP each scenario was most closely aligned. Following input from our stakeholder survey (see below), it was decided that this should be done *per variable* since, for example a given Dutch scenario might match SSP1 best for environment but match SSP4 best for economy and technology.

This matching was done by considering each SSP and variable in turn and going through the different Dutch scenarios and assigning them a score out of ten based on how well they matched the global SSP and Eur-SSP descriptions. This gave us a ranking, so if two Dutch scenarios disagreed with one another, there was a clear choice on which to follow. If two Dutch scenarios that received a similar ranking disagreed with one another then we made an informed decision, preferring scenarios which were developed recently, broad (i.e. covering a range of variable rather than just one), not based on certain assumptions about climate change, developed through a process of co-creation and providing quantitative information. The results of this ranking are available in Online Resource 1. Some Dutch scenarios were not included as they were not closely aligned with any of the SSPs. We found that SSPs 1 and 3 were best represented within the Dutch scenarios, with fewer aligning with SSPs 4 or 5 and hardly any aligning with SSP2.

Stakeholder consultation

Co-creation, i.e. developing scenarios together with stakeholders and subject experts, has been found to improve the salience, legitimacy and credibility of scenarios (Ansems et al. 2019). To this end, we took several opportunities to gain input from such experts and to work with them to develop realistic and useful scenarios.

Focus groups: We held two in-person day-long focus groups on 7th of October 2021 and 15th of July 2022, with thirteen and seven participants respectively. When choosing who to invite, we mapped stakeholders, considering potential users of the scenarios, experts across sectors and disciplines, people with experience in creating national-level Dutch scenarios and people who could help us in making the scenarios accessible and understandable to a wide audience. Participants were chosen to cover a range of expertise as well as a balanced age and gender distribution. Eleven participants were from academia, five from government and four from the private sector and their expertise covered health, spatial planning, land use, travel, tourism, agriculture, climate adaptation, water quality, governance, scenario creation and communications. We discussed what key variables should be included in One Health SSPs and how each of these variables might develop in the future in the Netherlands under the different SSPs. The participants jointly produced timelines and storylines for each scenario and tables showing expected trends in each key variable for 2030, 2050 and 2100. The focus groups went up to 2100 as this helped to promote creativity and to help people to consider major societal changes; however, our final scenarios only go up to 2050. The participants also provided the names for our scenarios.

Survey: We sent a survey to developers and users of the different Dutch scenarios and received forty responses in total. The survey had several objectives: (i) determine what users consider when selecting scenarios to use; (ii) determine what scenario elements are most useful to users and (iii) check our proposed alignment of existing Dutch scenarios with the SSPs. The first goal was helpful when choosing which Dutch scenarios to prioritise, the second helped us decide how to present our scenarios and the third provided information and legitimacy for our use of Dutch scenarios. The survey and a summary of the responses are provided in Online Resources 2 and 3.

Creating the scenarios

The scenarios were created one variable (see Table 1) at a time; this process is outlined in Fig. 2. For each variable, we began with the relevant text from the global SSPs. This was predominantly qualitative, but also included national-level quantitative information for population and GDP. These estimates are based on a set of very general assumptions and it is sensible to check that they are reasonable for the country in question. In our case, the range of values across the SSPs was consistent with the ranges proposed in existing Dutch scenarios, so we decided to use the Dutch population and GDP values from the global SSPs (Cuaresma 2017; Dellink et al. 2017; Leimbach et al. 2017; Riahi et al. 2017; Samir and Lutz 2017).

We then expanded the global SSP text using information from the European- and national-level scenarios, the focus groups and existing plans. Existing plans cover planned developments, national policies and international commitments, and were found through researching government websites and consulting subject experts. A decision was made for each existing plan whether it was likely to be upheld under each scenario, based on the input from the other information sources. We particularly tried to include information which would be relevant to the One Health context for the Netherlands. This was informed by the literature review (Identifying key variables) on One Health challenges and the focus groups were an especially useful source of One Health-related information.

Different plans and scenarios often contradicted each other, in which case a choice had to be made. We prioritised sources based on the SSP scenarios (i.e. Eur-SSPs, Eur-Agri-SSPs) and the focus groups. Input from the focus groups was occasionally adjusted to fit the global- and European-level

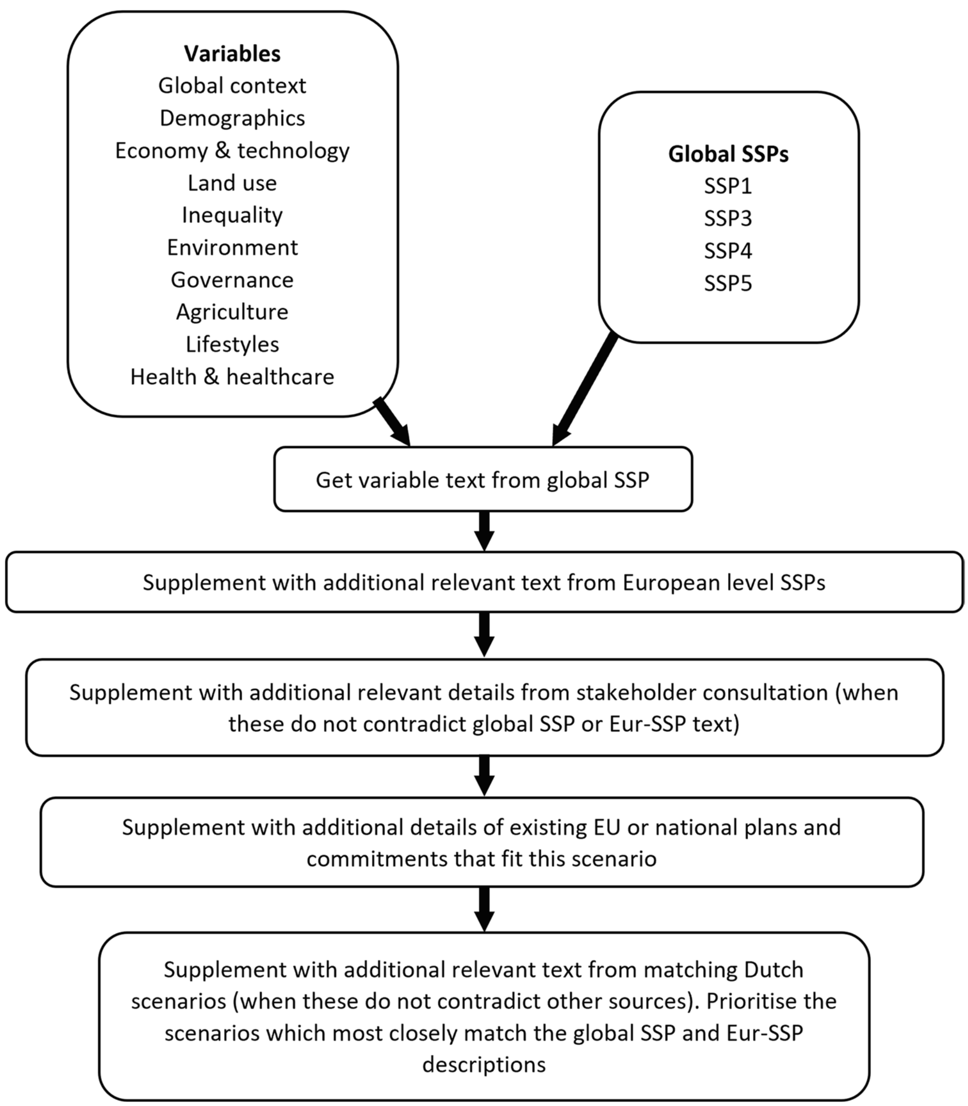


Fig. 2 Process for developing One Health Shared Socio-economic Pathway (SSP) descriptions. These steps were followed for each of the 10 variables and for each SSP. The first step was to get the text from the global SSP. This was supplemented with additional relevant text from European-level SSPs. This was then supplemented with additional relevant details from the stakeholder consultation, assuming it did not contradict the global or European-level text. This was then supplemented with additional details of existing plans and commitments which are likely to be upheld under the given scenario. Finally, this was supplemented with additional relevant text from the matching Dutch scenarios, assuming this did not contradict the previous sources. The scenarios with the highest ranks (see National level) were prioritised

SSPs, while making every effort to stick to its 'spirit'. Figure 2 demonstrates the order of priority used for the different sources of information.

Where quantitative information was included, we adjusted it to use 2019 as our baseline. This is the most recent year for which data were not affected by the effects of SARS-CoV-2. We made scenarios based on SSPs 1, 3, 4 and 5. SSP2, the 'average' scenario, is not discussed separately for reasons introduced above.

Once we had a first draft of the Dutch scenario descriptions, we checked them for consistency. Because we created the scenarios variable by variable, dependencies between the different variables were not necessarily included. For example, the political priorities and effectiveness of governance in a scenario will have a significant impact on how agriculture, demographics, etc. will develop under that scenario. To ensure consistency between the different variables, we identified the dependencies between the variables (Online Resource 4). These were initially based on our best estimates and were later verified by independent experts. We went through each of these dependencies individually for each scenario, checking that the information was consistent. For example, one of the dependencies was that governance affects inequality, so we checked that the Inequality information did indeed follow from the Governance information and that there were no contradictions. Adjustments were made as necessary, using the same order of priority as shown in Fig. 2. If it was unclear how to resolve a contradiction, it was flagged to be checked later by independent experts.

The final step in the scenario creation process was expert consultation. We conducted interviews with several experts, both academic and governmental. These interviews included:

- Checking the plausibility of the scenario descriptions
- Checking the dependencies between variables (Online Resource 4)
- Asking for input on contradictions raised by the consistency check
- Variable-specific questions with experts on these subjects
- Identification of inevitable trends which are likely to be consistent across all scenarios
- Determining what might put the Netherlands on the path towards these scenarios

Some of these questions were also raised in the focus groups; however, it was helpful to use this opportunity to gain additional input. The results of the expert consultation were incorporated in the draft scenario descriptions to create the final scenario descriptions.

One Health risks and climate change

Once we had the final scenario descriptions, we considered the possible One Health risks under each scenario. This was done by revisiting the scenario descriptions and considering the possible consequences for One Health. For example, several of the scenarios involve more green spaces in urban areas. These have certain health benefits, but they also have the potential to provide habitat for disease vectors and can worsen respiratory issues from pollen allergies. The severity of these risks is related to governance, healthcare provision, lifestyles and general population health, all of which vary under the different scenarios. Combining all this information, we could assess the potential health risks of urban greening under each scenario. We also used sources from the literature to provide additional input and to help us refine the list of potential health risks to focus on the most urgent challenges. There have been many studies considering specific future health risks (e.g. spread of disease vectors (Oliveira et al. 2021), obesity-related diseases (Webber et al. 2014)) as well as studies on likely consequences of climate change on health (e.g. Sellers & Ebi 2018; Weilnhammer et al. 2021). Governmental websites and reports were also a useful source of information (e.g. RIVM 2022a, b; Van Gaalen et al. 2020).

Many expected future One Health risks relate to climate change. While climate is not included in the SSPs, response to climate change certainly is. Climate change, and the associated extreme weather events, has the potential to have large impacts on the health of people, animals and the environment, and it is vital to consider how these risks are responded to under each scenario. The scenario descriptions include attitudes to climate change adaptation and mitigation, as well as responses to sea-level rise. They also indicate how effective these measures might be. In the Netherlands, climate change is expected to bring rising sea levels, heavier and more frequent rainstorms, increased drought, changes in rainfall patterns and higher temperatures (KNMI 2021). The magnitude of climate change depends on a variety of factors, including socio-economic trends, but here the global scale is most relevant. We are assuming that most of the world follows the same SSP pathway, so if we are looking at a low-emission scenario in the Netherlands, many other countries will likely also have low emissions and thus climate change (and extreme events) will be noticeably less than in a high-emission scenario. Our assumptions are in line with CMIP6 on the most plausible combinations between SSPs and climate scenarios (O'Neill et al. 2016).

Application

We shared summaries of each scenario with a group of around 30 experts on various aspects of mosquito-borne disease risk as part of a workshop (22nd of June 2023). This allowed us to evaluate how accessible the scenarios are and how useful they could be for assessing particular health risks. Participants were each given one scenario and they discussed in small groups the implications for disease risk and what key factors were affecting that risk.

Results

Combining the information from the SSPs, Eur-SSPs, Dutch scenarios, stakeholder consultation and existing plans, we have created the Dutch One Health SSPs. Brief storylines and an overview of possible One Health risks for each scenario are given below and a summary is provided in Fig. 3. Detailed descriptions for each key variable, as well as where the information was taken from, is provided in Online Resource 5. Finally, an application to VBD risk is outlined.

SSP1: Together green (*Samen Groen*)

As the effects of climate change become more apparent, reducing emissions and preparedness for the changes to come are seen as increasingly important. There is strong international cooperation for climate change mitigation and ambitious targets are set. Within the Netherlands, the government puts a high priority on sustainability, with a rapid shift to renewable energy sources, strict environmental regulation and increased public engagement. There is high investment in research and development, particularly of technologies to promote sustainability. This leads to high economic growth and attracts more people to the Netherlands. Immigrants are largely accepted and people appreciate their contribution to the economy and to the well-being of society. Overall, the Netherlands becomes a more equal and tolerant society with a strong environmental focus.

There are fewer health risks in this scenario compared with the others. An effective government which is actively aware of the risks of climate change and is working towards resilience and robustness means that a lot of risks are removed or reduced. Extreme weather events are becoming more common and bring a wide range of dangers (Weilnhammer et al. 2021), but thanks to the high level of climate change mitigation these events are not as extreme as in other scenarios. Health services are well prepared, detailed plans are in place for different eventualities and there are effective early-warning systems (Sellers and Ebi 2018). There are also good flood defences in place and urban areas have been adapted to combat heat stress (e.g. through green and blue spaces). In the far future, rising sea levels may lead the Netherlands to take a ‘living with water’ approach which would see large parts of the country being deliberately flooded (Haasnoot and Diermanse 2022). This would have a large negative effect on existing plants and wildlife but would create opportunities for other species to thrive.

People travel less but the population is growing and there is rising immigration, as well as moderate levels of trade with few barriers in an ever more globalised world. This means there is more potential for the importation of diseases to the Netherlands, whether this be via people, livestock, plants or vectors (mosquitoes, rodents, etc.). The changing climate can also shift the ranges or migration patterns of certain species, potentially introducing new diseases to the Netherlands. It may also be the case that the increased green and blue spaces in urban areas may attract disease vectors. On the other hand, the effective institutions in this scenario deal with outbreaks of pests or diseases quickly and efficiently (Pedde et al. 2021), and the increased biodiversity means that as well as more vectors there are also more predators of such species.

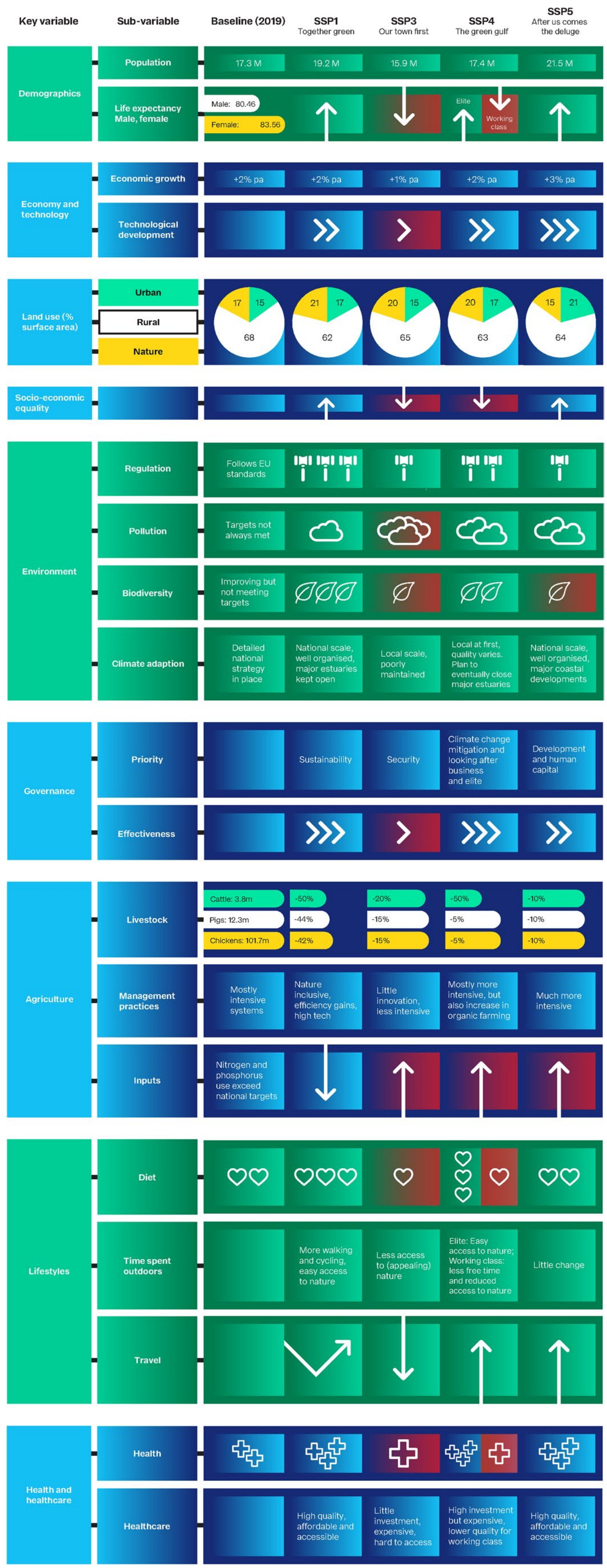
There is more space for nature in this scenario than at present, as well as strong environmental legislation which is strictly enforced. As a result, biodiversity increases and air and water pollution are reduced to safe levels. Compared with the early 2020s, the environment is healthier, as is wildlife, and there are fewer harmful materials that could impact humans or domestic animals. Livestock are also healthier as there is more focus on animal welfare. The generally healthy lifestyles and high education levels mean that people are less vulnerable to environmental stressors and they understand and follow public health messages (Sellers and Ebi 2018). Possible increased risks to people in this scenario could include skin cancer since people spend more time outdoors and have more exposure to UV radiation, although this will be mitigated by the increased adherence to public health messages. In addition, the increase in green spaces in urban areas could lead to an increase in respiratory issues from pollen allergies, especially as higher temperatures will lead to a longer flowering season (PBL 2012).

SSP3: Our town first (*Ons dorp eerst*)

Increasing global tensions and economic uncertainties lead countries to focus more on security and self-sufficiency. The Dutch decide to leave the Eurozone and return to using their own currency. This is not a success and rapid inflation leads to increased poverty and widespread unrest. Some areas are able to cope better than others and there is rising division between different regions of the Netherlands. People tend to stay in their own areas and there is little tolerance for ‘outsiders’. In these circumstances, there is hardly any room for environmental concerns and the lack of trust or cooperation between different regions makes large-scale interventions very difficult.

This scenario combines greatly increased health risks with a poorer ability to deal with them. The lack of climate

Fig. 3 Summary of key variables in each of the Dutch One Health SSPs for 2050. Graphical table summarising each SSP, including information on demographics, economy & technology, land use, socio-economic equality, environment, governance, agriculture, lifestyles and health & healthcare, with indications of development directions and trends



mitigation leads to large rises in the frequency and intensity of extreme weather events. Flooding becomes common, both due to heavy rainstorms and rising sea levels. These cause injuries, disease outbreaks and fatalities as well as widespread damage to nature and loss of wildlife. Heat stress is a major problem in summer, leading to considerable excess mortality, particularly among the elderly. Increased droughts are damaging to plant and animal life, including agricultural crops and livestock. Ineffective governance and the lack of coordination across the country mean that there are few plans in place to deal with such events and the emergency response is inadequate (Sellers and Ebi 2018).

Travel is reduced in this scenario and there are severe trade restrictions, meaning there is less opportunity for new diseases to be introduced (Mitter et al. 2020). On the other hand, if a new disease were to be introduced (for example via shifting species ranges or bird migration patterns), then the government would struggle to contain it (Pedde et al. 2021). *Aedes albopictus* mosquitoes are a particular threat for humans and animals; they are spreading north from southern Europe and are a vector of various diseases including dengue and Zika (Oliveira et al. 2021; Laporta et al. 2023). Low-income groups (of which there are many in this scenario) have been found to be particularly at risk (Rohat et al. 2020).

While space for nature increases in this scenario, it is often the result of abandonment rather than for ideological reasons. The land is not well maintained and the lack of environmental regulation causes pollution. This leads to decreasing biodiversity and harmful materials cause health problems for humans and animals. In particular, nutrient pollution in water leads to large amounts of algae which has negative effects for plants and wildlife (Van Gaalen et al. 2020). Dirty water also offers appealing breeding grounds for certain mosquito species which are already native to the Netherlands (*Culex* and *Anopheles* species), meaning there would likely be increased nuisance from these insects as well as greater disease risk for both humans and animals. The lack of respect for the living world also extends to livestock and animal welfare is reduced. Unhealthy lifestyles, high levels of stress, low-quality healthcare and poorer education mean that people are more vulnerable to environmental stressors and may not necessarily understand or follow public health messages (Sellers and Ebi 2018). Possible increased health risks to people in this scenario are numerous and include age-related issues (from an aging population and lack of innovation to support this), diet-related issues (e.g. allergies, diabetes and cardiovascular disease from unhealthy diets) (Mitter et al. 2020), asthma and cardiovascular disease as a result of air pollution (EEA 2021), drinking water shortages (from more frequent droughts, salinisation and poor management) (VEWIN 2022) and mental health problems.

SSP4: The green gulf (*De groene kloof*)

There is a growing divide between two distinct groups: the elite and the working class. The elite work in high-paying sectors and enjoy a comfortable lifestyle, while for the working class things get steadily more difficult. They struggle with the rising costs of food and energy and they are increasingly vulnerable to sudden shocks. Increasing automation makes it harder for them to find work and this leads to rising unrest. The government's response is increased surveillance and restrictions, with the aim of protecting the elite. Free from concern about day-to-day necessities, the elite are free to think about larger issues. They are concerned with mitigating climate change and cooperating with the elites of other countries. However, they have less concern for their local environment except in areas which they themselves frequent.

In this scenario, there are large differences between the risks faced by the elite and the working class. Thanks to the efforts to mitigate climate change, extreme events are neither as frequent or as severe as in SSPs 3 or 5. However, the lack of widespread adaptation measures means that these can still have major impacts. The government makes attempts to protect the elite through warning systems, local flood defences and measures to combat heat stress, though these are less effective than if they had been applied on a national scale. The working class have fewer protections and will be affected similarly to people under SSP3. Likewise, there is little attention to nature outside the recreation areas for the elite and natural areas will suffer from high temperatures, droughts and flooding.

There is a large increase in travel in this scenario; the elite travel globally for recreation and the working class travel extensively both within the Netherlands and across Europe for work. This leads to a large increase in the risk of imported diseases. It also means that once a disease is introduced it will likely spread quickly throughout the Netherlands and the lack of investment in services and resources for the working class will mean that the government is poorly positioned to control such outbreaks (Pedde et al. 2021). This will also be true for pests or diseases introduced via shifts in species ranges or migration patterns, such as *Aedes albopictus* mosquitoes.

There is an increase in natural areas under this scenario, and while some is well maintained, a lot is unmanaged and becomes polluted and degraded. Overall biodiversity decreases and harmful materials cause health problems for humans (particularly the working class) and animals. In particular, nutrient pollution in water leads to large amounts of algae which has negative effects for plants and wildlife (Van Gaalen et al. 2020). Also, the large amount of travel, much of it still based on fossil fuels for the working class, leads to increasing air pollution, increasing the risk of asthma and cardiovascular disease (EEA 2021) and damaging plant life (Ashmore 2003). The lack of respect for the living world extends to livestock and animal welfare is also reduced. Differences in healthcare, education and lifestyles mean that the elite face fewer health risks than the highly vulnerable working class and are comparable to people under SSP1. The working class experiences similar risks to those under SSP3.

SSP5: After us comes the deluge (*Na ons de zondvloed*)

People are tired of being told to change their behaviour for the sake of the climate and the environment. A socialist government is elected with a focus on personal freedom and ensuring that people's short-term needs are met. There is considerable public investment and a weakening of environmental legislation, leading to rapid economic growth and widespread development. Technological innovation is substantial and it is assumed that technology will solve all the problems of climate change as and when they arise. There is massive population growth as the Netherlands becomes an attractive destination for immigrants. This puts more pressure on the environment, which becomes severely degraded.

The lack of climate mitigation in this scenario leads to particularly strong and frequent extreme weather events, but the government is committed to protecting its citizens from the worst effects. Recognising the threat of sea-level rise they begin construction of a series of islands along the coast, connected by dams (Haasnoot and Diermanse 2022). In long term, this will provide the mainland excellent protection from rising sea levels, but it also causes major disruption to natural dynamics. In urban areas, there are measures in place to protect people from heat stress (green–blue areas, cooling centres (Widerynski et al. 2017), etc.). However, the natural world is highly vulnerable to high temperatures and droughts. Initially, local flood defences are effective; however, as the population increases, it becomes necessary to build houses on areas which are more vulnerable and flooding becomes a problem. As in SSP1, there are good emergency-response services and effective early-warning systems, but extreme weather events are more severe than in SSP1 and there is increasing strain on the system (Sellers and Ebi 2018).

There is huge growth in both travel and trade as well as high immigration, leading to a large increase in the risk of disease importation (Mitter et al. 2020). In addition, the high level of climate change will likely mean greater and more rapid shifts in species ranges and migration patterns than in some of the other scenarios, potentially introducing new pests and diseases. Authorities have a medium level of effectiveness in responding to outbreaks. On the one hand, technical advancements and effective institutions are an advantage, but at the same time the authorities' reactive approach to environmental issues means that outbreaks could get out of hand before they can be contained (Pedde et al. 2021).

There is less room for nature in this scenario, and while some is well maintained for the purposes of recreation, a lot is degraded as a result of weak environmental legislation. People are mostly protected from the effects of pollutants, but plants and wildlife are not. There is a large reduction in biodiversity as nature deals with the effects of toxins, microplastics and other harmful materials. In particular, nutrient pollution in water leads to large amounts of algae which has negative effects for plants and wildlife (Van Gaalen et al. 2020). The lack of respect for the living world extends to livestock and animal welfare is reduced. There is little improvement in the healthiness of peoples' lifestyles, but medical advancements mean that they do not suffer so much from the negative effects of poor personal choices. Possible increased risks to people in this scenario could include asthma and cardiovascular disease from increasing air pollution (EEA 2021), respiratory issues from pollen allergies (from increased green spaces in urban areas and a longer flowering season (PBL 2012)), drinking water shortages (from the combined pressures of high population growth, more frequent droughts and increasing salinisation) (VEWIN 2022) and mental health issues (from increasing extreme events, environmental degradation, etc.).

Application to mosquito-borne disease risk

We found that the workshop participants were able to easily understand the scenarios and could draw a lot of conclusions about future mosquito-borne disease risk in the Netherlands. The results are summarised in Table 2. Participants also noted that under SSP5, there was a particularly high risk of new invasive species becoming established and that wildlife were at greater risk of disease outbreaks than humans.

Discussion

How to use these scenarios

When the global SSPs were released, it was assumed that they would be expanded and downscaled to focus on specific topics and geographical areas (O'Neill et al. 2017). This has already been performed many times and in many contexts (Pedde et al. 2022), but our study is the first time SSP scenarios have been created with a focus on One Health. We have proposed a methodology for creating national-level One Health SSP scenarios and have applied this to the Netherlands, as an example of an urban delta. These provide a starting point for assessing future One Health risks and enable more detailed analysis on specific topics. We have already shown a preliminary application

Table 2 Input from workshop participants on mosquito-borne disease risk under each One Health scenario

One Health scenario	Factors increasing disease risk	Factors decreasing disease risk
SSP1: Together green	High population density Increased contact with nature More blue-green spaces in cities	Increased biodiversity Effective governance Good healthcare
SSP3: Our town first	Habitat degradation and biodiversity loss Ineffective surveillance and response to outbreaks Warmer temperatures Poor health and healthcare Abandoned land Increased pesticide use	Less time outdoors Lower population density Less travel and trade
SSP4: The Green Gulf	Increased travel Ineffective response to outbreaks in working class areas, which will then spread to elite areas Working class areas more vulnerable to outbreaks Biodiversity loss Increased pesticide use	
SSP5: After us comes the deluge	Habitat degradation and biodiversity loss Warmer temperatures More blue-green spaces in cities Increased travel	Less time outdoors Increased use of AC Good healthcare

of these scenarios to mosquito-borne disease risk, but this could be pursued in more detail. The scenarios provide information on a wide range of relevant factors: the details of demographics, agricultural practices and the environment affect vector and host populations. The economy and lifestyles affect the likelihood of new diseases being introduced and the governance and technology gives us details on how disease outbreaks may be responded to. In addition, the information on health, lifestyles and inequality tells us how individuals may be affected by such outbreaks. This analysis could be taken further by adding quantitative information to the scenarios. We are planning on releasing land use maps for each scenario (in preparation), and combined with appropriate climate scenarios, this would enable detailed spatial modelling of the future distribution and abundance of key vector and host species. It would then be possible to model how diseases might spread in each scenario. This is just one example of what could be done with such scenarios. They can also be applied to a wide range of other One Health risks, including pathogens, non-communicable diseases, obesity, etc. These scenarios can also be used to study and forecast potential risks to animal health (e.g. the spread of infectious diseases) and environmental health (e.g. pollution levels and biodiversity). By bringing together human, animal and environmental health aspects across a wide range of variables, we can get a more holistic and coherent view of possible future health risks, equalling a true One Health approach (The World Bank 2018). Humans, animals and the environment are closely interlinked, as our scenarios demonstrate, and it is not possible to determine realistic future possibilities without considering everything together.

Having these insights into future One Health risks enables us to prepare for them. We can take steps to mitigate certain risks and make preparedness plans. The scenarios help us to identify which elements are having a particularly negative impact and so determine what changes to prioritise. For example, for mosquito-borne disease, experts highlighted green–blue areas in cities, which are important climate adaptation measures, as a source of increased risk. This is something which can be adapted for in the planning stages, for example by providing a suitable environment for mosquito predators and limiting aquatic vegetation (Lõhmus and Balbus 2015). Many studies have highlighted the importance of a One Health approach for preparedness and for effectively preventing and controlling emerging risks (Aarestrup et al. 2021; Steele et al. 2021; Ghai et al. 2022). Taking the example of VBDs, we have described how these scenarios could support modelling vector and host populations and disease spread, as well as the effects of potential intervention strategies. Also, by comparing the results from each scenario, researchers could determine which variables had the greatest effect on VBD risk. For example, perhaps the risk might be particularly large in scenarios with certain agricultural practices or environmental regulations.

It is also possible to downscale these scenarios even further. The scenario descriptions include some regional-level information, but it is possible to make them much more specific. By using these scenarios as a starting point and consulting with local experts, it would be possible to develop regional-level SSPs. Some Dutch municipalities and water boards are already looking into this as a tool to support their long-term planning, indicating that there is a demand for such scenarios.

One Health risks in the Netherlands

While there are dramatic differences between the scenarios, there are some common themes and many of the challenges are the same. All the scenarios have an aging population, they all face the threat of infectious disease introductions and they are all at risk from extreme weather events and rising sea levels. In some cases (SSPs 1 and 5) they rely on new technologies, for example innovations to keep people healthy and active for longer in life, which are facilitated by good international cooperation. Other scenarios (particularly SSP3) do not prepare well for these challenges and suffer as a result. Mora et al. (2022) found that over half of human pathogenic diseases can be aggravated by climate change. The severity of these risks will depend on the magnitude of the climatic changes, and in some scenarios, risks will be larger than in others. In SSP5, we see a society which prioritises its citizens' welfare, but still struggles to protect them from the risks of climate change, environmental degradation and disease. We see the best outcome in SSP1, where low emissions are combined with a well-functioning society which looks after both its citizens and the environment.

Limitations

Of course, these scenarios do have limitations. For a start, there are only a limited number of SSP scenarios. While the four scenarios presented paint a reasonably broad overview of possible future pathways, it is certainly possible that the world takes a very different route and there may be significant One Health risks which have not been considered here. In particular, so-called black swan events, such as pandemics, conflicts or natural disasters, can have major impacts. While some scenario studies choose to include such events (Spangenberg 2018), we elected not to, since health risks will vary wildly depending on the type of event and it is also not clear that they will have a major long-term impact on health. These scenarios represent possibilities rather than probabilities and there are many eventualities which are not included. Our methodology also has limitations. The input from the stakeholder consultation was invaluable in filling in details for the local context, but it is also subject to bias. Most participants were highly educated, left-leaning advocates of sustainability and this definitely affected our results. Another time it would be better to try to get a more balanced group with greater variation in worldviews. The process of combining the information from the different sources was also necessarily subjective when there was missing or contradictory information. The final round of expert consultation was designed to mitigate this.

Addressing these limitations would potentially provide broader coverage of possible future One Health risks. However, the scenarios we have developed already cover a wide range of possibilities and should be a valuable tool for assessing and preparing for future One Health challenges.

Conclusion

Overall, this study provided One Health scenarios that will prove to be a valuable tool for analysing possible future health risks in the Netherlands and beyond. In addition, this study proposes a methodology for making similar scenarios for other countries. The method should be applicable to any country that already has a range of existing national-scale scenarios. National-level One Health scenarios enable a holistic approach to assessing future health risks. They allow the local context, policies and customs to be accounted for and are a valuable tool for protecting the health of future humans, animals and environments.

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