Emerging Technologies in the Humanitarian Sector

Technology Deep Dive Series

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Summary

Between November 2023 and April 2024, RAND Europe, in partnership with Athena Infonomics and glass.ai, explored current practices in the use of emerging technologies in the humanitarian sector. As part of a project commissioned by the UK Humanitarian Innovation Hub (UKHIH), the study team investigated opportunities for future responsible adoption of technologies. This project also aimed to develop guidance to help humanitarians seeking to adopt these technologies and to investigate opportunities for foresight initiatives embedding emerging technologies.

This document presents a series of technology deep dives exploring five promising areas for the humanitarian sector out to 2030 as well as an overview of potential changes that are likely to shape the humanitarian operating environment out to 2030. Following an initial scan of the current use of emerging technologies in the humanitarian sector combined with various prioritisation activities (a survey, humanitarian workshops and LinkedIn polls), the study team identified and developed the five deep dive areas presented in Figure S.1 under the second phase of the project. A detailed overview of the activities conducted to develop the five deep dive areas is presented in the Methodology report.[1]

The five deep dive areas are structured along a 'three horizons' framework[2] and present potential trajectories for each of the five areas out to 2030, including risks and opportunities as well as enablers and barriers

Figure S.1 Overview of the five deep dive areas

Source: Study team analysis.

1 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak, Sergi Martorell, Iain McLaren, Christopher Tyson, Charlie Wilkening & Jacob Ohrvik-Stott. 2024. *Emerging technologies in the humanitarian sector: Methodology report*. Santa Monica, Calif.: RAND Corporation. RR-A3192-2. As of 17 October 2024: www.rand.org/t/RRA3192-2

2 Curry, Andrew, & Anthony Hodgson. 2008. 'Seeing in Multiple Horizons: Connecting Futures to Strategy.' *Journal of Futures Studies* 13(1): 1–20. As of 23 August 2024: https://jfsdigital.org/wp-content/uploads/2014/01/131-A01.pdf

that could influence the development of these technology areas:

- Horizon 1 ('the present') presents the current use of the technology area considered;
- Horizon 2 ('the transitory period') encompasses the interim period between the present and the future that can be used to identify factors or changes that could lead or hamper the development of Horizon 3; and
- Horizon 3 ('the future') designates the long-term future operating environment – in the context of this project, 2030.

The five deep dives presented in this document result from exploratory activities conducted by the study team and are not designed to be a comprehensive overview of the current and potential future uses of the considered technologies in the humanitarian sector.

The three horizon frameworks developed for each of the five deep dive areas are presented in Figures 3.1, 4.1, 5.1, 6.1 and 7.1.

Preface

This report was produced as part of a project commissioned by the UK Humanitarian Innovation Hub (UKHIH) that explored the adoption and use of emerging technologies in the humanitarian sector and associated barriers and challenges.

This document presents a series of technology deep dives exploring five promising areas for the humanitarian sector out to 2030: (i) camp monitoring systems; (ii) privacy-enhancing technologies; (iii) coordination platforms; (iv) advanced manufacturing systems; and (v) Early Warning Systems. This project also aimed to develop guidance to help humanitarians seeking to adopt these technologies and to investigate opportunities for foresight initiatives embedding emerging technologies.

The project methodology and underpinning activities are presented in a dedicated document.[3] This report should be read in conjunction with the other outputs of this study: the *Technology Foresight Concepts*[4] and *Technology Guidance*[5] documents. In addition, the study developed two additional case studies on technology-enabled Cash and Voucher Assistance (CVA) and biometrics.[6]

The study was conducted by a multidisciplinary team led by RAND Europe in partnership with Athena Infonomics and glass.ai.

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4 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak & Jacob Ohrvik-Stott. 2024. *Opportunities for supporting humanitarians: Technology Foresight Concepts*. Santa Monica, Calif.: RAND Corporation. RR-A3192-4. As of 17 October 2024: www.rand.org/t/RRA3192-4

5 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak & Jacob Ohrvik-Stott. 2024. *Opportunities for Supporting Humanitarians: Technology Guidance*. Santa Monica, Calif.: RAND Corporation. RR-A3192-3. As of 17 October 2024: www.rand.org/t/RRA3192-3

6 Toole, Hampton, Pauline Paillé, Chryssa Politi & Jacob Ohrvik-Stott. 2024. *Humanitarian Technology Adoption Case Study: Technology-enabled Cash and Voucher Assistance.* Santa Monica, Calif.: RAND Corporation. RR-A3192-5. As of 17 October 2024: www.rand.org/t/RRA3192-5;
Paillé, Pauline, Hampton Toole, Chryssa Politi & Jacob Ohrvik-Stott. 2024. *Humanitarian Adoption Case Study: Biometrics*. Santa Monica, Calif.: RAND Corporation. RR-A3192-6. As of 17 October 2024: www.rand.org/t/RRA3192-6

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Abbreviations

AI	Artificial Intelligence
CCCM	Camp Coordination and Camp Management
CCI	Collective Crisis Intelligence
CDEWS	Community driven Early Warning System
CEWS	Community Early Warning System
EO	Earth Observation
EWS	Early Warning System
FCV	Fragility, Conflict and Violence
GDPR	General Data Protection Regulation
GIS	Geographic Information Systems
GSMA	Global System for Mobile Communications Association
HDX	Humanitarian Data Exchange
ICRC	International Committee of the Red Cross
IFRC	International Federation of Red Cross and Red Crescent Societies
IOD	Internet of Drones
IoES	Internet of Emergency Services
IoT	Internet of Things
LMIC	Low- and Middle-Income Country
MHEWS	Multi-Hazard Early Warning System
NGO	Non-Governmental Organisation
OCHA	UN Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
PET	Privacy-Enhancing Technology
PRC	Philippine Red Cross

SDG	United Nations Sustainable Development Goals
UN	United Nations
UNDP	United Nations Development Ptogramme
UNDRR	United Nations Office for Disaster Risk Reduction
UNHCR	UN High Commissioner for Refugees
UNICEF	United Nations International Children’s Emergency Fund
WASH	Water and Sanitation

Chapter 1. **Introduction**

1.1. Study scope and context

In November 2023, RAND Europe, in partnership with Athena Infonomics and glass.ai, launched the *Emerging Technologies for the Humanitarian Sector* project. This initiative, funded by the UK Humanitarian Innovation Hub (UKHIH), is the first stage of the Hub's wider programme of work exploring opportunities to support humanitarian-sector organisations to effectively consider how, or whether, to adopt technologies in their work.

The United Nations (UN) Organisation for the Coordination of Humanitarian Affairs' (OCHA) *Strategic Plan 2023-2026* notes that the humanitarian sector is facing an exponential rise in humanitarian needs while simultaneously 'buckling under its resource constraints'.[7] Technologies offer a vital means of potentially bridging this growing needs–resources gap,[8] but OCHA cautions that these systems should be people-centred, durable and promote concrete outcomes. Acknowledging this context, this project included three overarching aims:

1. Understand and define trends in the adoption and use of emerging technologies within the humanitarian sector.[9]
2. Identify key emerging technologies that could strengthen humanitarian practice through an online survey.
3. Envisage a future research and innovation journey for the identified key emerging technologies.

To fulfil these objectives, the study team adopted a mixed-methods approach that included a literature review, semi-structured interviews, surveys and questionnaires, workshops, horizon scanning and web reading. These activities are presented in detail in the *Methodology Report*.[10]

This document was developed during the third and final phase of the study, between March and April 2024, and supplements

7 Office for the Coordination of Humanitarian Affairs. 2023. *OCHA's Strategic Plan 2023–2026: Transforming Humanitarian Coordination.* As of 23 August 2024: https://www.unocha.org/publications/report/world/ochas-strategic-plan-2023-2026-transforming-humanitarian-coordination

8 Foreign Commonwealth and Development Office. 2022. 'Policy paper: UK humanitarian framework.' FCDO Humanitarian and Migration Directorate. As of 23 August 2024: https://www.gov.uk/government/publications/uk-humanitarian-framework/uk-humanitarian-framework

9 UKHIH commissioned a distinct project to explore the adoption and use of artificial intelligence (AI) and machine learning (ML) in the humanitarian sector. These technologies were not within the scope of the project presented in this document.

10 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak, Sergi Martorell, Iain McLaren, Christopher Tyson, Charlie Wilkening & Jacob Ohrvik-Stott. 2024. *Emerging technologies in the humanitarian sector: Methodology report*. Santa Monica, Calif.: RAND Corporation. RR-A3192-2. As of 17 October 2024: www.rand.org/t/RRA3192-2

the *Technology Foresight Concepts*[11] and *Technology Guidance*[12] documents. This document draws upon all project activities, in particular the targeted desk research, a survey, two workshops with humanitarian stakeholders and three semi-structured interviews conducted with humanitarian stakeholders who have relevant knowledge and experience of the use of foresight methods and tools and their application to humanitarian contexts.

1.2. Structure of the document

In addition to this introductory chapter, the document is structured as follows:

- **Chapter 2** provides an overview of the future operating environment for the humanitarian sector out to 2030 and presents some of the key challenges that could shape the sector's adoption and use of emerging technologies, including in relation to the selected deep dive areas.
- **Chapters 3 to 7** present the technology deep-dives:
  - » Advanced manufacturing systems in Chapter 3;
  - » Early Warning Systems in Chapter 4;
  - » Camp monitoring systems in Chapter 5;
  - » Coordination platforms in Chapter 6; and
  - » Privacy-enhancing technologies in Chapter 7.

11 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak & Jacob Ohrvik-Stott. 2024. *Opportunities for supporting humanitarians: Technology Foresight Concepts*. Santa Monica, Calif.: RAND Corporation. RR-A3192-4. As of 17 October 2024: www.rand.org/t/RRA3192-4

12 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak & Jacob Ohrvik-Stott. 2024. *Opportunities for Supporting Humanitarians: Technology Guidance*. Santa Monica, Calif.: RAND Corporation. RR-A3192-3. As of 17 October 2024: www.rand.org/t/RRA3192-3

Chapter 2. **The future operating environment for emerging humanitarian technologies**

Emerging humanitarian technologies are not developed or implemented in a vacuum. They can be influenced by, and in turn influence, the social, economic, environmental, infrastructural and geopolitical systems that collectively define the operating environment for the humanitarian sector. Global 'megatrends', defined by the European Commission Competence Centre on Foresight as 'long-term driving forces that are observable now and will most likely have a global impact',[13] are likely to shape the context for these systems and the sector over the next decades.

Interconnected megatrends, including heightened resource scarcity, climate change, environmental degradation, and the increasing significance of migration, may intensify humanitarian need, particularly in low- and middle-income countries (LMICs) with relatively higher exposure to climate risks.[14] Other megatrends relating to continuing urbanisation, changing security paradigms, shifting health challenges, widening inequalities and increasing demographic imbalances could shift the operational demands on humanitarian response – for example, where crises-affected populations have increasing relative proportions of elderly and vulnerable communities, response logistics and technologies need to navigate complex urban environments, and a broader range of security and epidemiological threats[15] need to be researched and guarded against. Some megatrends also represent opportunities for the humanitarian sector: the diversification of education and learning, changing nature of work, and accelerating technological change and hyperconnectivity offer new ways to reach and support crises-affected communities and strengthen collective learning and collaboration across humanitarian practitioner networks. The increasing influence of new governing systems and expanding influence of the global East and South can be vehicles for involving more diverse, non-traditional actors in humanitarian response, advancing the humanitarian localisation agenda, and addressing historic inequities in humanitarian practice.

OCHA outlines how these global forces are increasing the **gap between humanitarian funding and needs**,[16] with an **increased focus on anticipatory action** and **localisation** put forward as potential mitigating solutions. The future outlook for humanitarian practice

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13 European Commission. n.d. 'Megatrends Hub.' Joint Research Centre (JRC) Digital Media Hub. As of 23 August 2024: https://visitors-centre.jrc.ec.europa.eu/en/media/publications/megatrends-hub

14 Zorn, M. 2018. 'Natural Disasters and Less Developed Countries.' *Nature, Tourism and Ethnicity as Drivers of (De) Marginalizations: Insights to Marginality from Perspective of Sustainability and Development*, edited by Stanko Pelc & Miha Koderman, Volume 3. Cham: Springer. As of 23 August 2024: https://doi.org/10.1007/978-3-319-59002-8_4

15 Including 'perma-pandemics,' where infectious diseases remain as chronic risks across economies. See: UNDP. 2023. *UNDP RBAP: Anticipating Risks and Uncertainties for Asia and the Pacific: 2023 Updated Key Risks Report*. New York: United Nations Development Programme Regional Bureau for Asia and the Pacific. As of 23 August 2024: https://www.undp.org/sites/g/files/zskgke326/files/2023-06/rbap_key_risks_and_uncertainties_2023.pdf

16 Humanitarian Action. 2023. 'Global Humanitarian Overview 2024.' Humanitarianaction.info. As of 23 August 2024: https://humanitarianaction.info/document/global-humanitarian-overview-2024

reflects these broad shifts. The humanitarian non-governmental organisation (NGO) network International Council for Voluntary Agencies' (ICVA) 2030 strategy describes a future humanitarian environment where 'the pressure to **integrate humanitarian action into other agendas of peace, development and other political goals** will increase' and humanitarian actors become **more diverse and localised**.[17]

Emerging developments are also likely **to challenge foundational international humanitarian law and governance**, for example through the development of new digital governance fora and mechanisms (such as a Digital Geneva Convention), strengthened mechanisms for keeping humanitarian organisations accountable for their activities in conflicts,[18] or legal rights for the environment during and after crises and conflict.[19]

2.1. Future challenges at the intersections of technology and the humanitarian sector

Where the trends outlined in the previous section meet the nexus of the humanitarian sector and emerging technologies, they pose various potential challenges – accelerating both current systemic issues and creating new risks.

In the context of the growing humanitarian needs–funding gap and accelerating hyperconnectivity, participants in project workshops exploring the ethical implications of emerging technologies foresee increasing risks of **digital extractivism** (defined as 'a form of exploitation based on the virtualization or digitization of commodities and services through a borderless digital capitalism that perpetuates pre-existing colonial practices of value grabbing and wealth accumulation'[20]), **power asymmetries** resulting from over-reliance on technologies controlled by private companies, and **safety and security risks stemming from accelerated adoption** over the next decade.[21] This accelerated adoption is also likely to exacerbate current challenges relating to a **lack of transparency around humanitarian–private sector partnerships**, and subsequent undermining of the humanitarian neutrality principle.

Increased cyber-security threats in the humanitarian sector[22] also challenge a core principle of humanitarian international law that distinguishes between civilians and combatants. Distinction between civilian and combatant

17 International Council for Voluntary Agencies (ICVA). 2021. 'ICVA Strategy 2030.' Icvanetwork.org. As of 23 August 2024: https://www.icvanetwork.org/resource/icva-2030-strategy/

18 Barber, Martin, & Mark Bowden. 2023. *Rethinking the role of humanitarian principles in armed conflict: A challenge for humanitarian action.* Research paper, International Security programme. As of 23 August 2024: https://www.chathamhouse.org/sites/default/files/2023-12/2023-12-13-humanitarian-principles-barber-bowden.pdf

19 Sjöstedt, Britta, & Karen Hulme. 2023. 'Re-evaluating international humanitarian law in a triple planetary crisis: New challenges, new tools.' *International Review of the Red Cross* 105(924): 1238–66. As of 23 August 2024: doi:10.1017/S1816383123000449

20 Iyer, Neema, Garnett Achieng, Favour Borokini & Uri Ludger. 2021. *AUTOMATED IMPERIALISM, EXPANSIONIST DREAMS: Exploring Digital Extractivism in Africa*. As of 23 August 2024: https://archive.pollicy.org/wp-content/uploads/2021/06/Automated-Imperialism-Expansionist-Dreams-Exploring-Digital-Extractivism-in-Africa.pdf

21 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging technologies' workshop, 28 February 2024.

22 Chen, Christopher. 2022. 'Cybersecurity in the Humanitarian Sector: New Challenges and Solutions.' Centre for Non-Traditional Security Studies. As of 23 August 2024: https://reliefweb.int/report/world/cybersecurity-humanitarian-sector-new-challenges-and-solutions

individuals and objects has been blurred in the cyber space.[23] This has led some humanitarian researchers and institutions to call for a new research and practice agenda around **'cyber humanitarian interventions'**[24] that proactively prevent and mitigate these risks.

Effective digital governance to respond to these issues is likely to remain an enduring challenge for much of the globe, with the United Nations Development Programme (UNDP) noting that LMICs may face particular difficulties in exercising authority over global digital platforms and data flows within their regions.[25] Concerns of **'regulatory colonialism'** and **'data imperialism'** – where globally dominant regulatory frameworks set de-facto global standards that have an extra-territorial effect on other countries[26] – are likely to be particularly relevant in this context, as regions including Europe develop precedent-setting digital regulations through their Digital Decade policy programme.[27]

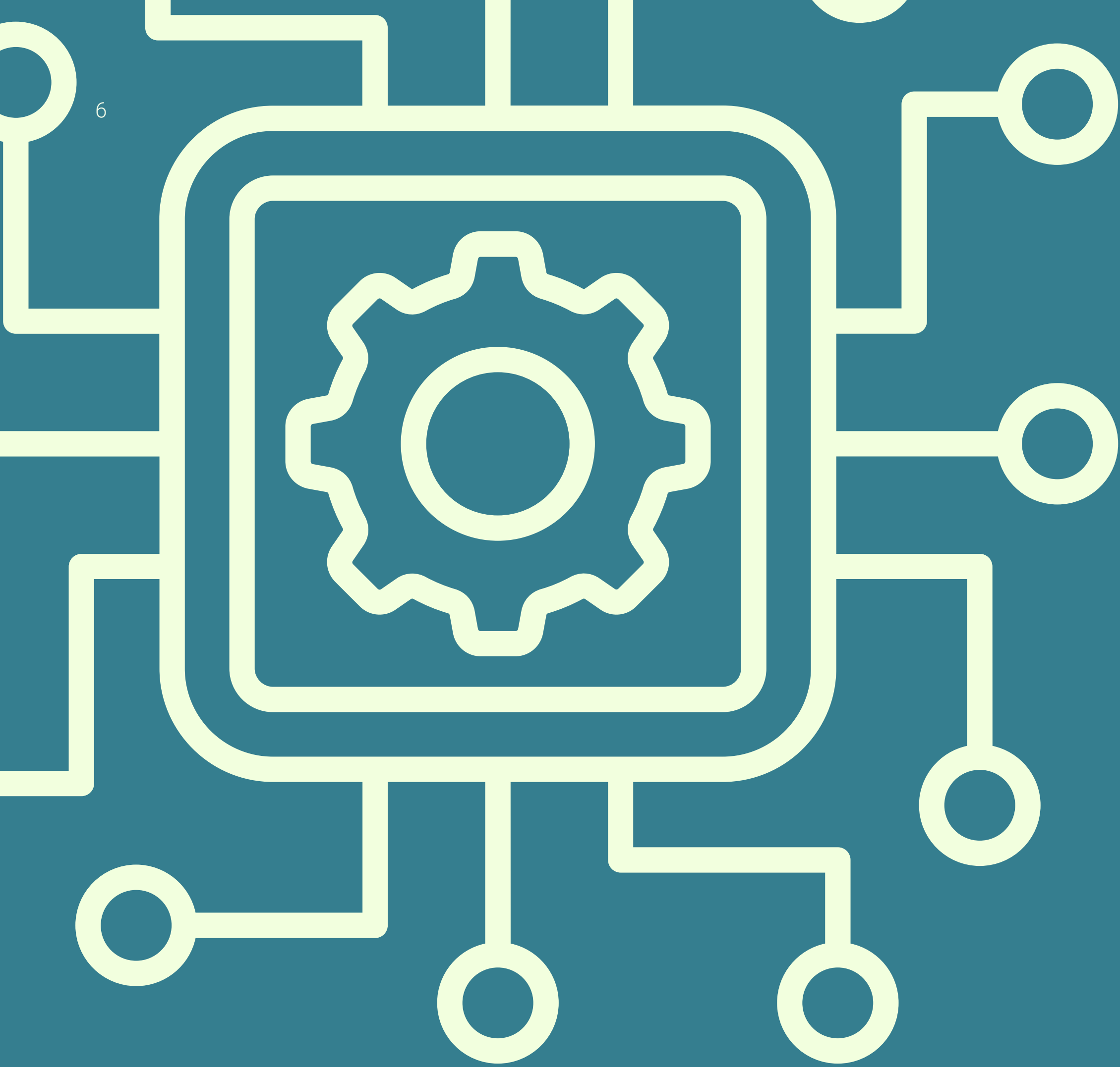
23 Mačák, Kubo. 2023. 'Will the centre hold? Countering the erosion of the principle of distinction on the digital battlefield.' *International Review of the Red Cross* 105(923): 965–91. As of 23 August 2024: doi:10.1017/S1816383123000152

24 Neilsen, Rhiannon. 2023. 'Coding protection: "cyber humanitarian interventions" for preventing mass atrocities.' *International Affairs* 99(1): 299–319. As of 23 August 2024: https://doi.org/10.1093/ia/iiac261

25 Schoemaker, Emrys. 2024. *A Shared Vision for Digital Technology and Governance: The role of governance in ensuring digital technologies contribute to development and mitigate risk. UNDP Tech for Democracy.* As of 23 August 2024: https://www.undp.org/publications/dfs-shared-vision-digital-technology-and-governance-role-governance-ensuring-digital-technologies-contribute-development-and-mitigate-risk

26 Mannion, Cara. 2021. 'Data Imperialism: The GDPR's Disastrous Impact on Africa's E-Commerce Markets.' *Vanderbilt Journal of Transnational Law* 53(2): 685–711. As of 23 August 2024: https://scholarship.law.vanderbilt.edu/vjtl/vol53/iss2/6

27 European Commission. n.d. 'Europe's Digital Decade: digital targets for 2030.' As of 23 August 2024: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en



Chapter 3. **Advanced manufacturing systems**

Advanced manufacturing refers to the suite of emerging material production technologies and systems that offer performance improvements relative to conventional manufacturing approaches, in the form of enabling greater geometric complexity of products, improving energy and material usage efficiency, reducing infrastructure and resource needs for deployment, or enabling the use of a broader range of feedstock materials.[28]

3.1. Horizon 1: Current context for advanced manufacturing in the humanitarian sector

Advanced manufacturing technologies have the potential to address myriad supply-chain challenges in the humanitarian sector, such as reducing the cost of essential products and enabling more timely and efficient production of humanitarian equipment in crises-affected

28 Science Direct. 2024. 'Advanced Manufacturing.' ScienceDirect.com. As of 23 August 2024: https://www.sciencedirect.com/topics/engineering/advanced-manufacturing

areas.[29] Many of these technologies are established and already being deployed within the humanitarian sector. For example, **3D printing** (a term often used interchangeably with **'additive manufacturing'**), which uses digital design models to print physical, three-dimensional objects layer by layer,[30] was first conceptualised in the 1980s and piloted in the humanitarian sector in the 2010s.[31] In 2020, Handicap International piloted the production of 3D-printed prosthetics in remote areas,[32] while the NGO Field Ready has applied 3D printing to their work in local manufacturing in Haiti, Nepal and Syria, producing simple medical tools such as personal protection equipment, tweezers and otoscopes.[33] The organisation 3DP4ME is also currently seeking to scale up its pilot 3D-printing hearing aids for refugees in Jordan. Wider use cases beyond health include the printing of sensors for water quality testing and sanitation,[34] printed toys embedded in soap to encourage handwashing by displaced children,[35] and the development of carbon-neutral disaster relief shelters.[36]

These developments both reflect and support wider movements in the humanitarian field towards **'decentralised'** and **'distributed' manufacturing** – technologies and systems that change the economics and logistical organisation of manufacturing, with a focus on changing the scale and range of regional spread of manufacturing locations.[37] Beyond additive manufacturing, such models also utilise a range of other technical tools and approaches, including laser-cutting technology and subtractive manufacturing that removes material from initial feedstock,

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29 Kauffmann, Aline, Jocelise Jacques & Fabio da Silva. 2023. 'Design and 3D Technologies in the Humanitarian Sector.' Rio De Janeiro: Service Design and Innovation Conference. As of 23 August 2024: https://ecp.ep.liu.se/index.php/servdes/article/view/866

30 Kanishka, Kumar, & Bappa Acherjee. 2023. 'Revolutionizing manufacturing: A comprehensive overview of additive manufacturing processes, materials, developments, and challenges.' *Journal of Manufacturing Processes* 107: 574–619. As of 23 August 2024: https://www.sciencedirect.com/science/article/abs/pii/S1526612523009726?via%3Dihub

31 James, Eric, & Daniel Gillman. 2015. 'Shrinking the Supply Chain: Hyperlocal Manufacturing and 3D printing in Humanitarian Response.' OCHA. As of 23 August 2024: https://reliefweb.int/report/world/shrinking-supply-chain-hyperlocal-manufacturing-and-3d-printing-humanitarian-response

32 EC Directorate-General for Research and Innovation. 2020. 'EIC Horizon Prize on Affordable High-Tech for Humanitarian Aid: Commission awards five outstanding solutions.' Research-and-innovation.ec.europa.eu. As of 23 August 2024: https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/eic-horizon-prize-affordable-high-tech-humanitarian-aid-commission-awards-five-outstanding-solutions-2020-09-24_en?darkschemeovr=1

33 James, Laura 2017. 'Opportunities and challenges of distributed manufacturing for humanitarian response.' San Jose IEEE Global Humanitarian Technology Conference. As of 23 August 2024: https://ieeexplore.ieee.org/abstract/document/8239297?casa_token=d23cWIAIAFUAAAAA:BxHXeRsC1wF7qaAXjyvRkGffPtDmP5evdGpKeEqlIUVe-yEjy4S1sKlbVhf82wFLY9mExeu3

34 Tatham, Peter, Jennifer Loy & Umberto Peretti. 2014. *3D printing (3DP): a humanitarian logistic game changer*. Auckland: 12th ANZAM Operations, Supply Chain and Services Management Symposium.

35 Elrha. 2017. 'The Hidden Incentives: the Journey has Begun!' Elrha.com. As of 23 August 2024: https://www.elrha.org/project-blog/hidden-incentives-journey-begun/

36 Gangotra, Ankita, Emanuela Del Gado & Joanna I. Lewis. 2023. '3D printing has untapped potential for climate mitigation in the cement sector.' *Communications Engineering* 2(6): 1–5. As of 23 August 2024: https://www.nature.com/articles/s44172-023-00054-7

37 Srai, Jagjit Singh, Gary Graham, Patrick Hennelly, Wendy Phillips, Dharm Kapletia & Harri Lorentz. 2020. 'Distributed manufacturing: a new form of localised production?' *International Journal of Operations & Production Management* 40(6): 697–727. As of 23 August 2024: https://www.emerald.com/insight/content/doi/10.1108/IJOPM-08-2019-0600/full/html

and computerised numerical control (the use of remotely controlled machines for manufacturing).[38]

Current risks and opportunities for humanitarian stakeholders

In a humanitarian context, distributed manufacturing seeks to address the supply-chain challenges outlined previously while also advancing the wider humanitarian localisation agenda.[39] This is exemplified by the development of humanitarian **'maker spaces'** that enable access to manufacturing facilities in collaborative spaces where local communities can share expert and peer-to-peer knowledge on product design and manufacturing. While many of these spaces are orientated towards pre- and post-crisis regional development, there are examples of their use in humanitarian crisis contexts: in Turkey, a maker space operated by the NGO Field Ready produced airbags used for moving rubble during the response effort to the 2023 earthquake; in Iraq, a maker space in Mosul worked to repair medical equipment.[40]

More broadly, additive manufacturing has potential to **advance United Nations Sustainable Development Goals relevant to humanitarian contexts**, including supporting quality education (e.g. through its use as an assistive teaching tool for affected populations with disabilities) and responsible consumption and production (where it reduces environmental emissions associated with transport of humanitarian goods).[41] Stakeholders engaged through project workshops also highlighted how additive manufacturing can support the humanitarian **value of independence** (where it reduces reliance on purchasing externally produced goods).[42]

Despite the potential advanced manufacturing systems hold for humanitarians, their development is currently constrained by systemic challenges facing the wider sector:

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38 StartUs. 2022. 'Discover 5 Top Distributed Manufacturing Solutions developed by Startups.' Startus-insights.com. As of 23 August 2024: https://www.startus-insights.com/innovators-guide/distributed-manufacturing-startups/; Hutchings, Ian, & Phillip Shipway. 2017. '9 - Applications and case studies.' In *Tribology: Friction and Wear of Engineering Materials (Second Edition)*, 303–52. Butterworth-Heinemann. As of 23 August 2024: https://www.sciencedirect.com/science/article/abs/pii/B978008100910900009X?via%3Dihub; Manufacturing Change. 2023. 'A Framework for Scaling Distributed Manufacturing in the Global South.' Manufacturing Change, Frontier Tech Hub and UK Aid. As of 23 August 2024: https://static1.squarespace.com/static/6160742e58596279bef906ba/t/644256cc8c97d24a5bbad ac4/1682069207984/DMDD_Framework_17042023.pdf

39 Corsini, Lucia, Clara B. Aranda-Jan & James Moultrie. 2019. 'Using digital fabrication tools to provide humanitarian and development aid in low-resource settings.' *Technology in Society* 58: 101117. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S0160791X18302264; Manufacturing Change. 2023. 'A Framework for Scaling Distributed Manufacturing in the Global South.' Manufacturing Change, Frontier Tech Hub and UK Aid. As of 23 August 2024: https://static1.squarespace.com/static/6160742e58596279bef906ba/t/644256cc8c97d24a5bbad ac4/1682069207984/DMDD_Framework_17042023.pdf

40 Horton, Ashley Rose. 2022. 'Make yourself at home: makerspaces as a tool for resettlement and reconstruction in conflict-affected settings.' Ås: Norwegian University of Life Sciences. As of 23 August 2024: https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/11250/3005419/Masters%20Thesis%20Make%20 Yourself%20at%20Home%2C%20Makerspaces%20as%20a%20Tool%20for%20Resettlement%20and%20 Reconstruction%20in%20Conflict-Affected%20Settings-Ashley%20Rose%20Horton%20.pdf

41 Muth, Jonathan, Andre Klunker & Christina Völlmecke. 2023. 'Putting 3D printing to good use—Additive Manufacturing and the Sustainable Development Goals.' *Frontiers in Sustainability* 4: 1196228. As of 23 August 2024: https://www.frontiersin.org/articles/10.3389/frsus.2023.1196228/full

42 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging humanitarian technologies' workshop, 29 February 2024.

coordination and inclusive governance mechanisms to establish **common standards for product safety and efficacy** are still developing, and **enabling infrastructure, funding and resources for their deployment in less-developed contexts** is relatively lacking. This includes patent and other intellectual property restrictions that may limit access to open-source information for manufacturing.[43] Many systems cannot produce products at the scale and speed necessitated by crisis response, as current systems tend to focus on slower, low-volume production that represents a barrier to scale. 3D printing can be costly, and scaling this technology can be slow and non-linear, as distributed manufacturing requires the effective establishment and ongoing coordination of networks of local manufacturers.

3.2. Future trajectories, opportunities and challenges for advanced manufacturing in the humanitarian sector

3.2.1. Horizon 2: Medium-term transition phase

Potential development trajectories for advanced manufacturing technologies in the medium-term time horizon – drawing on pilot applications that could mature, and current applications in other sectors that could translate – include:

- **Mobile manufacturing systems and movable factories** that enable agile relocation of manufacturing facilities – for example, units that can be transported in shipping containers, portable assembly of medical products, mobile 3D-printing units, mobile biofuel production, and mobile solar power plant manufacturing.[44] Mature applications in military and non-humanitarian health contexts could feasibly translate to humanitarian contexts, where they could support rapid translation of facilities between nearby crisis locations. Mobile humanitarian hospitals offer a precedent for this.[45]
- **Open-source hardware** based on open-access blueprints and design standards that can be produced by additive manufacturing facilities.[46] This could mature in humanitarian cluster areas not subject to stringent safety regulation and certification regimes. Initiatives and platforms to develop open-source designs – such as IEEE's Humanitarian Open Source Initiative[47] and Glia's open-source medicine library, which includes simple

43 Birtchnell, Thomas, & William Hoyle. 2014. 3D Printing for Development in the Global South: The 3D4D Challenge. Basingstoke, United Kingdom: Palgrave Macmillan. As of 23 August 2024: https://ro.uow.edu.au/cgi/viewcontent.cgi?referer=&httpsredir=1&article=2298&context=sspapers

44 Kazemi, Zahra, Jonas Kjaer Rask, Cláudio Gomes, Emre Yildiz & Peter Gorm Larsen. 2023. 'Movable factory—A systematic literature review of concepts, requirements, applications, and gaps.' *Journal of Manufacturing Systems* 69: 189–207. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S027861252300119X

45 Kazemi, Zahra, Jonas Kjaer Rask, Cláudio Gomes, Emre Yildiz & Peter Gorm Larsen. 2023. 'Movable factory—A systematic literature review of concepts, requirements, applications, and gaps.' *Journal of Manufacturing Systems* 69: 189–207. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S027861252300119X

46 The Turing Way Community. 2022. 'Open Source Hardware.' As of 23 August 2024: https://the-turing-way.netlify.app/reproducible-research/open/open-hardware.html#:~:text=Open%20Source%20Hardware-,Definition,created%2C%20and%20distributed%20by%20anyone

47 McKnight, Glenn H., & Alfredo Herrera. 2010. 'IEEE Humanitarian Projects: Open Hardware for the Benefit of the Poorest Nations.' *Open Source Business Resource*. As of 23 August 2024: https://www.semanticscholar.org/paper/IEEE-Humanitarian-Projects%3A-Open-Hardware-for-the-McKnight-Herrera/7cfe6ad36785d7bd340ba2715ef6bf610d0483f3

medical devices such as stethoscopes and tourniquets – enable local and decentralised humanitarian production.[48] Such initiatives could converge with the development of local humanitarian 'maker space' networks to become more widespread.

- **Remote 'telemanufacturing' supported by computerised numerical control** that enables the automated control and movement of manufacturing tools through remote computer interfaces. Existing humanitarian practice relating to the provision of remote aid (e.g. telemedicine or crisis observation)[49] could expand to include manufacturing facilities.
- **3D-printed replicas of human remains** for the purposes of supporting forensics investigations (already currently used in legal systems in some regions).[50] This could translate into humanitarian contexts to support investigations of humanitarian law breaches. Building on current uses of 3D printing to produce artificial human limbs, further developments could be implemented in crises-affected contexts.[51]

Barriers and enablers for development

In relation to the development of open-source hardware and the wider distributed manufacturing community in supports, there remain challenges to scaling and coordinating these initiatives. Such challenges include securing **funding and participation for building local technical capacity**,[52] and scaling governance mechanisms for **assuring and certifying open-source designs** to demonstrate their safety and efficacy.[53] Growing **communities of practice**, such as the Humanitarian Makers and Honey Bee networks (which share frugal innovation ideas developed in Asian contexts),[54] could potentially facilitate and accelerate this transition.

Barriers to the development of mobile manufacturing systems include local regulatory differences (including those relating to worker mobility and visa requirements), differences in local feedstock access and pricing, and ensuring sustainable funding of transport and

48 Glia. 2024. 'Welcome to Glia!' Docs.glia.org. As of 23 August 2024: https://docs.glia.org/docs/getting-started/introduction/

49 Kaplan, Lewis J., Scott Levin, Jay Yelon, Jeremy M. Cannon, Samir Mehta, Patrick M. Reilly, Stephen J. Kovach III, D. J. Donegan, K. Claycomb, M. Savchenko-Fullerton & E. Filonenko. 2023. 'Providing Remote Aid During a Humanitarian Crisis.' *Critical Care Explorations* 5(11): e0992. As of 23 August 2024: https://www.researchgate.net/publication/375098738_Providing_Remote_Aid_During_a_Humanitarian_Crisis

50 Carew, Rachael M., James French, Carolyn Rando & Ruth M. Morgan. 2023. 'Exploring public perceptions of creating and using 3D printed human remains.' *Forensic Science International: Reports* 7: 100314. As of 23 August 2024: https://doi.org/10.1016/j.fsir.2023.100314

51 Humanity & Inclusion. 2018. 'Print a limb: encouraging results using 3D printed prosthetics'. As of 23 August 2024: https://www.humanity-inclusion.org.uk/en/news/print-a-limb-encouraging-results-using-3d-printed-prosthetics

52 Corsini, Lucia, Clara B. Aranda-Jan & James Moultrie. 2019. 'Using digital fabrication tools to provide humanitarian and development aid in low-resource settings.' *Technology in Society* 58: 101117. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S0160791X18302264

53 James, Laura. 2017. 'Opportunities and challenges of distributed manufacturing for humanitarian response.' San Jose: IEEE Global Humanitarian Technology Conference. As of 23 August 2024: https://ieeexplore.ieee.org/abstract/document/8239297?casa_token=d23cWIAIAFUAAAAA:BxHXeRsC1wF7qaAXjyvRkGffPtDmP5evdGpKeEqlIUVe-yEjy4S1sKlbVhf82wFLY9mExeu3

54 Humanitarian Makers. 'Homepage.' Humanitarianmakers.org. As of 23 August 2024: https://www.humanitarianmakers.org/

maintenance costs.[55] **Increasing exposure of traditional static and centralised manufacturing facilities to extreme weather risks** could, however, incentivise funding and research into both mobile manufacturing and decentralised manufacturing models, which are comparatively more resilient to these risks. **Accelerated development of robotic teleoperation and virtual reality applications** in fast-growing fields, including nuclear management, deep sea exploration and space exploration,[56] could translate to remote manufacturing solutions for the humanitarian sector.

Risks and opportunities for humanitarian stakeholders

Some emerging applications carry **ethical risks and considerations:** the use of 3D-printed human remains for crime forensics and reconstruction should account for significant regional and cultural differences in how human remains should be treated (and associated lack of international codes of practice and ethics), challenges around gaining consent from deceased individuals and their families, and the ethical use and disposal of printed models.[57] Increased use of telemanufacturing and mobile manufacturing systems – reliant on data sharing and remote digital access tools – may also increase humanitarian stakeholders' exposure to **digital risks,** including cyber-threats that compromise the integrity of production outputs or disrupt their operation.[58] The potential social impacts of these approaches could also undermine efforts to support the humanitarian localisation agenda, by, for example, **reducing availability of employment opportunities for local workers and increasing reliance on international expertise and resources**.

Progress in open-hardware standards, and the distributed manufacturing they enable, are in contrast an opportunity to facilitate a wider shift towards **'distributed humanitarianism'**: the shift of humanitarian assistance models away from large-scale, institutionalised aid towards networks of local, self-organising groups and volunteers that could be more cost-efficient and resilient.[59] When seen as part of a wider shift towards **remote humanitarian management**, the next generation of additive manufacturing technologies could also potentially help to address **access constraints and increase worker safety**.[60]

55 Kazemi, Zahra, Jonas Kjaer Rask, Cláudio Gomes, Emre Yildiz & Peter Gorm Larsen. 2023. 'Movable factory—A systematic literature review of concepts, requirements, applications, and gaps.' *Journal of Manufacturing Systems* 69: 189–207. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S027861252300119X

56 Su, Yun-Peng, Xiao-Qi Chen, Cong Zhou, Lui Holder Pearson, Christopher G. Pretty & J. Geoffrey Chase. 2023. 'Integrating Virtual, Mixed, and Augmented Reality into Remote Robotic Applications: A Brief Review of Extended Reality-Enhanced Robotic Systems for Intuitive Telemanipulation and Telemanufacturing Tasks in Hazardous Conditions.' *Applied Sciences* 13(22): 12129. As of 23 August 2024: https://www.mdpi.com/2076-3417/13/22/12129

57 Carew, Rachael M., James French & Ruth M. Morgan. 2023. 'Drilling down into ethics: A thematic review of ethical considerations for the creation and use of 3D printed human remains in crime reconstruction.' *Science & Justice* 63: 330–42. As of 23 August 2024: https://discovery.ucl.ac.uk/id/eprint/10168307/1/1-s2.0-S1355030623000217-main.pdf

58 Kazemi, Zahra, Jonas Kjaer Rask, Cláudio Gomes, Emre Yildiz & Peter Gorm Larsen. 2023. 'Movable factory—A systematic literature review of concepts, requirements, applications, and gaps.' *Journal of Manufacturing Systems* 69: 189–207. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S027861252300119X

59 Cullen Dunn, E., and I. Kaliszewska. 2023. 'Distributed humanitarianism: Volunteerism and aid to refugees during the Russian invasion of Ukraine.' *American Ethnologist* 50(1): 19–29. As of 23 August 2024: https://anthrosource.onlinelibrary.wiley.com/doi/full/10.1111/amet.13138

60 Humanitarian Advisory Group. 2020. *Remote humanitarian management and programming: Guidance note*. As of 23 August 2024: https://library.alnap.org/help-library/remote-humanitarian-management-and-programming-guidance-note

3.3.2. Horizon 3: Long-term future

Potential development trajectories for advanced manufacturing technologies in the longer-term time horizon – drawing on nascent technology research areas and pilot applications that face barriers to maturing in the medium term – include:

- **3D bioprinting and tissue engineering** that uses 'bioink' consisting of living cells, biomolecules or biomaterials as a manufacturing feedstock.[61] Potential use cases in crisis health treatment are broad, including organ and tissue printing, development of biological scaffolds to improve drug delivery, and manufacturing of personalised medicines, but various ethical, technical and governance barriers (discussed below) mean they are unlikely to be widely used in the humanitarian sector in the short- and medium-term.
- **Organic feedstocks[62]** for advanced manufacturing facilities that enable more effective use in low-resource settings, where they are locally abundant. Design concepts for refugee shelters in desert environments using quartz sand as a feedstock have been proposed,[63] while mycelium feedstocks have been shown to improve the mechanical strength of 3D-printed structures[64] and support the development of self-repairing materials.[65]
- **Open-source hardware** for humanitarian activities subject to stringent safety regulations, including medical devices that require approval from medical regulation authorities. This could include additive manufacturing of pills and medicines to fill demand closer to the sites of humanitarian emergencies.[66]
- **Additive food manufacturing**, where dehydrated food is combined with water on-site for use as a feedstock. This could be used to support humanitarian food security and nutrition activities during conflict and famine.[67] These products could also modify food structure to make it more portable and resistant to physical damage in transit, and tailored in shape for individuals with conflict injuries or health

61 Dey, Madhuri, & Ibrahim T. Ozbolat. 2020. '3D bioprinting of cells, tissues and organs.' *Scientific Reports* 10(1): 14023. As of 23 August 2024: https://www.nature.com/articles/s41598-020-70086-y

62 Feedstock is defined as 'a raw material going into a chemical process or plant as input to be converted into a product.' See: European Commission. 2024. 'Feedstock' Knowledge for Policy glossary. As of 23 August 2024: https://knowledge4policy.ec.europa.eu/glossary-item/feedstock_en

63 Labuda, Igor, Federica Pugliese & Jolanata Dzwierzynska. 2024. 'An Innovative Concept for 3D Sand-Printed Sustainable Refugee Shelters in a Sandy Desert in a Hot and Dry Climate.' *Sustainability* 16(6): 2294. As of 23 August 2024: https://www.mdpi.com/2071-1050/16/6/2294

64 Soh, Eugene, Jia Heng Teoh, Brendon Leong, Tingrong Xing & Hortense Le Ferrand. 2023. '3D printing of mycelium engineered living materials using a waste-based ink and non-sterile conditions.' *Materials & Design* 236: 112481. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S0264127523008961

65 Gantenbein, Silvan, Emanuele Colucci, Julian Käch, Etienne Trachsel, Fergal B. Coulter, Patrick A. Rühs, Kunal Masania & André R. Studart. 2023. 'Three-dimensional printing of mycelium hydrogels into living complex materials.' *Nature Materials* 22(1): 128–34. As of 23 August 2024: https://arxiv.org/ftp/arxiv/papers/2203/2203.00976.pdf

66 World Health Organization. 2023. 'Emerging technologies and scientific innovations: a global public health perspective (WHO global health foresight series).' As of 23 August 2024: https://www.who.int/publications/i/item/9789240073876

67 Canfield, Stella. 2023. 'UF/IFAS scientists rethink food possibilities with 3D food printer.' Blogs.ifas.ufl.edu. As of 23 August 2024: https://blogs.ifas.ufl.edu/news/2023/02/02/uf-ifas-scientists-rethink-food-possibilities-with-3d-food-printer/

conditions such as dysphagia that make it difficult to swallow foods.[68]

- The use of **metal and multi-material feedstocks** for additive manufacturing, including to support **3D-printed electronics**. For the latter, researchers are exploring the potential to make flexible, wearable sensors for health monitoring, which may offer potential for healthcare in emergency settings.[69]
- **Synthetic biology**, the modification of living organisms' genes to change their performance. This could be used to create construction materials resistant to extreme weather conditions or to prevent the spread of communicable diseases in humanitarian contexts. Access to patents and techniques as well as ethical concerns of using synthetic biology on human beings could constraint future uses.[70]

Barriers to and enablers for development

The major barriers to the development of open-source humanitarian hardware and bioprinted products in heavily regulated fields, including health and medicine, are **costs, availability and capacity**: gaining approval and certification for these devices requires substantial investment to evidence that designs are safe, and regulatory authorities' capacity to process approvals is unlikely to keep up with demand in the foreseeable future.[71] Similar regulatory challenges have been noted for additive food manufacturing, where food safety regulations – and concerns about a lack of nutritional value in the context of growing evidence on the risks of ultra-processed food – may impede the progress of future development.[72]

Several systemic trends could be common enablers for the development of the next generation of advanced manufacturing approaches, however: **challenges relating to the sustainability and availability of existing feedstocks and equivalent non-manufactured**

68 Zhu, Wenxi, Michèle M. Iskandar, Vahid Baeghbali & Stan Kubow. 2023. 'Three-Dimensional printing of foods: A critical review of the present state in healthcare applications, and potential risks and benefits.' *Foods* 12(17): 3287. As of 23 August 2024: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10487194/

69 Tan, Hong Wei, Yu Ying Clarrisa Choong, Che Nan Kuo, Hong Yee Low & Chee Kai Chua. 2022. '3D printed electronics: Processes, materials and future trends.' *Progress in Materials Science* 127: 100945. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S0079642522000263

70 Dorfan, Yuval, Yael Morris, Benny Shohat & Ilana Kolodkin-Gal. 2023. 'Sustainable construction: Toward growing biocement with synthetic biology.' Research Directions: *Biotechnology Design* 1: e14. As of 23 August 2024: https://doi.org/10.1017/btd.2023.7;
Davies, Sarah, & Louis Stupple-Harris. 2023. 'Tech in the Dock: should synthetic biology be the next decade's big bet to tackle climate change?'. As of 23 August 2024: https://www.nesta.org.uk/feature/tech-in-the-dock-synthetic-biology/;
Douglas, Conor M., & Dirk Stemerding. 2013. 'Governing synthetic biology for global health through responsible research and innovation.' *Systems and Synthetic Biology* 7(3): 139–50. As of 23 August 2024: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3740102/

71 Beddoe-Rosendo, Jacqueline, Clare L. Heaysman, Joseph V. Hajnal, Sebastien Ourselin & Anne Vanhoestenberghe. 2023. 'Medical device regulatory challenges in the UK are affecting innovation and its potential benefits.' *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine* 237(11): 1243–47. As of 23 August 2024: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10685680/

72 Zhu, Wenxi, Michèle M. Iskandar, Vahid Baeghbali & Stan Kubow. 2023. 'Three-Dimensional printing of foods: A critical review of the present state in healthcare applications, and potential risks and benefits.' *Foods* 12(17): 3287. As of 23 August 2024: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10487194/

products (including food insecurity[73] and organ donation supply[74]) could drive the search for alternatives.

Risks and opportunities for humanitarian stakeholders

As advanced manufacturing approaches become more accessible and sophisticated in the longer term, organisations including the United Nations have speculated that it could be used to facilitate the production of weapons (including autonomous weapon components) by malicious actors, increasing **risks to both humanitarian safety and of general conflict development**.[75] A World Health Organization report on the future of bioprinting highlights similar potential issues around **bioprinted biological weapons**, and wider potential issues relating to **social stigmatisation** of 3D-printed tissue recipients and **exclusion of LMICs** in both the development of and access to such technologies.[76]

Organic feedstocks have the potential to drive **sustainability in humanitarian operations** (through reducing reliance on feedstocks associated with higher ecological impacts) and support the development of new local economies for feedstock cultivation and harvesting as part of a wider shift to 'regenerative circular economies'.[77]

Based on the risks, opportunities, barriers and enablers discussed in the previous paragraphs, the study team identified some questions that could guide future uses of advanced manufacturing by humanitarians in Box 3.1 below.

Box 3.1 Considerations for responsible adoption of advanced manufacturing systems

In response to the potential future development trajectories, risks and opportunities associated with advanced manufacturing systems, humanitarian stakeholders could consider addressing the following questions:

- How can humanitarian 'maker spaces' and distributed manufacturing networks be supported to scale?
- How could humanitarian funders, policymakers and advocacy groups promote new institutional and governance mechanisms for certifying open-source hardware designs?
- How can locally abundant advanced manufacturing feedstocks (including organic substances and bioinks) be sustainably cultivated and scaled?

73 Alami, Abdul Hai, Abdul Ghani Olabi, Siren Khuri, Haya Aljaghoub, Shamma Alasad, Mohamad Ramadan & Mohammad Ali Abdelkareem. 2023. '3D printing in the food industry: Recent progress and role in achieving sustainable development goals.' *Ain Shams Engineering Journal* 15(2): 102386. As of 23 August 2024: https://www.sciencedirect.com/science/article/pii/S2090447923002757

74 Akenroye, Temidayo O., Adegboyega Oyedijo, Vishnu C. Rajan, George A. Zsidisin, Marcia Mkansi & Jamal El Baz. 2023. 'Connecting the dots: uncovering the relationships between challenges confronting Africa's organ transplant supply chain systems.' *Supply Chain Management: An International Journal* 28(7): 43–61. As of 23 August 2024: https://www.emerald.com/insight/content/doi/10.1108/SCM-12-2022-0457/full/html

75 United Nations. 2024. 'A New Era of Conflict and Violence.' Un.org. As of 23 August 2024: https://www.un.org/en/un75/new-era-conflict-and-violence

76 World Health Organization. 2024. 'Imagining futures of 3D bioprinting: WHO global health foresight series.' As of 23 August 2024: https://iris.who.int/bitstream/handle/10665/375873/9789240087774-eng.pdf?sequence=1

77 Mohseni, Alale, Fabricio Rocha Vieira, John A. Pecchia & Benay Gürsoy. 'Three-Dimensional Printing of Living Mycelium-Based Composites: Material Compositions, Workflows, and Ways to Mitigate Contamination.' *Biomimetics* 8(2): 257. As of 23 August 2024: https://www.mdpi.com/2313-7673/8/2/257

Figure 3.1 Future development trajectories, barriers, enablers, risks and opportunities associated with advanced manufacturing systems in the humanitarian sector

	Horizon 1	Horizon 2	Horizon 3
Development trajectories	• Additive manufacturing	• Mobile manufacturing • Open-source hardware (non-regulated products) • Telemanufacturing • 3D-printed forensics	• Bioprinting • Organic feedstocks • Open-source hardware (regulated products) • Additive food manufacturing • Multi-material feedstocks
Barriers to development		• Worker mobility • Regional feedstock differences • Funding open-source hardware networks • Production speeds and volume	• Regulatory capacity • Regulatory approvals cost • Concerns about ultra-processed foods
Enablers of development		• Maturing virtual reality • Maturing telerobotics • Distributed manufacturing models • Humanitarian maker networks	• Ecological impacts of current feedstocks • Food and organ supply challenges
Risks		• Ethics of 3D-printed human remains • Increased digital risks • Constraining local manufacturing	• Weapons and biohazard production • Exclusion of LMIC actors
Opportunities	• Advancing United Nations Sustainable Development Goals • Championing independence	• Promoting distributed humanitarianism • Addressing access constraints • Increasing worker safety	• Driving sustainable humanitarian operations

Source: Study team analysis.

Chapter 4. **Early Warning Systems**

An Early Warning System (EWS), as defined by the United Nations Office for Disaster Risk Reduction (UNDRR), is an ‘integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events’.[78] The hazards these systems seek to address range from natural disasters such as floods and earthquakes through to disease risks and food insecurity. They span the four core pillars of early warning action, including: disaster risk knowledge development; detection, monitoring and forecasting of hazards; warning dissemination and communication; and preparedness to respond.[79] In the context of the humanitarian sector and acute crisis

78 United Nations Office for Disaster Risk Reduction. 2024. ‘Early warning system.’ As of 26 August 2024: https://www.undrr.org/terminology/early-warning-system

79 United Nations Office for Disaster Risk Reduction. 2024. ‘Early warnings for all (EW4All).’ As of 26 August 2024: https://www.undrr.org/implementing-sendai-framework/sendai-framework-action/early-warnings-for-all

response systems for the latter two pillars are particularly relevant. It is important to note that the development of EWS can also help identify financing priorities (e.g. against the risk of famine or to strengthen action prior to tropical typhoons).[80] Beyond the identification of climate-related risks, EWS in the humanitarian context can also help identify human rights violations and early signs of conflict.[81]

While a substantial amount of funding and resource is being devoted to EWS on a global level, there remains a need to consider how to develop effective localised systems in LMICs. Localised EWS systems that are designed to address the unique geographical, environmental and socio-economic factors that influence disaster risk within a particular area could have significant impacts in effectiveness and in developing local technological capacity.

4.1. Horizon 1: Current context for Early Warning Systems in the humanitarian sector

Today, **EWS can take advantage of different types of data and advanced computing systems** to improve preparedness. In the Philippines, for example, a collaboration between a Dutch company and the Philippine Red Cross (PRC) led to a tool that could analyse social media data and reporting from volunteers on the ground in combination with hydrologic models to better inform flood preparedness and response.[82]

A range of **sensor technologies**, both established and emerging, underpin hazard detection and monitoring activities. Technologies such as static rainfall, water level and flow, humidity, radar and satellite monitoring sensors are relatively established, while approaches incorporating Internet of Things (IoT) and Light Detection and Ranging (Lidar) sensors are at an earlier stage of development.[83] Cambodia's EWS 1294, for example, uses solar-powered and mobile data-enabled water gauges for flood risk monitoring,[84] while a system being developed in Timor-Leste uses weather stations, ocean sensors and Doppler radars that utilise the Doppler effect to produce information about the speed of objects travelling at a distance (for example, to measure approaching wave speeds).[85]

Multi-Hazard Early Warning Systems (

80 Office for the Coordination of Humanitarian Affairs. 2021. *From digital promise to frontline practice: new and emerging technologies in humanitarian action*. As of 23 August 2024: https://reliefweb.int/report/world/digital-promise-frontline-practice-new-and-emerging-technologies-humanitarian-action

81 Rød, Espen Geelmuyden, Tim Gåsste & Håvard Hegre. 2024. 'A review and comparison of conflict early warning systems.' *International Journal of Forecasting* 40(1): 96–112. As of 26 August 2024: https://doi.org/10.1016/j.ijforecast.2023.01.001

82 FloodTags. 2024. 'Success Stories.' As of 26 August 2024: https://www.floodtags.com/real-time-flood-monitor-at-the-philippine-red-cross/

83 Girotto, Cristiane D., Farzad Piadeh, Vahid Bkhtiari, Kourosh Behzadian, Albert S. Chen, Luiza C. Campos & Massoud Zolgharni. 2023. 'A critical review of digital technology innovations for early warning of water-related disease outbreaks associated with climatic hazards.' *International Journal of Disaster Risk Reduction* 100: 104151. As of 26 August 2024: https://www.sciencedirect.com/science/article/pii/S2212420923006313

84 People In Need. 2022. 'Cambodia's Early Warning System 1294: An Adaptable Technology Promoting Safety for All.' As of 26 August 2024: https://reliefweb.int/report/cambodia/cambodia-s-early-warning-system-1294-adaptable-technology-promoting-safety-all

85 UN Environment Programme. 2023. 'An early warning system for disasters takes shape in Timor-Leste.' As of 26 August 2024: https://www.unep.org/news-and-stories/story/early-warning-system-disasters-takes-shape-timor-leste

), which are able to forecast the cumulative effect of different types of disasters, are a growing area of application in LMICS: 39 per cent of Small Island Developing States, and 46 per cent of Least Developed Countries (LDCs), currently have established MHEWS.[86] In the island nation of Barbados, for example, this combines systems for natural disaster risks such as hurricanes and flooding with monitoring for vector-borne diseases that increase in the wake of high temperatures and natural disasters. Since 2022, the African Union has also implemented a new EWS, the Africa Multi-Hazard Early Warning and Early Action System, aimed at benefiting countries across the continent and helping identify potential crises or coups, as it did successfully in Mali in 2012 or Burkina Faso in 2015, though there have been rising concerns about the efficiency of the system since.[87]

Community Early Warning Systems (CEWS), which are developed and implemented at a community level and emphasise solutions that work within existing resources and by empowering local actors, are increasingly seen as vital to establishing EWS in developing countries and achieving 'early warning for all' ambitions (discussed in more detail below).[88] While the systems developed vary, depending on the local infrastructure and context, in general they use technologies that are relatively lower in cost and technical complexity, as CEWS are often deployed where there are gaps in coverage of, or no, national-level systems. In the case of Chitwan village in Nepal, for example, CEWS have evolved from the use of manual watch-and-warn towers and sirens in 2002 to the establishment of a community disaster management committee that monitors upstream river levels two decades later.[89]

Common warning communication systems include the use of **mobile phone-based alert systems,** such as those used to respond to an unprecedented volcanic eruption and tsunami in Tonga in 2022,[90] or India's national flood alert warning system.[91] These systems can operate even in low-connectivity contexts

86 Sneddon, Alison, & Mirianna Budimir. 2023. 'Community-based early warning systems.' UCL Warning Research Centre. As of 26 August 2024: https://www.ucl.ac.uk/sts/sites/sts/files/briefingnotecbews.pdf

87 African Union. 2023. 'Shaping the Future: Africa's Drive for Multi-Hazard Early Warning Systems.' As of 26 August 2024: https://au.int/en/pressreleases/20230730/shaping-future-africas-drive-multi-hazard-early-warning-systems; ISS Africa. 2024. 'Should the old Continental Early Warning System be restored?' As of 26 August 2024: https://issafrica.org/pscreport/psc-insights/should-the-old-continental-early-warning-system-be-restored; African Union. 2023. *Framework for Multi-Hazard Early Warning and Early Action System for Africa*. As of 26 August 2024: https://www.undp.org/africa/publications/framework-multi-hazard-early-warning-and-early-action-system-africa

88 Sneddon, Alison, & Mirianna Budimir. 2023. 'Community-based early warning systems.' UCL Warning Research Centre. As of 26 August 2024: https://www.ucl.ac.uk/sts/sites/sts/files/briefingnotecbews.pdf

89 Sneddon, Alison, & Mirianna Budimir. 2023. 'Community-based early warning systems.' UCL Warning Research Centre. As of 26 August 2024: https://www.ucl.ac.uk/sts/sites/sts/files/briefingnotecbews.pdf

90 Climate Risk & Early Warning Systems. 2022. 'In response to unprecedented volcano and tsunami, Kingdom of Tonga develops Tonga Mobile Applications Community MHEW and Response System (MACRES) through the CREWS Accelerated Support Window.' As of 26 August 2024: https://crews-initiative.org/news/response-unprecedented-volcano-and-tsunami-kingdom-of-tonga-develops-tonga-mobile-0/

91 Department of Administrative Reforms & Public Grievances, Ministry of Personnel, Public Grievances & Pensions, Government of India. 2024. 'Flood Early Warning System – A Warning Mechanism for Mitigating Disasters During Flood.' As of 26 August 2024: https://darpg.gov.in/sites/default/files/70.%20Flood%20Early%20Warning%20SystemFLEWS-Documentation-Final.pdf

both for humanitarian actors and affected communities.[92]

Current risks and opportunities for humanitarian stakeholders

The UNDRR's Global Assessment Report on Disaster Risk Reduction identifies access to disaster EWS as one of the foundations of achieving the Sustainable Development Goals (SDG) and overcoming the **'resilience deficit'**, where regions' needs in relation to disaster protection are not met by their capabilities. [93]

Despite the increasing adoption of EWS in LMICs, some key challenges and systemic risks remain. Many EWS, and the technological systems of which they comprise, are developed by private organisations or institutions in high-income countries, creating risks of 'technology lock-in' and **overreliance on systems** beyond their control in LMIC regions that depend on them. Despite progress on implementing CEWS, many systems still have **exclusionary warning communication systems** that fail to adequately account for considerations such as diversity in local dialects, beliefs and norms, and disability-friendly warnings. Multimedia EWS formats could, however, help to overcome some of these concerns.[94] Digitised EWS may also pose social risks where they **create operational challenges for, or displace, existing community-based** approaches.

4.2. Future trajectories, opportunities and challenges for Early Warning Systems in the humanitarian sector

4.2.1. Horizon 2: Medium-term transition phase

Potential development trajectories for EWS in LMICs in the medium term (Horizon 2) include:

- **Internet of Things** (IoT): the advancement of IoT that enables real-time data collection and analysis, aiding in predicting and mitigating natural disasters, could be widespread in LMICs in the medium term.[95] IoT sensors can monitor environmental factors like temperature, vibration, movement, displacement, pressure and air quality to support disaster detection and monitoring. Systems on connected drones – collectively referred to as **Internet of Drones** (IoD) – could also become more commonplace as a form of backup communication network in support of disaster response communications. An example of this is AT&T's use of drone-based 'cells on wings' to restore communication in Puerto Rico after the 2017 hurricane.[96]

92 Office for the Coordination of Humanitarian Affairs. 2021. *From digital promise to frontline practice: new and emerging technologies in humanitarian action*. As of 26 August 2024: https://reliefweb.int/report/world/digital-promise-frontline-practice-new-and-emerging-technologies-humanitarian-action

93 United Nations Office for Disaster Risk Reduction. 2023. 'GAR Special Report: Measuring Resilience for the Sustainable Development Goals.' As of 26 August 2024: https://www.undrr.org/gar/gar2023-special-report

94 GSMA. 2022. 'Early Warning Systems in the Philippines: Building resilience through mobile and digital technologies.' As of 26 August 2024: https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-for-development/wp-content/uploads/2022/06/PhilippinesEWS_R_Web.pdf

95 TagoIO. 2024. 'Using IoT to Predict and Prevent Natural Disasters.' As of 26 August 2024: https://tago.io/blog/iot-to-predict-prevent-natural-disasters

96 Pregler, Art. 2018. 'Extreme Connections.' AT&T Blog. As of 26 August 2024: https://about.att.com/innovationblog/extreme_connections

- Novel **low-cost sensors** currently being developed could enable the expansion of disaster detection systems in low-resource contexts. One example is microelectromechanical systems-based ground motion sensors for earthquake risk detection, which have been piloted in countries including China, Japan, Taiwan and the USA.[97]
- **Virtual Reality for preparedness** and anticipatory action planning could translate from high-income countries where they are being piloted or widely applied. Countries including Italy, China, the USA and Brazil have used these systems for a range of purposes, including disaster simulation and decision support, engaging the public with flood risks and response actions, and training humanitarian responders.[98]
- **Community-driven EWS** (CDEWS): The International Federation of Red Cross and Red Crescent Societies (IFRC) highlights how future stages of CEWS development may need to be led by communities themselves. Specifically, CDEWS can occur in the absence of established EWS at the national level or should risks be limited to a very specific location (e.g. risk of flash floods). Similarly, such systems can focus on conflict-related risks. In Sri Lanka, for example, CEWS were established to monitor at-risk areas. In the Horn of Africa, EWS were also implemented to focus on pastoral conflicts.[99]

Barriers to and enablers for development

Research suggests that there is a **need for enhanced interoperability and integration** among these systems, particularly for addressing multi-hazard situations where systems tailored to individual risks may face particular integration challenges.[100] For instance, project consultation with a sector expert suggested that Madagascar currently operates over 30 warning systems; however, there is a lack of cohesive integration among them, which raises concerns about the efficiency and effectiveness of creating multiple EWS.

The establishment of **regional frameworks for EWS** could, however, help to address these coordination and interoperability challenges. The African Union has put forth a framework for an African Multi-Hazard Early Warning and Early Action System,[101] and in 2022 a Continental Multi-Hazard Advisory Centre was established by the African Centre of Meteorological Application for Development.[102] Other regional

97 Chandrakumar, Chanthujan, Raj Prasanna, Max Stephens & Marion Lara Tan. 'Earthquake early warning systems based on low-cost ground motion sensors: A systematic literature review.' *Frontiers in Sensors* 3: 1020202. As of 26 August 2024: https://www.frontiersin.org/articles/10.3389/fsens.2022.1020202/full

98 Girotto, Cristiane D., Farzad Piadeh, Vahid Bkhtiari, Kourosh Behzadian, Albert S. Chen, Luiza C. Campos & Massoud Zolgharni. 2023. 'A critical review of digital technology innovations for early warning of water-related disease outbreaks associated with climatic hazards.' *International Journal of Disaster Risk Reduction* 100: 104151. As of 26 August 2024: https://www.sciencedirect.com/science/article/pii/S2212420923006313

99 The International Federation of Red Cross and Red Crescent Societies. 2012. 'Community early warning systems: guiding principles.' As of 26 August 2024: https://www.climatecentre.org/wp-content/uploads/Community-early-warning-systems-guiding-principles.pdf

100 Centre of Excellence for Climate and Disaster Resilience. 2023. 'Early Warning Systems and Early Action in Fragile, Conflict, and Violent Contexts: Addressing growing climate & disaster risks.' As of 26 August 2024: https://www.undrr.org/media/91922/download

101 African Union. 2023. 'Institutional and Operational Framework for Multi-Hazard Early Warning and Early Action System for Africa.' As of 26 August 2024: https://www.undp.org/africa/publications/framework-multi-hazard-early-warning-and-early-action-system-africa

102 UNDRR Prevention Web. 2022. 'Early Warnings for all of Africa.' As of 26 August 2024: https://www.preventionweb.net/news/early-warnings-all-africa

coordination initiatives include the ASEAN Framework on Anticipatory Action in Disaster Management in Southeast Asia, the Regional Center for Seismology for South America, and the Coordination Center for the Prevention of Natural Disasters in Central America.[103] These regional initiatives are set against the backdrop of the United Nations' Early Warnings for All initiative, which aims to ensure that every country has an EWS by 2027.[104]

At a macro level, general **increasing digital connectivity** and mobile phone penetration could also enable greater adoption of mobile phone-based warning communications systems and strengthen the development of CEWS. The Global System for Mobile Communications Association (GSMA), for example, forecasts that 87 per cent of Sub-Saharan Africa's mobile phone connections will have access to the internet by 2025, relative to 38 per cent in 2017.[105]

Despite these promising initiatives and development, challenges relating to a **lack of sustainable long-term funding** for EWS in LMICs are likely to endure in the short and medium term. The Centre of Excellence for Climate and Disaster Resilience notes that this challenge is particularly significant in fragile, conflict and violent (FCV) contexts, where the potential need for co-funding mechanisms across climate resilience, humanitarian and development funders creates added complexity.[106] **Community mistrust and cultural insensitivities** of nationally and internationally driven EWS could simultaneously be a barrier to these systems while enabling development of CDEWS. Communication warnings may, for example, not acknowledge local belief systems – one paper on flood early warning systems in Pakistan highlights how communities feel a sense of responsibility for and belonging to their ancestral lands, and therefore did not engage with evacuation requests.[107]

Risks and opportunities for humanitarian stakeholders

Community-driven EWS have the potential to symbolise and advance the **humanitarian localisation agenda**, as they are focused on empowering local communities to design, deliver and own their EWS with limited or no reliance on institutions outside of their contexts. The physical localisation of these systems is important to consider. The IFRC, for example, suggest that EWS monitoring activities could be established within the country's capital city.[108] Similarly, community-driven approaches could help to **address gendered impacts of disaster**

103 United Nations Office for Disaster Risk Reduction. 2023. 'Global Status of Multi-Hazard Early Warning Systems.' As of 26 August 2024: https://www.undrr.org/media/91954

104 United Nations. 2024. 'Early Warnings for All.' As of 26 August 2024: https://www.un.org/en/climatechange/early-warnings-for-all

105 GSMA. 2018. 'More Than Half of Sub-Saharan Africa to be Connected to Mobile by 2025, Finds New GSMA Study'. Gsma.com. As of 26 August 2024: https://www.gsma.com/newsroom/press-release/more-than-half-of-sub-saharan-africa-to-be-connected-to-mobile-by-2025-finds-new-gsma-study/

106 Centre of Excellence for Climate and Disaster Resilience. 2023. 'Early Warning Systems and Early Action in Fragile, Conflict, and Violent Contexts: Addressing growing climate & disaster risks.' As of 26 August 2024: https://www.undrr.org/media/91922/

107 Shah, Ashfaq Ahmad, Ayat Ullah, Nasir Abbas Khan, Abid Khan, Muhammad Atiq Ur Rehman Tariq & Chong Xu. 2023. 'Community social barriers to non-technical aspects of flood early warning systems and NGO-led interventions: The case of Pakistan.' *Frontiers in Earth Science* 11. As of 26 August 2024: https://www.frontiersin.org/articles/10.3389/feart.2023.1068721/full

108 The International Federation of Red Cross and Red Crescent Societies. 2012. 'Community early warning systems: guiding principles.' As of 26 August 2024: https://www.climatecentre.org/wp-content/uploads/Community-early-warning-systems-guiding-principles.pdf

risks observed in some regions – a UN Women and International Institute for Sustainable Development (IISD) report found that natural hazards and climate change impact men and women differently because of a host of factors, such as different family responsibilities and design of disaster risk policy and service delivery by mandating bodies.[109]

The use of data-intensive IoT and virtual-reality systems for disaster monitoring and preparatory action, however, creates **surveillance and privacy risks**, which could slide into **data extractivism** (potentially destructive modes of data extraction to maximise profits[110]) where developers of these systems utilise local data to develop products for commercial gain.[111]

4.2.2. Horizon 3: Long-term future

Potential development trajectories for EWS in LMICs in the longer-term future (Horizon 3) include:

- **Edge computing** and **cloud-based EWS**. Edge computing is a distributed computing model that uses local networks and devices for data analysis, reducing reliance on centralised servers and allowing faster processing of data. Research suggests that this could also improve the accuracy of the data.[112] Cloud computing infrastructure that is not currently commonly used for EWS could also mature, facilitating the reuse of risk models across different regions (potentially saving costs and lowering technical barriers).[113]
- The **integration of AI** holds significant potential for enhancing disaster management practices, including, for example, risk analysis for flood early warning systems[114] and anticipatory cash transfers to populations forecasted to experience climate-induced crises.[115] While AI is currently being used in some LMIC EWS – including for decision support in the Pacific regions, and a risk intelligence platform in the Philippines[116] – the use of this technology remains expensive and technically challenging for many communities. Some initiatives already explore these developments through partnerships developed between private-sector companies and LMIC governments.

109 UN Women. 2019. 'Gender and Age Inequality of Disaster Risk.' As of 26 August 2024: https://www.unwomen.org/en/digital-library/publications/2021/11/research-paper-gender-and-age-inequality-of-disaster-risk

110 Chagnon, Christopher W., & Sophia E. Hagolani-Albov. 2023. 'Data extractivism: Social pollution and real-world costs.' In *The European Digital Economy*, 186-203. Routledge. As of 26 August 2024: https://www.researchgate.net/publication/376462541_Data_extractivism

111 Khanal, Shishir, Uma Shankar Medasetti, Mustafa Mashal, Bruce Savage & Rajiv Khadka. 2022. 'Virtual and augmented reality in the disaster management technology: a literature review of the past 11 years.' *Frontiers in Virtual Reality* 3: 30. As of 26 August 2024: https://www.frontiersin.org/articles/10.3389/frvir.2022.843195/full

112 Hao, Hao, Shuli, Wenjie Hao, Jie Fu, Fan Jiang and Qing Zhang. 2021. 'Landslide Monitoring and Early Warning System based on Edge Computing.' *IOP Conference Series: Earth and Environmental Science* 861. As of 26 August 2024: https://doi.org/10.1088/1755-1315/861/4/042056

113 Agbehadji, Israel Edem, Tafadzwanashe Mabhaudhi, Joel Botai & Muthoni Masinde. 'A systematic review of existing early warning systems' challenges and opportunities in cloud computing early warning systems.' *Climate* 11(9): 188. As of 26 August 2024: https://www.mdpi.com/2225-1154/11/9/188

114 IntechOpen. 2022. 'Challenges and Technical Advances in Flood Early Warning Systems (FEWSs).' As of 26 August 2024: https://www.intechopen.com/chapters/72571

115 Risk-informed Early Action Partnership. 2023. 'Early Action: The State of Play 2023.' As of 26 August 2024: https://www.early-action-reap.org/sites/default/files/2024-02/20240227_REAP_StateofPlay2023.pdf

116 United Nations Office for Disaster Risk Reduction. 2023. 'Global Status of Multi-Hazard Early Warning Systems.' As of 26 August 2024: https://www.undrr.org/media/91954/

For example, Microsoft launched an initiative to strengthen EWS across Africa.[117] Stakeholders engaged through this project suggest that the use of AI could be a long-term future trend in LMIC EWS, if these systems become much cheaper and possibly more transparent and accessible.

- **MHEWS** that encompass EWS for new forms of disaster risks, perhaps incorporating novel sensor technologies. Recent research has formulated the use of carbon nanotube sensors on plants that could act as an EWS for crop threats,[118] for example. Elsewhere, EWS for a range of non-disaster-related risks that could exacerbate humanitarian crises could be integrated into MHEWS, such as online misinformation EWS[119] or models that use climate-related information to predict and prevent disease outbreak.[120]

Barriers and enablers for development

Challenges relating to the performance of AI for anticipatory action include **data scarcity** (particularly in relation to marginalised populations in LMICs) and 'dataset shifts' where differences between the data used to train models and the data in their real-world use mean the risk models used may not be as effective.[121] Taken collectively, these issues represent a significant barrier for effective **translation of AI models** to LMIC contexts.

Maturing **algorithmic auditing approaches** may mitigate these risks and provide some assurances to sceptical communities and stakeholders. Community-based auditing approaches, which have the potential advantages of surfacing biases research-led or internal company auditors may overlook and fostering community awareness and mobilisation, may be particularly useful for supporting CDEWS.[122]

Recent increases in academic research exploring the use of **'explainable AI techniques for disaster risk management'**[123] (i.e. that facilitate the interpretation and understanding of EWS models) could foster future developments in this area, and potentially help LMIC stakeholders to better understand and scrutinise the use of AI EWS in their

117 Microsoft News Center. 2022. 'Microsoft and Tomorrow.io announce climate adaptation and early warning technology solution in Africa.' As of 26 August 2024: https://news.microsoft.com/en-xm/2022/11/10/microsoft-and-tomorrow-io-announce-climate-adaptation-and-early-warning-technology-solution-in-africa/

118 Ang, Mervin Chun-Yi, Jolly Madathiparambil Saju, Thomas K. Porter, Sayyid Mohaideen, Sreelatha Sarangapani, Duc Thinh Khong, Song Wang et al. 2024. 'Decoding early stress signaling waves in living plants using nanosensor multiplexing.' *Nature Communications* 15(1): 2943. As of 26 August 2024: https://www.nature.com/articles/s41467-024-47082-1

119 Yankoski, Michael, Tim Weninger & Walter Scheirer. 2020. 'An AI early warning system to monitor online disinformation, stop violence, and protect elections.' *Bulletin of the Atomic Scientists* 76(2): 85–90. As of 26 August 2024: https://doi.org/10.1080/00963402.2020.1728976

120 Girotto, Cristiane D., Farzad Piadeh, Vahid Bkhtiari, Kourosh Behzadian, Albert S. Chen, Luiza C. Campos & Massoud Zolgharni. 2023. 'A critical review of digital technology innovations for early warning of water-related disease outbreaks associated with climatic hazards.' *International Journal of Disaster Risk Reduction* 100: 104151. As of 26 August 2024: https://www.sciencedirect.com/science/article/pii/S2212420923006313

121 Huynh, Benjamin Q., & Mathew V. Kiang. 2023. 'AI for Anticipatory Action: Moving beyond Climate Forecasting.' *Proceedings of the AAAI Symposium Series* 2(1): 78–84. As of 26 August 2024: https://arxiv.org/pdf/2307.15727.pdf

122 Vecchione, Briana, Karen Levy & Solon Barocas. 2021. 'Algorithmic auditing and social justice: Lessons from the history of audit studies.' *Proceedings of the 1st ACM Conference on Equity and Access in Algorithms, Mechanisms, and Optimization* 19: 1–9. As of 26 August 2024: https://doi.org/10.1145/3465416.3483294

123 Ghaffarian, Saman, Firouzeh Rosa Taghikhah & Holger R. Maier. 2023. 'Explainable artificial intelligence in disaster risk management: Achievements and prospective futures.' *International Journal of Disaster Risk Reduction* 98: 104123. As of 26 August 2024: https://www.sciencedirect.com/science/article/pii/S2212420923006039

communities. Public-private partnerships are also increasingly developed. For example, IBM developed a partnership with the African Union's Risk Capacity Group to leverage AI- and cloud-based systems to support upskilling and capacity-building efforts but also to develop cutting-edge risk assessment and early warning products.[124]

Risks and opportunities for humanitarian stakeholders

Researchers have questioned the **ethics of automated anticipatory resource distribution** and the design choices of underpinning AI models. For example, if economic loss is treated as an absolute (rather than relative) metric for disaster impact assessment models, this would tend to favour wealthier communities and individuals who on average have more capital assets to lose from disaster damage.[125] Risks of **algorithmic bias** – where models discriminate against certain demographics based on underlying biases in the training data – observed in general AI systems are likely to be particularly harmful if they impact anticipatory resource distribution and community risk exposure models.[126]

Based on the risks, opportunities, barriers and enablers discussed in the previous paragraphs, the study team identified some questions that could guide the future adoption of EWS by humanitarians across LMICs in Box 4.1.

Box 4.1 Considerations for responsible adoption of Early Warning Systems in LMICs

In response to the potential future development trajectories, risks and opportunities associated with EWS in LMICs, humanitarian stakeholders could consider addressing the following questions:

- What international funding, governance and community engagement initiatives are needed to sustain LMIC EWS after the conclusion of the UN's Early Warning for All initiative in 2027?
- What oversight and design mechanisms should be developed to ensure LMICs can design, influence and audit AI-based EWS in their communities?
- How can early warning communication systems be made more inclusive (e.g. reflecting local religious or spiritual beliefs)?

124 ARC-Comms. 2022. 'African Risk Capacity agency and IBM corporation sign Memorandum of Understanding'. As of 26 August 2024: https://arc.int/news/african-risk-capacity-agency-and-ibm-corporation-sign-memorandum-understanding-cop-27; Jones, Anne, Kommy Weldemariam, Julian Kuehnert, Zaheed Gaffoor, Paolo Fraccaro, Toby Kurien & Jorge Luis Guevara Diaz. 2022. 'Addressing climate risks in Africa with AI and hybrid cloud'. As of 26 August 2024: https://research.ibm.com/blog/ibm-arc-africa-climate

125 Huynh, Benjamin Q., & Mathew V. Kiang. 'AI for Anticipatory Action: Moving beyond Climate Forecasting.' *Proceedings of the AAAI Symposium Series* 2(1): 78–84. As of 26 August 2024: https://arxiv.org/pdf/2307.15727.pdf

126 Oxford Insights. 2023. 'AI for Climate Change: Managing floods using AI Early Warning Systems.' As of 26 August 2024: https://oxfordinsights.com/insights/ai-for-climate-change-managing-floods-using-ai-early-warning-systems/

Figure 4.1 Future development trajectories, barriers, enablers, risks and opportunities associated with Early Warning Systems in the humanitarian sector

	Horizon 1	Horizon 2	Horizon 3
Development trajectories	• Multi-Hazard Warning Systems (MHEWS) • Mature sensor technologies • Community EWS • Mobile alert systems	• IoT and IoD • Low-cost sensors • Virtual reality for preparedness • Community-driven EWS (CDEWS)	• AI-enabled EWS • Edge computing and cloud-based EWS • Privacy-enhancing technologies for EWS (PETs) • Advanced multi-hazard EWS
Barriers to development		• Interoperability challenges • Community trust • Sustained funding	• Context translation for AI EWS • Data scarcity
Enablers of development		• Increasing mobile penetration and internet connectivity • Increasing political commitment • Establishment of regional frameworks to promote EWS	• Algorithmic auditing • Explainable AI for EWS
Risks	• Overreliance on foreign-owned EWS • Exclusionary warning communication • Displacement of community infrastructure	• Data extractivism, privacy and security risk	• Ethics of automated resource distribution
Opportunities	• Overcoming resilience deficits • Targeted support for vulnerable populations	• Advancing localisation through CDEWS • Addressing gendered disaster risks	

Source: Study team analysis.

Chapter 5. **Camp monitoring systems**

Camp monitoring systems are an important enabling technology area for humanitarian camp coordination and camp management (CCCM) cluster activities. Established under the responsibility of the International Organization for Migration (IOM) and the Office of the High Commissioner for Refugees (UNHCR) in 2005, this encompasses a range of activities related to the management of population displacement and migration flows, temporary or permanent, in the aftermath of crises such as conflicts and natural disasters.[127] Affected populations can be relocated

127 UNHCR. 2021. 'Camp Coordination and Camp Management (CCCM) Cluster (IASC)'. As of 26 August 2024: https://emergency.unhcr.org/coordination-and-communication/cluster-system/camp-coordination-and-camp-management-cccm-cluster-iasc

outside camps[128] (e.g. with host families or housing schemes) or within camps (this includes both formal and planned camps as well as informal, self-established and transit settlements).[129] To support the activation and management of these settings, a myriad of actors are involved either directly or indirectly, including the affected population themselves, national government authorities, local populations, agencies across the UN system and national and international non-governmental organisations (NGOs).[130] The roles and responsibilities of these various actors depends on the type of camp that is established. It should also be noted that the establishment of camps is understood as a last-resort measure in contexts of displacement.[131]

Throughout the life cycle of a camp there are commonly three phases: camp set-up; camp care and maintenance; and camp closure. There can be periods of overlap between the various phases and temporary settings can become permanent. Camp management is often under the responsibility of national or international NGOs with national authorities. This task encompasses the maintenance of camp infrastructure as well as ensuing that the displaced population can access and benefit from services and that their needs are met over time.[132]

Against this backdrop, camp monitoring systems in the context of this deep dive are defined as outlined in Box 5.1.

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128 'The term camp is used [to] refer to a variety of camps or camp-like settings and temporary settlements including planned or self-settled camps, collective centres, reception and transit centres, and evacuation centres established for hosting displaced persons. It applies to rural or urban settings, to ongoing and new situations, to those resulting from conflict or natural disasters, in other words, wherever displaced people are compelled to find shelter in temporary places.' The term 'site' is also increasingly used. See UNHCR. 2021. 'Camp Coordination and Camp Management (CCCM) Cluster (IASC)'. As of 29 July 2024:
https://emergency.unhcr.org/coordination-and-communication/cluster-system/camp-coordination-and-camp-management-cccm-cluster-iasc;
International Organization for Migration (IOM), Norwegian Refugee Council (NRC) and UN Refugee Agency (UNHCR). 2015. Camp Management Toolkit. As of 29 July 2024:
https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf

129 International Organization for Migration. 2020. 'Camp Coordination and Camp Management (CCCM)'. As of 26 August 2024:
https://www.iom.int/sites/g/files/tmzbdl486/files/documents/CampCoordinationandCampManagement%20Manual.pdf

130 UNHCR. 2021. 'Camp Coordination and Camp Management (CCCM) Cluster (IASC)'. As of 26 August 2024:
https://emergency.unhcr.org/coordination-and-communication/cluster-system/camp-coordination-and-camp-management-cccm-cluster-iasc

131 UNHCR. 2021. 'Camp Coordination and Camp Management (CCCM) Cluster (IASC)'. As of 26 August 2024:
https://emergency.unhcr.org/coordination-and-communication/cluster-system/camp-coordination-and-camp-management-cccm-cluster-iasc;
International Organization for Migration, Norwegian Refugee Council & UN Refugee Agency. 2015. *Camp Management Toolkit*. As of 26 August 2024:
https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf;
CCM Cluster and International Organization for Migration. 2021. *Minimum Standards for Camp Management – 2021 Edition*. As of 26 August 2024:
https://reliefweb.int/report/world/minimum-standards-camp-management-2021-edition

132 International Organization for Migration, Norwegian Refugee Council & UN Refugee Agency. 2015. *Camp Management Toolkit*. As of 26 August 2024:
https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf

Box 5.1 Camp monitoring systems definition

'Systems [used] to monitor and manage refugee camps, detention centres, and other temporary settlements including deploying sensors, cameras, and other monitoring devices to track the movement of people and goods, as well as using data analytics and machine learning to identify patterns and trends in camp activities. Camp monitoring systems are designed to improve the safety, security, and well-being of people living in temporary settlements, and to help humanitarian organisations and governments respond more effectively to crises and emergencies.'[133]

These technologies can be used, for example, to count individual camp structures with the use of satellite imaging and remote sensing.[134] Within camps, technology can also be used for information-sharing purposes with displaced populations, or to support camp design and develop key camp infrastructure (e.g. adapt the number of water points based on camp population data to ensure water access, or to reduce fire hazards and exposure to indoor pollution and smoke.[135]

5.1. Horizon 1: Current context for camp monitoring systems in the humanitarian sector

A variety of tools and technologies are currently used to monitor and support the day-to-day management of refugee camp infrastructure, including remote sensors and cameras, as well as using data analytics and machine learning to identify patterns and trends in camp activities.[136]

Drones, satellite imagery and Earth observation have also been proposed for camp monitoring purposes beyond security management, for example to forecast needs and aid in-camp infrastructure planning.[137] UNICEF Jordan currently operates a camp

133 ChatGPT output from a prompt by the research team, 'Define [technology area] with reference to the humanitarian sector', 15 December 2023. The study team subsequently reviewed and adapted all results in line with the project scope. See Annex A: Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak, Sergi Martorell, Iain McLaren, Christopher Tyson, Charlie Wilkening & Jacob Ohrvik-Stott. 2024. *Emerging technologies in the humanitarian sector: Methodology report*. Santa Monica, Calif.: RAND Corporation. RR-A3192-2. As of 17 October 2024: www.rand.org/t/RRA3192-2

134 Quinn, John A., Marguerite M. Nyhan, Celia Navarro, Davide Coluccia, Lars Bromley & Miguel Luengo-Oroz. 2018. 'Humanitarian applications of machine learning with remote-sensing data: review and case study in refugee settlement mapping.' *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376: 2128. As of 26 August 2024: https://doi.org/10.1098/rsta.2017.0363

135 International Organization for Migration, Norwegian Refugee Council & UN Refugee Agency. 2015. *Camp Management Toolkit*. As of 26 August 2024: https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf

136 While AI solutions are outside of the scope of this project, we explore how these solutions could integrate with the technology areas outlined in the deep dives.

137 Rothe, Delf, Christiane Fröhlich & Juan Miguel Rodriguez Lopez. 2021. 'Digital Humanitarianism and the Visual Politics of the Refugee Camp: (Un)Seeing Control. '*International Political Sociology* 15(1): 41–62. As of 26 August 2024: https://doi.org/10.1093/ips/olaa021;
Tomaszewski, Brian, Nijad Al-Najdawi, Jean-Laurent Martin, Sara Tedmori, Irene Omondi & Yusef Hamad. 2017. 'Using Geographic Information Systems (GIS) in Za'atari refugee camp, Jordan for refugee community information management and mobilization: The RefuGIS project.' *2017 IEEE Global Humanitarian Technology Conference (GHTC), San Jose*: 1–10. As of 26 August 2024: https://doi.org/10.1109/GHTC.2017.8239276

monitoring system in the nearby Za'atari refugee camp that draws inspiration from 'smart city' waste collection models utilising IoT smart sensors connected to remote computing platforms[138] in order to monitor and schedule waste collection.[139] Similarly, in 2018 Elrha funded a pilot program that used IoT to monitor water quality and distribution at the Dadaab refugee camp in Kenya.[140]

Technologies have also been used with regards to security concerns and surveillance of camps. For example, the EU-funded BASYLIS project piloted in 2013 the use of low-cost portable sensing platforms (consisting of distributed radio, video, magnetic, seismic, optical and acoustic sensors and body-worn panic buttons) in refugee camps, intended to be able to detect multiple security threats to humanitarian workers.[141] More recent examples include the Centaur system designed to manage the security of five reception camps for asylum seekers across Greece. Previously described by Greek government officials as an 'integrated digital system of electronic and physical security management placed inside and around the facilities using cameras and a motion analysis algorithm',[142] it combines behavioural analytics, drones, cameras and other sensors to monitor outdoor and indoor spaces within camps. In the Azraq refugee camp in Jordan, Geographic Information Systems (GIS) have been used to manage the occupancy of shelters and monitor the whereabouts of camp inhabitants, linking to registration databases.[143] Such security surveillance systems are among the most controversial applications of camp monitoring systems, as we outline in further detail in the 'Current risks and opportunities' section below.

Other camp monitoring systems have sought to protect the health and well-being of displaced populations. For example, rapid deployment fire alert systems were developed following a fire in a township in South Africa in 2014, with the objective to be deployed in informal settlements.[144] NGOs and UN agencies have also used technologies for health surveillance or communication purposes within formal

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138 Chaudhari, Chaudhari, Megha S., Bharti Patil & Vaishali Raut. 2019. 'IoT based Waste Collection Management System for Smart Cities: An Overview.' *2019 3rd International Conference on Computing Methodologies and Communication (ICCMC).* As of 26 August 2024: https://doi.org/10.1109/ICCMC.2019.8819776

139 International Organization for Migration, Norwegian Refugee Council & UN Refugee Agency. 2015. *Camp Management Toolkit*. As of 26 August 2024: https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf;
Techfugees. 2022. 'Here are 9 of the most innovative new projects using tech to help refugees and NGOs.' As of 26 August 2024: https://techfugees.com/all_news/here-are-9-of-the-most-innovative-new-projects-using-tech-to-help-refugees-and-ngos/

140 Elrha. 2018. 'Realtime Monitoring and Reporting of Water in Refugee Camps.' As of 26 August 2024: https://www.elrha.org/project/realtime-monitoring-reporting-water-refugee-camps/

141 European Commission. 2014. 'Final Report Summary - BASYLIS (moBile, Autonomous and affordable SYstem to increase safety in Large unpredIctable environmentS).' cordis.europa.eu. As of 26 August 2024: https://cordis.europa.eu/project/id/261786/reporting

142 Petridi, Corina. 2021. 'National Migration Strategy 2020-2021: Protecting the Aegean Islands.' As of 26 August 2024: https://www.documentcloud.org/documents/20689221-493570553-ethnike-strategike-metana-steuses-sa-mos-le-sbos-khi-os-le-ros-kos-1

143 Hoffmann, Sophia. 2017. 'Humanitarian security in Jordan's Azraq Camp.' *Security Dialogue* 48(2): 97–112. As of 26 August 2024: https://doi.org/10.1177/0967010616683311

144 Lumkani. 2024. 'About Us.' Lumkani.com. As of 26 August 2024: https://lumkani.com/about-us/

camps.[145] GIS have also been used to assess the risk of disease outbreak during natural disasters through the production of maps from data collected on the ground,[146] and solar energy has been used to enable displaced populations to get electricity and internet connectivity, within and beyond formal camps.[147]

Current risks and opportunities for humanitarian stakeholders

Some camp monitoring systems have been critiqued by humanitarian NGOs and stakeholders on several legal and ethical grounds. The NGO Homo Digitalis, for instance, has expressed concern over the role camp monitoring systems have played in violations of migrants' rights to privacy, due process and dignity (a core humanitarian principle).[148] The 2015 Camp Management Toolkit also emphasises the need for displaced individuals to be able to exercise informed consent relating to the collection of their data or personal information.[149] Algorithm Watch have criticised the Greek Centaur system for enabling mass containment and 'control' of refugees at the expense of refugee well-being and rights.[150] In April 2024, the Greek Data Protection Authority issued a €175,000 fine against the country's Ministry of Migration and Asylum after the privacy regulator's investigation found 'serious shortcomings' in its compliance with the European General Data Protection Regulation (GDPR).[151] The integration of camp monitoring systems in border control and policing functions, where these systems are repurposed for political objectives and integrated with wider state security functions, poses further risks to humanitarian principles of independence.[152]

145 Mesmar, Sandra, Reem Talhouk, Chaza Akik, Patrick Olivier, Imad H. Elhajj, Shady Elbassuoni, Sarah Armoush et al. 2016. 'The Impact of Digital Technology on Health of Populations Affected by Humanitarian Crises: Recent Innovations and Current Gaps.' *Journal of Public Health Policy* 37: 167–200. As of 26 August 2024: https://doi.org/10.1057/s41271-016-0040-1;
Bolon, Isabelle, Jade Mason, Paul O'Keeffe, Philippe Haeberli, Hassan Abdi Adan, Joel Makamba Karenzi, Ali Abdirahman Osman et al. 2020. 'One Health education in Kakuma refugee camp (Kenya): From a MOOC to projects on real world challenges.' *One Health* 10: 100158. As of 26 August 2024: https://doi.org/10.1016/j.onehlt.2020.100158

146 Mesmar, Sandra, Reem Talhouk, Chaza Akik, Patrick Olivier, Imad H. Elhajj, Shady Elbassuoni, Sarah Armoush et al. 2016. 'The Impact of Digital Technology on Health of Populations Affected by Humanitarian Crises: Recent Innovations and Current Gaps.' *Journal of Public Health Policy* 37: 167–200. As of 26 August 2024: https://doi.org/10.1057/s41271-016-0040-1

147 Mesmar, Sandra, Reem Talhouk, Chaza Akik, Patrick Olivier, Imad H. Elhajj, Shady Elbassuoni, Sarah Armoush et al. 2016. 'The Impact of Digital Technology on Health of Populations Affected by Humanitarian Crises: Recent Innovations and Current Gaps.' *Journal of Public Health Policy* 37: 167–200. As of 26 August 2024: https://doi.org/10.1057/s41271-016-0040-1;
Techfugees. 2022. 'Here are 9 of the most innovative new projects using tech to help refugees and NGOs.' As of 26 August 2024: https://techfugees.com/all_news/here-are-9-of-the-most-innovative-new-projects-using-tech-to-help-refugees-and-ngos/

148 Karaiskou, Alexandra. 2023. 'Drones & Artificial Intelligence at Greece's high-tech borders.' Homodigitalis.gr. As of 26 August 2024: https://homodigitalis.gr/en/posts/131019/

149 International Organization for Migration, Norwegian Refugee Council & UN Refugee Agency. 2015. *Camp Management Toolkit*. As of 26 August 2024: https://www.iom.int/sites/g/files/tmzbdl486/files/our_work/Shelter/documents/Camp-Management-Toolkit_2015_Portfolio_compressed.pdf

150 Petridi, Corina. 2021. 'Greek camps for asylum seekers to introduce partly automated surveillance systems.' Algorithmwatch.org. As of 26 August 2024: https://algorithmwatch.org/en/greek-camps-surveillance/

151 European Data Protection Board. 2024. 'Ministry of Migration and Asylum receives administrative fine and GDPR compliance order following an own-initiative investigation by the Greek SA.' As of 26 August 2024: https://www.edpb.europa.eu/news/national-news/2024/ministry-migration-and-asylum-receives-administrative-fine-and-gdpr_en

152 Parmar, Alpa. 2019. 'Borders as Mirrors: Racial Hierarchies and Policing Migration.' *Critical Criminology* 28: 175–92. As of 26 August 2024: https://doi.org/10.1007/s10612-020-09517-1

Camp monitoring systems do, however, offer opportunities for humanitarian stakeholders. The development of open-source satellite imagery databases, where data is made available to a range of non-humanitarian stakeholders, may enable the **mobilisation of non-traditional actors** (e.g. NGOs, independent researchers, private-sector actors or potentially malicious actors) in camp monitoring efforts. The use of such imagery could promote transparency and accountability around camp operations and management. For example, nighttime lighting data has been used to monitor efforts for the relocation of Rohingya refugees from Cox's Bazaar camp in Bangladesh, where they faced violence and security threats (e.g. kidnappings).[153]

5.2. Future trajectories, opportunities and challenges for camp monitoring systems in the humanitarian sector

5.2.1. Horizon 2: Medium-term transition phase

From pilot and current applications of camp monitoring systems, there are various potential development trajectories for these technologies in the medium term (Horizon 2). For each of the potential options, ethical considerations in line with the four humanitarian principles should also be considered. Potential medium-term camp monitoring technologies include:

- **Integrated shelter construction and monitoring tools**, including rapid deployment perimeter monitoring, lightweight portable modular shelters and computational tools for optimising shelter designs based on camp monitoring data. Improved design could increase refugees' and Internally Displaced Persons' (IDP) access to basic services (e.g. water, sanitation and hygiene [WASH]) and reduce risks of violence sometimes linked to overpopulation.[154]
- **Infrastructure monitoring for efficiency improvements and safety** that translate to a broader range of camp infrastructure areas and benefit displaced populations (e.g. electric grid, connectivity, food and water). For example, cooking stoves could use wireless sensors to support energy efficiency planning while reducing risks of fire or smoke.[155]
- **Health monitoring** approaches, currently primarily delivered by healthcare professionals, could be widened to improve the health and well-being of displaced

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153 Robinson, Eric, Maggie Habib, Sean Mann & Ed Burke. 2022. 'Tracking the Relocation of Rohingya Refugees in Bangladesh.' Tearline.mil. As of 26 August 2024: https://www.tearline.mil/public_page/nighttime-lights-refugees

154 Ji, Ce, Huagui Huang, Tao Wang & Qingxue Huang. 2023. 'Recent advances and future trends in processing methods and characterization technologies of aluminum foam composite structures: A review.' *Journal of Manufacturing Processes* 93: 116–52. As of 26 August 2024: https://doi.org/10.1016/j.jmapro.2023.03.015;
Almomani, Mohammed A., Nedal Al-Ababneh, Khairedin Abdalla, Nadim I. Shbeeb, John-Paris Pantouvakis & Nikos D. Lagaros. 2023. 'Selecting the Best 3D Concrete Printing Technology for Refugee Camp's Shelter Construction Using Analytical Hierarchy Process: The Case of Syrian Refugees in Jordan.' *Buildings* 13(7): 1813. As of 26 August 2024: https://doi.org/10.3390/buildings13071813;
Schofield, Mark. 2022. 'An Artificial Intelligence (AI) Approach to Controlling Disaster Scenarios.' In *Future Role of Sustainable Innovative Technologies in Crisis Management,* 28–46. IGI Global. As of 26 August 2024: https://www.irma-international.org/viewtitle/298928/?isxn=9781799898153;
Tomaszewski, Brian. 2023. 'Teaching Forced Displacement with Geospatial Technology in Refugee Camps: Lessons from Rwanda and Jordan.' In *Migration, Displacement, and Higher Education*, edited by Brittany Murray, Matthew Brill-Carlat & Maria Höhn, 163-171. Cham: Palgrave Macmillan. As of 26 August 2024: https://doi.org/10.1007/978-3-031-12350-4_13

155 Halford, Alison, Jonathan Nixon, Elena Gaura, Kriti Bhargava, Nandor Verba & James Brusey. 2022. 'Off the boil? The challenges of monitoring cooking behaviour in refugee settlements.' *Energy Research & Social Science* 90: 102603. As of 26 August 2024: https://doi.org/10.1016/j.erss.2022.102603

populations. Remote systems (e.g. telemedicine) could help refugees access health services that are not available on-site, support efforts to address gender-based violence, or monitor the spread of communicable diseases. Wastewater surveillance systems with these goals are currently being piloted in the Cox's Bazar camp in Bangladesh.[156]

Barriers to and enablers for development

Heightened data protection enforcement actions could both enable and limit the use of camp monitoring systems. As reflected in the decision issued by the Greek Data Protection Authority on the misuse of personal data, the EU GDPR could act as a near-term constraint on the deployment of data-intensive camp surveillance technologies. Conversely, the implementation of the EU AI Act could further widen the use of automated camp monitoring systems in a European context, albeit with the constraint to ensure the respect of fundamental rights. Though the use of these systems in the fields of migration, asylum or border control is defined as 'high-risk' under the AI Act, authorities and institutions in these sectors can continue to use these systems, though some constraints are likely to apply to ensure human oversight (e.g. risk assessment, maintenance of use logs, transparency, accuracy).[157] The application of the AI Act beyond Europe remains uncertain.[158] Emerging privacy regulations, such as the draft American Privacy Rights Act published in April 2024,[159] might have implications for the implementation of camp monitoring systems in other regions (e.g. where systems rely on international data transfers to data centres in the US to operate). Given the nascent nature of these regulations, their impact on the deployment and utilisation of automated camp monitoring systems remains highly speculative.

The integration of camp monitoring and health surveillance systems, including through automation, could be enabled by a broader long-term trend outside of the humanitarian sector towards increasing automation of healthcare.[160] In the area of camp sensors and infrastructure monitoring, researchers have

156 Hamilton, Masha. 2020. *Fighting Disease Through Wastewater Monitoring in World's Largest Refugee Settlement*. The Rockefeller Foundation. As of 26 August 2024: https://www.rockefellerfoundation.org/insights/grantee-impact-story/bringing-wastewater-monitoring-to-rohingya-in-bangladeshi-refugee-camps;
Evans, Conner, Andrew Parsons, Madiha Samadi, Jamie Seah & Caroline Wallace. 2016. *Leveraging Humanitarian Technology to Assist Refugees*. Perry World House, University of Pennsylvania. As of 26 August 2024: https://global.upenn.edu/sites/default/files/perry-world-house/HumanitarianTechnologyReport1.pdf

157 European Parliament. 2024. 'Artificial Intelligence Act: MEPs adopt landmark law.' European Parliament News. europarl.europa.eu. As of 26 August 2024: https://www.europarl.europa.eu/news/en/press-room/20240308IPR19015/artificial-intelligence-act-meps-adopt-landmark-law

158 #ProtectNotSurveil. 2024. 'Joint statement – A dangerous precedent: how the EU AI Act fails migrants and people on the move.' Accessnow.org. As of 26 August 2024: https://www.accessnow.org/press-release/joint-statement-ai-act-fails-migrants-and-people-on-the-move/

159 United States Senate Committee on Commerce, Science, and Transportation. 2024. *The American Privacy Rights Act of 2024: Section-by-Section Summary*. As of 26 August 2024: https://www.commerce.senate.gov/services/files/E7D2864C-64C3-49D3-BC1E-6AB41DE863F5

160 Fruehwirt, Wolfgang, & Paul Duckworth. 2021. 'Towards better healthcare: What could and should be automated?' *Technological Forecasting and Social Change* 172: 120967. As of 26 August 2024: https://doi.org/10.1016/j.techfore.2021.120967;
Seal, Andrew J., Mohamed Jelle, Carlos S. Grijalva-Eternod, Hani Mohamed, Raha Ali & Edward Fottrell. 2021. 'Use of verbal autopsy for establishing causes of child mortality in camps for internally displaced people in Mogadishu, Somalia: a population-based, prospective, cohort study.' *The Lancet. Global health* 9(9): e1286–e1295. As of 26 August 2024: https://doi.org/10.1016/S2214-109X(21)00254-0

proposed **ethical design principles**, including the inclusion of refugees in system design, approaches for ethical consent, and enabling access to data generated, that could promote their development and scaling.[161]

Risks and opportunities for humanitarian stakeholders

Regional divergences in data protection and AI regulations and regulatory approaches relevant to camp monitoring technologies could create disparities and foster risks (e.g. data imperialism[162]).[163] Alternatively, regions where regulatory regimes require fewer safeguards could increasingly become test-beds for novel monitoring technologies, with implications for local communities' fundamental rights. Stakeholders engaged in this project highlighted growing concerns about **disproportionate surveillance** of humanitarian workers in the context of camp monitoring technologies. However, the use of camp monitoring systems over the coming years is more likely to relate to refugee surveillance.[164] This could also become a driving factor in data protection regulation enforcement actions relating to camp monitoring. Against this backdrop, the main risk associated with the deployment of camp monitoring technologies relates to **wider misuse and sharing of personal data** of refugees and IDPs (e.g. voluntary data sharing between camp management authorities and other actors, such as national authorities, as well as data breaches, third party surveillance or hacking).[165]

Greater focus on camp infrastructure efficiency, enabled by more sophisticated and granular infrastructure monitoring systems, could help to **realise increased cost-saving opportunities.** Researchers have also speculated that making this monitoring data (e.g. in relation to energy use and cooking) available to displaced persons could **build community capabilities,** improve their living conditions, and enable them to constructively challenge or influence how camp infrastructure is designed.[166]

5.2.2. Horizon 3: Long-term future

Potential development trajectories for camp monitoring systems in the longer-term time horizon – drawing on nascent technology research areas and pilot applications that face barriers to maturing in the medium term – include:

161 Halford, Alison, Jonathan Nixon, Elena Gaura, Kriti Bhargava, Nandor Verba & James Brusey. 2022. 'Off the boil? The challenges of monitoring cooking behaviour in refugee settlements.' *Energy Research & Social Science* 90. As of 26 August 2024: https://doi.org/10.1016/j.erss.2022.102603

162 Mannion, Cara. 2020. 'Data imperialism: The GDPR's disastrous impact on Africa's E-commerce markets.' *Vanderbilt Journal of Transnational Law* 53(2): 685–711. As of 26 August 2024: https://scholarship.law.vanderbilt.edu/vjtl/vol53/iss2/6/

163 Mannion, Cara. 2020. 'Data imperialism: The GDPR's disastrous impact on Africa's E-commerce markets.' *Vanderbilt Journal of Transnational Law* 53(2): 685–711. As of 26 August 2024: https://scholarship.law.vanderbilt.edu/vjtl/vol53/iss2/6/

164 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging humanitarian technologies' workshop, 29 February 2024.

165 Kaurin, Dragan. 2019. *Data Protection and Digital Agency for Refugees*. World Refugee Council Research Paper No. 12. – May 2019. As of 26 August 2024: https://www.cigionline.org/static/documents/documents/WRC%20Research%20Paper%20no.12.pdf

166 Halford, Alison, Jonathan Nixon, Elena Gaura, Kriti Bhargava, Nandor Verba & James Brusey. 2022. 'Off the boil? The challenges of monitoring cooking behaviour in refugee settlements.' *Energy Research & Social Science* 90: 102603. As of 26 August 2024: https://doi.org/10.1016/j.erss.2022.102603

- **Emerging smart city technologies** (which could mature in the medium term in non-humanitarian contexts) that could translate to humanitarian camps as they grow in scale due to long-term increases in refugee numbers.[167] Exemplar applications that could translate to camp monitoring include distributed or cloud-based manufacturing technology infrastructure points (see Section 3 on smart manufacturing technologies), or 'City Information Modelling'. The latter combines data sources from GIS systems, technologies for urban and building management, and citizen-reported data to support better management of city infrastructure such as sewage systems or building ventilation. A discovery research pilot was conducted in 2023 in Al Baqa, Jordan, a city that was originally a Palestinian refugee camp.[168]
- Similarly, **digital twins** – digital mirrors of physical humanitarian camps – could enable humanitarian actors to make informed planning or training decisions. Digital twins are generated through a combined use of camp sensors and analytics and can integrate real-time data to produce accurate digital representations. Digital twins have been used in other sectors, such as manufacturing and aviation, and in small island nations facing acute climate risks, and could be adapted to camps.[169]
- **Risk-resilient monitoring technologies** (e.g. drones resistant to extreme weather conditions) could be used to monitor camp or displacement settlements due to population movements in the aftermath of climate crises or natural disasters.[170]

Barriers and enablers for development

Camps' **growing exposure to climate risk**, including desertification, flooding, monsoons and cyclones, are likely to drive a greater focus on risk-resilient monitoring technologies and camp monitoring for climate risk exposure.[171] This focus could lead to the further development of camp monitoring technologies, especially for monitoring and predicting changes in physical infrastructure

167 OCHA. 2024. 'Global Humanitarian Overview 2024.' Unocha.org. As of 26 August 2024: https://www.unocha.org/publications/report/world/global-humanitarian-overview-2024-enarfres

168 Trillo, Claudia, Rania Aburamadan, Victoria Andrea Cotella, Chiko Ncube Makore & Qassim Al-Betar. 2023. 'A Novel Application of City Information Modelling: Filling the Gap in the Data Through Better Citizens' Engagement. Insights from Al Baqa', Jordan.' In: Rubbo, Anna, Juan Du, Thomsen, Mette Ramsgaard & Martin Tamke (eds), *Design for Resilient Communities*. Cham: Springer. As of 26 August 2024: https://doi.org/10.1007/978-3-031-36640-6_28

169 Laplante, Phil. 2024. 'Deception and Intuition in Software Engineering.' *Computer* 57(1): 110–13. As of 26 August 2024: https://www.computer.org/csdl/magazine/co/2024/01/10380261/1TpyPmG3CEM;
Duff, Meg. 2024. 'How Wi-Fi sensing became usable tech: After a decade of obscurity, the technology is being used to track people's movements.' MIT Technology Review. As of 26 August 2024: https://www.technologyreview.com/2024/02/27/1088154/wifi-sensing-tracking-movements/;
Woodward, William. 2024. 'Backup nations: countries making digital twins to mitigate natural disasters.' As of 26 August 2024: https://www.nesta.org.uk/feature/future-signals-2024/countries-making-digital-twins/

170 Hasan, A., V. Krama, J. Hermansen & U. Schultz. 2022. 'Development of Resilient Drones for Harsh Arctic Environment: Challenges, Opportunities, and Enabling Technologies.' *International Conference on Unmanned Aircraft Systems (ICUAS):* 1227–36. As of 26 August 2024: https://doi.org/10.1109/ICUAS54217.2022.9836136

171 Jenerowicz-Sanikowska, Małgorzata, Cristina Domingo-Marimon, Lluís Pesquer Mayos, Edyta Woźniak, Marek Ruciński, Anna Foks-Ryznar, Michał Krupiński, Sebastian Aleksandrowicz, Magdalena Chułek, Karolina Sobczak-Szelc, Astrid Espegren, Jörg Haarpaintner & Daniel Starczewski. 2023. 'Developing early warning systems for land degradation around refugee camps: a preliminary approach.' Amsterdam: SPIE Remote Sensing. As of 26 August 2024:
https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12734/2683928/Developing-early-warning-systems-for-land-degradation-around-refugee-camps/10.1117/12.2683928.full#_=_

and geography, both within camps but also in the areas in which camps are set up in host countries that could also be subject to climate change. Mitigation plans against specific climate risk or potential relocation plans could be considered in this context. Increased availability of satellite imagery and development of new statistical techniques (e.g. to predict the likelihood of exposure of camps to natural disasters) is likely to further drive such development.[172]

For translation of smart city technologies to refugee camp contexts, wider barriers relate to a lack of research, funding, strategies and specialised models for their application in **rural contexts**.[173] Though most refugee camps are located in rural areas (75 per cent, according to World Bank Group estimates), camps are increasingly considered to be urban areas if not cities.[174] The technologies presented in the previous section could also support data collection activities conducted within camps to assess population' needs despite some of the risks previously identified.

Risks and opportunities for humanitarian stakeholders

Increasing use of digital twin technology could **potentially enhance worker safety and decrease camp crowding** where it enables workers to perform functions remotely outside of the camp environment. Academic research also speculates it could **enable better participatory planning** with camp inhabitants where they are used as a visual engagement tool during camp design.[175]

As with current camp surveillance technologies, however, many stakeholders have noted the **accelerated privacy and security risks** of increasingly interconnected and data-intensive smart city and digital twin applications, including potential abuse of surveillance and control infrastructure by malicious actors, unethical behavioural nudging of inhabitants, and repurposing of large datasets for purely commercial benefits.[176]

Based on the risks, opportunities, barriers and enablers discussed in the previous paragraphs, the study team identified some questions that could guide the future

172 Friedrich, Hannah K., & Jamon Van Den Hoek. 2020. 'Breaking ground: automated disturbance detection with landsat time series captures rapid refugee settlement establishment and growth in North Uganda.' *Computers, Environment and Urban Systems* 82: 101499. As of 26 August 2024: https://doi.org/10.1016/j.compenvurbsys.2020.101499; Gemitzi, Alexandra, & Nikos Koutsias. 2022. 'A Google Earth Engine code to estimate properties of vegetation phenology in fire affected areas–A case study in North Evia wildfire event on August 2021.' *Remote Sensing Applications: Society and Environment* 26: 100720. As of 26 August 2024: https://doi.org/10.1016/j.rsase.2022.100720

173 Alabdali, Salem Ahmed, Salvatore Flavio Pileggi & Dilek Cetindamar. 2023. 'Influential Factors, Enablers, and Barriers to Adopting Smart Technology in Rural Regions: A Literature Review.' *Sustainability* 15(10): 7908. As of 26 August 2024: https://doi.org/10.3390/su15107908

174 Coniglio, Nicola Daniele, Vitorocco Peragine & Davide Vurchio. 2024. 'The Geography of Displacement, Refugees' Camps and Social Conflicts.' World Bank Group. As of 26 August 2024: https://documents1.worldbank.org/curated/en/832121648043706062/pdf/The-Geography-of-Displacement-Refugees-Camps-and-Social-Conflicts.pdf; Crisp, Jeff. 2024. 'Refugee camps: some key issues and questions.' rli.blogs.sas.ac.uk. As of 26 August 2024: https://rli.blogs.sas.ac.uk/2024/06/06/refugee-camps-some-key-issues-and-questions/

175 Noor, Marji, Chen Lijun, Kumar Akshatha Ravi, Isik Gülbahar Emir & Kohout Michal. 2024. 'Transitional Typologies of Refugee Camps.' In *Refugees and Migrants - Current Conditions and Future Trends*, edited by Samson Maekele Tsegay. Rijeka: IntechOpen. As of 26 August 2024: https://doi.org/10.5772/intechopen.1004922

176 Fabrègue, Brian F. G., & A. Bogoni. 2023. 'Privacy and Security Concerns in the Smart City.' *Smart Cities* 6(1): 586–613. As of 26 August 2024: https://doi.org/10.3390/smartcities6010027

adoption of camp monitoring systems by humanitarians in Box 5.2.

Box 5.2 Considerations for responsible adoption of future camp monitoring systems

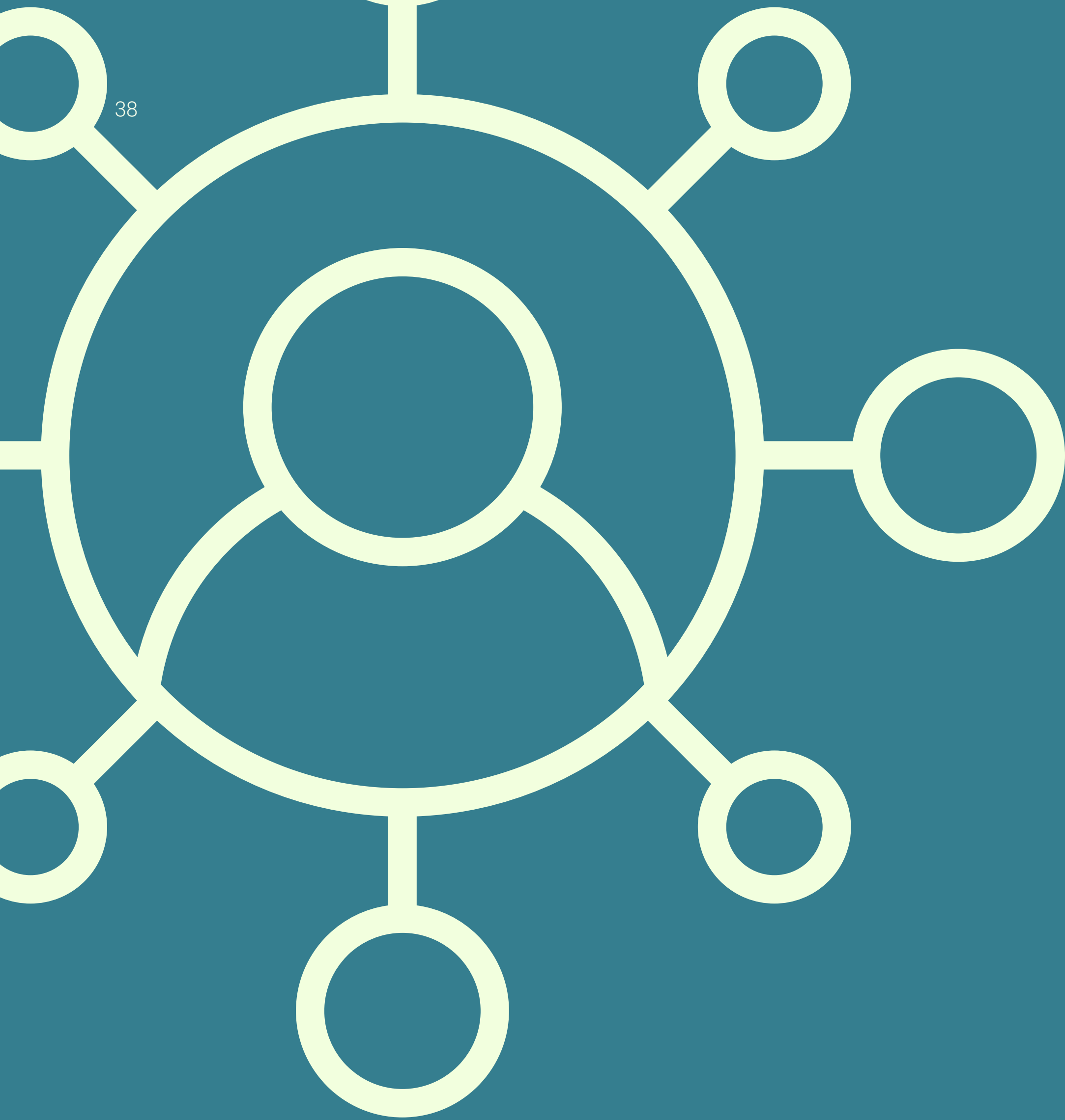
In response to the potential future development trajectories, risks and opportunities associated with camp monitoring systems, humanitarian stakeholders could consider addressing the following questions:

- Which technological, regulatory or advocacy interventions can best ensure current and future camp monitoring systems avoid excessive surveillance of camp inhabitants and humanitarian workers?
- How could camp monitoring tools such as digital twins or camp infrastructure monitoring be used to better empower camp inhabitants?
- How could camp monitoring systems be better resilient to, and used to anticipate, increasing camp exposure to climate risk?

Figure 5.1 Future development trajectories, barriers, enablers, risks and opportunities associated with camp monitoring systems in the humanitarian sector

	Horizon 1	Horizon 2	Horizon 3
Development trajectories	• Remote sensors • Camp fire alert systems • Security surveillance systems	• Shelter development and monitoring • Infrastructure efficiency monitoring • Camp health monitoring	• Emerging smart city technologies • City Information Management systems • Real-time digital twins • Extreme weather-resilient monitoring
Barriers to development		• European data protection enforcement • Emerging global privacy regulations	• Underdeveloped rural smart city models
Enablers of development		• Availability of satellite imagery • Ethical design principle development • The EU AI Act	• Camp climate risk exposure • Extreme weather
Risks	• Refugee privacy violations • Threatened well-being and dignity • Untransparent government data access • Risks to humanitarian principles	• Data imperialism • Surveillance of humanitarian workers	• Deepening privacy risks
Opportunities	• Mobilisation of non-traditional actors	• Camp cost savings • Community capability-building	• Enhancement of worker safety • Decreased camp crowding • Supporting participatory camp planning

Source: Study team analysis.



Chapter 6. **Coordination platforms**

Online platforms are defined by the Organisation for Economic Co-operation and Development (OECD) as 'digital services that facilitate interactions between two or more distinct but interdependent sets of users (individuals or organisations) who interact with the service via the internet'.[177] Many such platforms play a prominent role in promoting collaboration across and within different aspects of the humanitarian sector.

In this context, humanitarian coordination platforms refer to online platforms that enable humanitarian coordination, defined by the University of Harvard Advanced Training Program on Humanitarian Action as 'systematic utilization of [instruments] to deliver humanitarian assistance in a cohesive and effective manner'.[178] These coordination platforms enable two or more humanitarian actors (organisations or individuals) to

177 OECD. 2019. 'An Introduction to Online Platforms and Their Role in the Digital Transformation.' As of 26 August 2024: https://www.oecd.org/en/publications/an-introduction-to-online-platforms-and-their-role-in-the-digital-transformation_53e5f593-en.html

178 Advanced Training Program on Humanitarian Action. 2008. 'Humanitarian Coordination: An Overview.' As of 26 August 2024: https://www.hpcrresearch.org/sites/default/files/publications/ATHA%20Thematic%20Brief%20Humanitarian%20Coordination.pdf

exchange resources (e.g. information, money, goods or infrastructure) in order to enable or collaboratively enhance the quality of humanitarian functions and promote transparency and mutual accountability. **Aggregation platforms** can be seen as one form of coordination platforms that enable multiple humanitarian actors to pool and share resources,[179] or give humanitarians access to multiple different service providers through a single platform.

6.1. Horizon 1: Current context for coordination platforms in the humanitarian sector

Exemplar use cases of **organisational collaboration platforms** include those for refugee camp operations coordination tracking locations of humanitarian responders, contact list management,[180] multi-agency and multi-modal transport of humanitarian goods, and dynamic field operations and disaster response logistics coordination.[181] Crisis **service 'marketplaces'** such as NeedsList also enable government agencies, foundations and coordinating bodies to efficiently match needs (supplies, services, information) with relevant providers during crisis situations.[182] Various crowd-sourcing or **'collective crisis intelligence'** applications[183] also enable humanitarians to share data (often in real-time) to collaboratively generate intelligence on crisis situations – for example, to map crisis-affected terrains following the 2010 Haiti earthquake[184] or for real-time epidemiology.[185] OCHA's Humanitarian Data Exchange (HDX) platform enables users to find, share and use various humanitarian datasets to generate operationally-relevant insights.[186]

Aggregation platforms enable resource sharing that is mutually beneficial for participating stakeholders. Platforms that give humanitarian actors access to multiple service providers can enhance the quality of humanitarian functions, for example by providing more timely or cost-efficient access. Conversely, these systems can lead to risks associated with data protection and data privacy, such as the vulnerability of systems to malicious interference or attacks, or concerns related to the absence of informed consent

179 Sussitz, Hermann. 2010. 'Pool Sharing in Humanitarian Logistics.' Vienna University of Economics and Business, Institute for Transport and Logistics Management. As of 26 August 2024: https://research.wu.ac.at/ws/portalfiles/portal/19845542/Sussitz.pdf

180 Akhmatova, Dzhennet-Mari, & Malika-Sofi Akhmatova. 2020. 'Promoting digital humanitarian action in protecting human rights: hope or hype.' *Journal of International Humanitarian Action* 5(1): 6. As of 26 August 2024: https://doi.org/10.1186/s41018-020-00076-2

181 Flare. 2024. 'Flare Story.' Flare.co.ke. As of 26 August 2024: https://flare.co.ke/

182 NeedsList. 2024. 'Community-centred response, recovery and resilience platform.' As of 26 August 2024: https://needslist.co/

183 Nesta. 2021. 'Collective crisis intelligence for frontline humanitarian response.' As of 26 August 2024: https://www.nesta.org.uk/report/collective-crisis-intelligence-frontline-humanitarian-response/

184 Hunt, Amelia, & Doug Specht. 2019. 'Crowdsourced mapping in crisis zones: collaboration, organisation and impact.' *Journal of International Humanitarian Action* 4(1): 1–11. As of 26 August 2024: https://jhumanitarianaction.springeropen.com/articles/10.1186/s41018-018-0048-1

185 Nesta. 2021. 'Collective crisis intelligence for frontline humanitarian response.' As of 26 August 2024: https://www.nesta.org.uk/report/collective-crisis-intelligence-frontline-humanitarian-response/

186 The Humanitarian Data Exchange. 2024. 'Homepage.' As of 26 August 2024: https://data.humdata.org/

from affected populations.[187] Exemplar use cases of aggregation platforms include platforms for accessing local language translation services,[188] volunteer security services for preventing gender-based violence[189] and connecting refugees with remote work opportunities.[190]

Current risks and opportunities for humanitarian stakeholders

One overarching benefit of coordination and aggregation platforms is the **mobilisation of non-traditional actors** in humanitarian responses, where these platforms are used to source and connect volunteers for crisis response (both in regions local to affected crises and remote 'digital volunteers'). Researchers have suggested that this in turn has the potential to counteract 'neocolonial disaster capitalism' and **democratise aid approaches** where these platforms shift ownership of crisis response away from international agencies and multinational companies and towards local responders and communities.[191] The International Aid Transparency Initiative (IATI), launched in 2018, demonstrates how humanitarian aid can be democratised through the voluntary publication of data from a wide range of humanitarian stakeholders (governments, NGOs, donors or individuals) on their respective activities, contributing to wider accountability and transparency within the sector.[192]

However, as with online social media platforms in general, these more decentralised, self-organised and unregulated communities are open to threats of **social misinformation** and rumours and vigilantism.[193] Platforms for collaborative data and insights aggregation are also exposed to various data quality, privacy and security risks, including **data inaccuracy, malicious and unauthorised access** and **data poisoning** (deliberate contamination of datasets to compromise the performance of a system).[194]

187 Office for the Coordination of Humanitarian Affairs. 2021. 'From digital promise to frontline practice: new and emerging technologies in humanitarian action.' As of 26 August 2024: https://reliefweb.int/report/world/digital-promise-frontline-practice-new-and-emerging-technologies-humanitarian-action

188 Translators without Borders. 2024. 'Homepage.' As of 26 August 2024: https://twbplatform.org/

189 CrowdGuard. 2024. 'Homepage.' As of 26 August 2024: https://crowdguard.org/

190 Easton-Calabria, Evan, & Andreas Hackl. 2023. 'Refugees in the digital economy: The future of work among the forcibly displaced.' *Journal of Humanitarian Affairs* 4(3): 1–12. As of 26 August 2024: https://www.manchesterhive.com/view/journals/jha/4/3/article-p1.xml

191 Büscher, Monika, Michael Liegl & Vanessa Thomas. 2014. 'Collective intelligence in crises.' In *Social collective intelligence: Combining the powers of humans and machines to build a smarter society*, 243–65. Cham: Springer International Publishing. As of 26 August 2024: https://www.researchgate.net/publication/261708761_Collective_Intelligence_in_Crises

192 International Aid Transparency Initiative (IATI). 2024. 'About IATI'. As of 26 August 2024: https://iatistandard.org/en/about/;
UNHCR. n.d. 'IATI - International Aid Transparency Initiative'. As of 26 August 2024: https://reporting.unhcr.org/iati-international-aid-transparency-initiative

193 Büscher, Monika, Michael Liegl & Vanessa Thomas. 2014. 'Collective intelligence in crises.' In *Social collective intelligence: Combining the powers of humans and machines to build a smarter society*, 243–65. Cham: Springer International Publishing. As of 26 August 2024: https://www.researchgate.net/publication/261708761_Collective_Intelligence_in_Crises

194 Zomignani Barboza, Júlia, Lina Jasmontaitė-Zaniewicz & Laurence Diver. 2019. 'Aid and AI: The Challenge of Reconciling Humanitarian Principles and Data Protection.' In *14th IFIP International Summer School on Privacy and Identity Management (Privacy and Identity), Aug 2019, Windisch, Switzerland*, 161–76. As of 26 August 2024: https://inria.hal.science/hal-03378953/file/496005_1_En_11_Chapter.pdf

6.2. Future trajectories, opportunities and challenges for coordination platforms in the humanitarian sector

6.2.1. Horizon 2: Medium-term transition phase

Potential development trajectories for coordination platforms in the medium-term time horizon – drawing on pilot applications that could mature, and current applications in other sectors that could translate – include:

- Maturing **conversational AI agents** (software agents that can engage in natural conversations with users, grounded in large language models[195]) that are likely to be increasingly integrated with coordination and aggregation platforms, potentially enhancing usability and addressing translational language barriers.[196]
- Embedded **data modelling, visualisation and simulation functions** for aggregation and collective intelligence platforms utilising data visualisation and analysis, enabled by increasing access to cheaper computing power[197] – for example, modelling water demand and availability dynamics.[198]
- Integration and **merging of existing platforms** may be increasingly common, reflecting both a wider general trend in platform markets[199] and a desire to increase the speed and scale of crisis response in the humanitarian sector.[200]

Barriers and enablers for development

Open technical standards and protocols for information sharing, including within LMICs, were identified by some project research participants as a key medium-term enabler of collective crisis-intelligence and data-sharing platforms.[201] These can ease the process of data sharing and aggregation between different organisations. As an example, a report into the effectiveness of collaborative environmental management in the Cox's Bazaar refugee camp in Bangladesh recommends that technical working groups strengthen data quality management and standardisation for future collaborative responses. The IATI is also a promising example of efforts towards

195 McTear, Michael. 2022. *Conversational AI: Dialogue systems, conversational agents, and chatbots*. Springer Nature. As of 26 August 2024: https://books.google.co.uk/books?hl=en&lr=&id=C4lyEAAAQBAJ&oi=fnd&pg=PR1&dq=conversational+AI+agents+definition&ots=ajRONhKDwy&sig=7-zb-l02e3vNmjULWZUqqdapkfc#v=onepage&q=conversational%20AI%20agents%20definition&f=false

196 Margffoy, Mayra. 2023. 'AI for humanitarians: A conversation on the hype, the hope, the future.' The New Humanitarian. As of 26 August 2024: https://www.thenewhumanitarian.org/feature/2023/09/05/ai-humanitarians-conversation-hype-hope-future

197 Boakye, Bridget, Melanie Garson, Benedict Macon-Cooney, Tom Westgarth & Kevin Zandermann. 2023. 'State of Compute Access: How to Bridge the New Digital Divide.' Tony Blair Institute for Global Change. As of 26 August 2024: https://www.institute.global/insights/tech-and-digitalisation/state-of-compute-access-how-to-bridge-the-new-digital-divide

198 Michalak, Anna M., Jun Xia, Damir Brdjanovic, Aimée-Noël Mbiyozo, David Sedlak, Thalappil Pradeep, Upmanu Lall, Nitya Rao & Joyeeta Gupta. 2023. 'The frontiers of water and sanitation.' *Nature Water* 1(1): 10–18. As of 26 August 2024: https://www.nature.com/articles/s44221-022-00020-1

199 Kanter, Jonathan S. 2023. 'Digital markets and "trends towards concentration."' *Journal of Antitrust Enforcement* 11(2): 143–48. As of 26 August 2024: https://academic.oup.com/antitrust/article/11/2/143/7232385

200 Armillaria. 2024. 'Armillaria Acquires NeedsList in a Strategic Move to Enhance Crisis Resilience.' As of 26 August 2024: https://armillaria.substack.com/p/armillaria-acquires-needslist-in

201 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging humanitarian technologies' workshop, 5 March 2024.

increased transparency and the development of sector-wide standards.[202]

Increasing convergence between aid, humanitarian and development activities (as discussed in Section 2.1) may drive increased scaling of humanitarian crisis and coordination platforms, as mergers and acquisitions integrate different platforms – NeedsList, for example, was acquired by Armillaria in 2024, with a desire to 'significantly increase speed and scale of change' cited as a motivating factor.[203]

For the integration of conversational AI agents, currently unresolved challenges relating to the measurement and mitigation of sociotechnical risks may represent barriers to their medium-term development, particularly where they undermine public and organisational trust. These challenges relate to the perpetuation of harmful social stereotypes (which may be particularly problematic in the context of engaging with crises-affected communities and refugees),[204] the provision of inaccurate information, and wider user abuse.[205]

Risks and opportunities for humanitarian stakeholders

Despite promise in terms of the adoption of platforms to coordinate humanitarian work, there are concerns about the quality and security of data stored and shared via platforms. Broadening of access to data aggregation platforms to actors beyond the humanitarian sector may exacerbate risks of **unintended secondary data use** (e.g. utilising open-source humanitarian data to develop commercial products).[206] This undermines humanitarian principles such as the independence of humanitarian work from commercial objectives. Risks of cyber attacks or misuse of data by malicious actors should also be considered in this context.

The integration of multi-lingual conversational AI agents could help to **address translational language barriers**, where challenges of developing platforms that can be used across different regions, languages and institutions can hinder adoption. This challenge relates both to the textual languages utilised on user interfaces and more broadly to consistency of approaches and standards for data where different platform users are sharing and aggregating data.[207]

Conversational AI agents are not without risks, however: participants engaged in

202 International Aid Transparency Initiative (IATI). 2024. 'About IATI'. AS of 26 August 2024: https://iatistandard.org/en/about/;
UNHCR. n.d. 'IATI - International Aid Transparency Initiative'. As of 26 August 2024: https://reporting.unhcr.org/iati-international-aid-transparency-initiative

203 Armillaria. 2024. 'Armillaria Acquires NeedsList in a Strategic Move to Enhance Crisis Resilience.' As of 26 August 2024: https://armillaria.substack.com/p/armillaria-acquires-needslist-in

204 Shieh, Evan, Faye-Marie Vassel, Cassidy Sugimoto & Thema Monroe-White. 2024. 'Laissez-Faire Harms: Algorithmic Biases in Generative Language Models.' *arXiv preprint*. As of 26 August 2024: https://arxiv.org/abs/2404.07475

205 Weidinger, Laura, Jonathan Uesato, Maribeth Rauh, Conor Griffin, Po-Sen Huang, John Mellor, Amelia Glaese et al. 2022. 'Taxonomy of risks posed by language models.' In *Proceedings of the 2022 ACM Conference on Fairness, Accountability, and Transparency*, 214–29. As of 26 August 2024: https://doi.org/10.1145/3531146.3533088

206 Sandvik, Kristin Bergtora. 2023. *Humanitarian Extractivism: The Digital Transformation of Aid*. Manchester: Manchester University Press. As of 26 August 2024: https://manchesteruniversitypress.co.uk/9781526173355/

207 Frost, Laura, Saira Khan & Patrick Vinck. 2022. 'Technologies in Humanitarian Settings: Digital Upskilling of Humanitarian Actors.' United States Agency for International Development. As of 26 August 2024: https://hhi.harvard.edu/sites/hwpi.harvard.edu/files/humanitarianinitiative/files/digitalcasestudy_5_digitalliteracy_final.pdf

this research[208] raised concerns about the quality and accuracy of smart translation and conversational agent tools, as well as the potential for these tools to replace local translators and user-interface designers, raising issues of **regional equity and automation-driven unemployment**.

6.2.2. Horizon 3: Long-term future

Potential development trajectories for coordination platforms in the longer-term time horizon – drawing on nascent technology research areas and pilot applications that face barriers to maturing in the medium term – include:

- Integration with wider **'Internet of Emergency Services'** (IoES) systems, where these platforms, for example, are user interfaces for interoperable advanced communications systems, autonomous systems for search and rescue, and humanitarian supply-chain management.[209]
- Translation of **Collective Crisis Intelligence (CCI) platforms to LMICs**, where historical barriers facing underlying AI systems – relating to a lack of technological infrastructure and challenges in transferring algorithms to different contexts without loss of accuracy[210] – start to erode.

Barriers to and enablers for development

Nascent **'data provenance standards'** that define metadata on the origin, lineage and rights associated with datasets[211] could be more widely developed and adopted in the long term with a view to enhancing transparency and data quality for data aggregation and collective intelligence platforms.

Enduring systemic challenges relating to the inclusion of **local communities and stakeholders in the design of humanitarian platforms**[212] may be mitigated by increasingly prevalent **low-code and no-code software development** tools that enable users to develop platform applications without writing the underlying code. These tools could also help to address historical barriers relating to lack of technological capabilities and infrastructure for platform and AI development in LMIC contexts.

Risks and opportunities for humanitarian stakeholders

As mentioned in the previous section, smart translation tools and reduced technical barriers through low/no-code platform development have the potential to deepen collaboration between international and local humanitarian actors to **advance the humanitarian localisation agenda**. This could potentially

208 Paillé, Pauline, James Besse, Hampton Toole, Chryssa Politi, Shruti Viswanathan, Eunice Namirembe, Jyoti Nayak, Sergi Martorell, Iain McLaren, Christopher Tyson, Charlie Wilkening & Jacob Ohrvik-Stott. 2024. *Emerging technologies in the humanitarian sector: Methodology report*. Santa Monica, Calif.: RAND Corporation. RR-A3192-2. As of 17 October 2024: www.rand.org/t/RRA3192-2

209 Damaševičius, Robertas, Nebojsa Bacanin & Sanjay Misra. 2023. 'From sensors to safety: Internet of Emergency Services (IoES) for emergency response and disaster management.' *Journal of Sensor and Actuator Networks* 12(3): 41. As of 26 August 2024: https://www.mdpi.com/2224-2708/12/3/41

210 Nesta. 2021. 'Collective crisis intelligence for frontline humanitarian response.' As of 26 August 2024: https://www.nesta.org.uk/report/collective-crisis-intelligence-frontline-humanitarian-response/

211 LaCasse, Alex. 2024. 'Proposed data provenance standards aim to enhance trustworthiness of AI training data.' IAPP.org. As of 26 August 2024: https://iapp.org/news/a/leading-corporations-proposed-data-provenance-standards-aims-to-enhance-quality-of-ai-training-data/

212 Bruder, Maximilian, & Thomas Baar. 2024. 'Innovation in humanitarian assistance—a systematic literature review.' *Journal of International Humanitarian Action* 9(1): 2. As of 26 August 2024: https://jhumanitarianaction.springeropen.com/articles/10.1186/s41018-023-00144-3

empower local aid and humanitarian groups, alongside affected communities themselves, to build and incorporate coordination platforms to support a range of their humanitarian activities.

Data provenance standards can mitigate data quality risks and **promote collective platform governance and accountability models**. Doing so has the potential to further contribute to **localisation**, along with improving the responsiveness and accountability of humanitarian actors and improving public trust in the use of platforms.

The increasing technical complexity and intensified data gathering IoES platforms necessitate does, however, carry risks (many of which apply to generic IoT applications beyond the humanitarian sector): challenges in establishing effective cross-organisational and transregional **governance of data**; over-complexity leading to maintenance challenges; and general surveillance, security and privacy concerns.[213]

Based on the risks, opportunities, barriers and enablers discussed in the previous paragraphs, the study team identified some questions that could guide the future development of coordination platforms by humanitarians in Box 6.1.

Box 6.1 Considerations for responsible adoption of coordination platforms

In response to the potential future development trajectories, risks and opportunities associated with coordination platforms, humanitarian stakeholders could consider addressing the following questions:

- How can camp coordination platforms be designed with local communities and humanitarian stakeholders?
- How could coordination platforms contribute to enhanced transparency and accountability within the humanitarian sector?
- How could coordination platforms be used across a variety of regions and humanitarian contexts?

213 Damaševičius, Robertas, Nebojsa Bacanin & Sanjay Misra. 2023. 'From sensors to safety: Internet of Emergency Services (IoES) for emergency response and disaster management.' *Journal of Sensor and Actuator Networks* 12(3): 41. As of 26 August 2024: https://www.mdpi.com/2224-2708/12/3/41

Figure 6.1 Future development trajectories, barriers, enablers, risks and opportunities associated with coordination platforms in the humanitarian sector

	Horizon 1	Horizon 2	Horizon 3
Development trajectories	• Organisational collaboration platforms • Crisis service marketplaces • Collective crisis intelligence • Resource pooling platforms	• Conversational agent integration • Embedded data modelling • Platform mergers and scaling	• Internet of Emergency Services integrations • LMIC-led Collective Crisis Intelligence
Barriers to development		• Sociotechnical risks of conversational AI	
Enablers of development		• Open technical standards • Convergence between humanitarian and development activity	• Data provenance standards • Low-code/no-code software
Risks	• Data quality • Privacy and security • Misinformation	• Secondary data use • Social impacts of service automation • AI inaccuracy and bias	• Internet of Emergency Services governance
Opportunities	• Mobilisation of non-traditional actors • Democratisation of crisis response	• Addressing translational language barriers	• Localisation of platforms • Mitigated data quality risks • Collective platform governance

Source: Study team analysis.

Chapter 7. **Privacy-enhancing technologies**

While the ability of humanitarian organisations to collect, analyse and utilise data to improve operations has grown significantly, concerns around the safe use of this data and the privacy of the individuals whose data is collected have grown proportionally. Humanitarian actors continue to use manual tools (i.e. pen and paper) to collect information, but also increasingly leverage digital tools to collect and store information about crises-affected communities (e.g. mobile phones, tablets).[214] The spread of these tools requires humanitarians to become not only digitally literate but also familiar with data management practices, and to exercise 'data responsibility' – the safe, ethical and effective management of personal and non-personal data for operational

214 Okular Analytics & Save the Children. 2018. *Basic Needs Assessment Guidance & Toolbox Part 2: How-to Guide & Tools*. As of 26 August 2024: https://www.calpnetwork.org/wp-content/uploads/2020/03/basic-needs-assessment-how-to-pt-2-1.pdf

response, in accordance with established frameworks for data protection.[215]

In this context, privacy-enhancing technologies (PETs) – encompassing hardware and software solutions that protect data privacy while allowing responsible and secure use of the data[216] – offer a potential solution to these concerns. PETs include various cryptographic and statistical techniques aimed at obscuring sensitive data, decentralised data processing, and hardware solutions. PETs can be broadly categorised into four main functional areas[217]:

- **Data obfuscation methods** that remove or obscure identifying details from data. Example technologies include synthetic data sets (which are generated by algorithms rather than real-world data),[218] pseudonymisation tools (which enable users to modify or remove information that can lead to direct identification),[219] and zero-knowledge proofs (tools that demonstrate if data is valid without exposing its content).[220]
- **Encrypted data processing** that enables data to be computed and used (e.g. sending digital communication messages) without revealing its properties. Example technologies in this area include homomorphic encryption (which allows computation of encrypted data without decrypting it)[221] and trusted execution environments that are separated and secured from the wider operating system.
- **Federated and distributed analytics** that enable the execution of analytical tasks upon data that is not accessible to the systems and individuals executing the tasks. An emergent example of this is privacy-preserving machine learning where AI models are trained on data that stays local to the data subject's device, meaning

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215 Inter-Agency Standing Committee. 2021. 'Data Responsibility in Humanitarian Action, Operational Guidance. Results Group 1 on Operational Response.' As of 26 August 2024: https://interagencystandingcommittee.org/sites/default/files/migrated/2021-02/IASC%20Operational%20Guidance%20on%20Data%20Responsibility%20in%20Humanitarian%20Action-%20February%202021.pdf

216 United Nations. 2023. 'The United Nations guide on PETs for official statistics.' Unstats.un.org. As of 26 August 2024: https://unstats.un.org/bigdata/task-teams/privacy/guide/2023_UN%20PET%20Guide.pdf

217 OECD. 2023. 'Emerging privacy enhancing technologies: current regulatory and policy approaches.' *OECD Digital Economy Papers* 351. As of 26 August 2024: https://www.intgovforum.org/sites/default/files/webform/igf_2023_open_forums_town_hall_s/243938/bf121be4-en.pdf

218 Synthetic datasets are datasets that do not contain the exact datapoints of the original dataset, but retain its original statistical properties, or the 'shape' (distribution) of the original dataset. See: Royal Society. 2022. 'What is synthetic data, and how can it advance research and development?' As of 26 August 2024: https://royalsociety.org/blog/2022/05/synthetic-data/; Science Direct. 2024. 'Synthetic datasets.' As of 26 August 2024: https://www.sciencedirect.com/topics/computer-science/synthetic-datasets

219 Pseudonymisation tools refer to 'techniques that replace, remove or transform information that identifies individuals, and keep that information separate'. See: Information Commissioner's Office. 2022. 'Chapter 3: Pseudonymisation.' As of 26 August 2024: https://ico.org.uk/media/about-the-ico/consultations/4019579/chapter-3-anonymisation-guidance.pdf

220 Zero-knowledge proofs are 'A cryptographic scheme where a prover is able to convince a verifier that a statement is true, without providing any more information than that single bit (that is, that the statement is true rather than false)'. That statement could, for example, refer to characteristics of someone's identity, such as age. See: National Institute of Standards and Technology. n.d. 'Glossary: Zero-Knowledge Proof.' As of 26 August 2024: https://csrc.nist.gov/glossary/term/zero_knowledge_proof

221 Science Direct. 2016. 'Homomorphic Encryption.' Sciencedirect.com. As of 26 August 2024: https://www.sciencedirect.com/topics/computer-science/homomorphic-encryption

the model developers cannot store data on their own servers and systems.

- **Data accountability tools** that give users control over how data can be collected and used. Examples include personal data stores and management systems that allow individuals to control their own data.

7.1. Horizon 1: Current context for privacy-enhancing technologies in the humanitarian sector

Within the humanitarian sector, the cost, organisational changes and technical complexity of PETs mean applications are generally limited and nascent.[222] The International Committee of the Red Cross (ICRC) RedSafe platform is a **secure digital messaging platform** through which messages can be sent and humanitarian services can be sought (such as reliable information about where the user can access legal aid). Features include a secure **data vault** for refugees' important documents (such as passports, birth certificates or property deeds) and encryption to ensure security at different architectural levels of the platform.[223] OPAL's Flowminder system, piloted in 2020 in Haiti with a view to expanding to further LMICs in the future, is a system for **pseudonymising mobile data** and enabling secure access to it for the purposes of analysing migration patterns.[224] The PeaceTechLab has created HighSide, a communication system that uses **cryptographic file sharing** methods to enhance security.[225] HighSide has been developed with first responders in mind, to enable them to share files and communicate with reduced risk of cyber attacks, and this and systems like it offer promise for applications in the humanitarian sector.

PETs are also increasingly a focus for the UN, which in 2022 launched a PET Lab and later published guidance on PETs for official statistics[226] and a PET case study repository.[227] While none of the present examples within this repository relates to humanitarian practice, this focus could carry through to UN humanitarian agencies in the future. In addition, the UNHCR organised a 'hackathon' in late 2022 that gathered researchers and data scientists with the objective of identifying factors of vulnerability through data analysis of surveys. The event focused on analysing data collected from refugees in Kenya during the Covid-19 pandemic.[228]

222 The Royal Society. 2023. 'From privacy to partnership: the role of privacy enhancing technologies in data governance and collaborative analysis.' As of 26 August 2024: https://royalsociety.org/-/media/policy/projects/privacy-enhancing-technologies/From-Privacy-to-Partnership.pdf; Reimsbach-Kounatze, Christian, & Taylor Reynolds. 2023. 'Emerging Privacy Enhancing Technologies: Current Regulatory and Policy Approaches.' *OECD Digital Economy Paper* 351. As of 26 August 2024: https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/03/emerging-privacy-enhancing-technologies_a6bdf3cb/bf121be4-en.pdf

223 Reliefweb. 2022. 'ICRC Inspired: Inside RedSafe, the ICRC's Digital Future.' As of 26 August 2024: https://reliefweb.int/report/world/icrc-inspired-inside-redsafe-icrc-s-digital-future

224 Flowminder.org. n.d. 'New approach to opening data access.' Flowminder.org. As of 26 August 2024: https://www.flowminder.org/what-we-do/mobile-data-partnerships/new-approach-to-opening-data-access

225 PeaceTechLab. n.d. 'HighSide.' Peacetechlab.org. As of 26 August 2024: https://www.peacetechlab.org/accelerator-highside

226 United Nations Big Data. 2023. 'The United Nations Guide on Privacy-Enhancing Technologies for Official Statistics.' As of 26 August 2024: https://unstats.un.org/bigdata/task-teams/privacy/guide/index.cshtml

227 United Nations Big Data. 2024. 'UN PETs Case Study Repository.' As of 26 August 2024: https://unstats.un.org/bigdata/task-teams/privacy/case-studies/

228 Sanson, Federico. 2023. 'How A Hackathon Supported Personal Data Protection.' As of 26 August 2024: https://www.unhcr.org/blogs/how-a-hackathon-supported-personal-data-protection/

Current risks and opportunities for humanitarian stakeholders

Research participants throughout project phases have consistently emphasised the potential importance of PETs for **protecting the privacy of humanitarian workers and crises-affected communities.**[229]

While many PETs seek to enhance the privacy of individuals, solutions that enable analytics on groups of datasets (for example federated and distributed analytics) still pose **risks to group privacy** of communities such as refugee populations. In a humanitarian context, these risks include bias from unrepresentative data, unintentional sensitive information discovery from combining disparate datasets, and undermining community autonomy (e.g. where AI models are used to make decisions about group resource allocation).[230]

7.2. Future trajectories, opportunities and challenges for privacy-enhancing technologies in the humanitarian sector

7.2.1. Horizon 2: Medium-term transition phase

Potential development trajectories for privacy-enhancing technologies in the medium-term time horizon – drawing on pilot applications that could mature, and current applications in other sectors that could translate – include:

- **Zero-knowledge proof digital identity systems,** which are schemes that allow people to prove their identities without revealing further information about themselves. These are currently used in some regional age-restricted markets, including gambling and alcohol sales,[231] but could translate to the humanitarian sector. The UN Refugee Agency (UNHCR) are reportedly exploring such solutions for providing digital identity systems for refugees.[232] Zero-knowledge proofs could also be used for electronic health and vaccination records for refugees.[233]
- **'Private set intersection'** approaches (which can find common elements across multiple datasets without revealing their contents) that have been used for Covid-19 contact tracing and mutual contact discovery on mobile phones could translate to humanitarian contexts.[234] Example applications include health surveillance in camps or determining family connections between members of crises-affected communities without revealing identities and wider contact lists.

229 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging humanitarian technologies' workshop, 5 March 2024.

230 Masinde, Brian K., Caroline M. Gevaert, Michael H. Nagenborg & Jaap A. Zevenbergen. 2023. 'Group-Privacy Threats for Geodata in the Humanitarian Context.' *ISPRS International Journal of Geo-Information* 12(10): 393. As of 26 August 2024: https://doi.org/10.3390/ijgi12100393

231 Yoti. n.d. 'Verify age, boost sign up and reduce fraud.' As of 26 August 2024: https://www.yoti.com/gambling/

232 Rowden, Seth. 2023. 'UN Agency Endorses Decentralized ID and ZK-Proofs as Safeguards for Refugees.' As of 26 August 2024: https://bitkan.com/news/un-agency-endorses-decentralized-id-and-zk-proofs-as-safeguards-for-refugees-22991

233 OpenAlex. n.d. 'arXiv (Cornell University).' As of 26 August 2024: https://openalex.org/sources/s4306400194

234 Reimsbach-Kounatze, Christian, & Taylor Reynolds. 2023. 'Emerging Privacy Enhancing Technologies: Current Regulatory and Policy Approaches.' *OECD Digital Economy Paper* 351. As of 26 August 2024: https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/03/emerging-privacy-enhancing-technologies_a6bdf3cb/bf121be4-en.pdf

Barriers to and enablers for development

Despite the promised benefits of PETs for protecting humanitarian workers and affected communities, there remain challenges to ongoing development. Secure multi-party computation and other PET tools where different institutions share data sets rely on the development of shared protocols and standards across and within participating institutions – relating to challenges in developing **open information-sharing standards and protocols** within the humanitarian sector. Such standards, related to mitigation measures against information leaks and security measures to access or manage PET tools, may not be available for all PETs.[235] Relatedly, the costs and technical complexity of PETs mean there are likely to be inequalities of access and funding across humanitarian regions that could constrain their global development.

The current structure of many PETs mean they have **use-case specificity**,[236] i.e. their architecture is tailored to the specific structure of the dataset they are used with and their efficacy on differently structured datasets is therefore limited. In the context of acute humanitarian crises, where technology solutions need to be implemented quickly utilising a range of different data formats and standards, they may not be suitable.

Furthermore, PETs presently often require significant computational power, technical expertise and energy to operate,[237] constraining their **feasibility in low-resource humanitarian contexts**. General barriers around **low public awareness** of PETs due to their novelty, cost and technical complexity[238] are also likely to apply to crises-affected communities.

Despite these sociotechnical barriers, increasing focus on **data protection and AI regulation enforcement** in Europe and concerns around excessive surveillance of refugees (discussed in further detail in Section 2.1 and Chapter 5) could incentivise PET innovation and scaling. Continuing **integration of PETs and associated trust and identity technologies**, including blockchain and biometrics, could accelerate the scaling of PETs, in particular relating to aid distribution and monitoring.

Risks and opportunities for humanitarian stakeholders

Further deployment and scaling of PETs risks exacerbating current **technological inequalities and power asymmetries** within the humanitarian sector. The costs and present geographical spread of PET research and innovation clusters mean the short-term development of PETs is likely to be led by non-LMICs (in particular, the USA, UK,

235 Information Commissioner's Office. 2022. 'Chapter 5: Privacy-enhancing technologies (PETs) Draft anonymisation, pseudonymisation and privacy enhancing technologies guidance.' As of 26 August 2024: https://ico.org.uk/media/about-the-ico/consultations/4021464/chapter-5-anonymisation-pets.pdf

236 Centre for Information Policy Leadership. 2023. 'Privacy-Enhancing and Privacy-Preserving Technologies: Understanding the Role of PETs and PPTs in the Digital Age.' As of 26 August 2024: https://www.informationpolicycentre.com/uploads/5/7/1/0/57104281/cipl-understanding-pets-and-ppts-dec2023.pdf

237 Reimsbach-Kounatze, Christian, & Taylor Reynolds. 2023. 'Emerging Privacy Enhancing Technologies: Current Regulatory and Policy Approaches.' *OECD Digital Economy Paper* 351. As of 26 August 2024: https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/03/emerging-privacy-enhancing-technologies_a6bdf3cb/bf121be4-en.pdf

238 The Royal Society. 2023. 'From privacy to partnership.' As of 26 August 2024: https://royalsociety.org/-/media/policy/projects/privacy-enhancing-technologies/From-Privacy-to-Partnership.pdf

Canada and Singapore).[239] Excluding LMIC communities from the development of these technologies creates risks of potential power imbalances between PET developers and communities impacted by them, and lack of regional applicability where PETs have not been designed for use cases in those regions. PETs do not ameliorate the concerns identified during participant workshops for this project[240] that the need to utilise registration and identification systems to access humanitarian services still risks **excessive reliance on technology systems** imposed on these communities by third parties – regardless of what data is or is not shared.

The scaling of zero-knowledge proof systems does, however, have potential to **address concerns around biometric registration and surveillance systems** raised by a range of humanitarian advocacy organisations[241] [242] in the wake of controversies regarding the UNHCR allegedly sharing the biometric data of Rohingya refugees with the Myanmar government without consent.[243]

7.2.2. Horizon 3: Long-term future

Potential development trajectories for PETs in the longer-term time horizon – drawing on nascent technology research areas and pilot applications that face barriers to mature in the medium term – include:

- **Homomorphic encryption** that allows computations and queries to be performed on data without decrypting it. Potential humanitarian use cases include protection of drones from cyber attacks,[244] and shared resource tracking and analysis (e.g. analysing records of shared funding and payment flows in a region, without revealing information about individual institutions' transactions[245]). Current technical challenges associated with these applications suggest it is likely to be a longer-term solution for the humanitarian sector: as of 2023, homomorphic

239 The Royal Society. 2023. 'From privacy to partnership.' As of 26 August 2024: https://royalsociety.org/-/media/policy/projects/privacy-enhancing-technologies/From-Privacy-to-Partnership.pdf

240 RAND Europe, Athena Infonomics and glass.ai, 'Ethical implications of emerging humanitarian technologies' workshop, 29 February 2024.

241 Madianou, Mirca. 2019. 'The Biometric Assemblage: Surveillance, Experimentation, Profit, and the Measuring of Refugee Bodies.' *Television & New Media* 20(6): 581–99. As of 25 August 2024: https://doi.org/10.1177/1527476419857682

242 Braithwaite, Phoebe, & Christina Rogers. 2018. 'Our data doubles: how biometric surveillance ushers in new orders of control.' OpenDemoncracy.net. As of 26 August 2024: https://www.opendemocracy.net/en/digitaliberties/our-data-doubles-how-biometric-surveillance-ushe/

243 Holloway, Kerrie, & Oliver Lough. 2021. 'Although shocking, the Rohingya biometrics scandal is not surprising and could have been prevented.' ODI.org. As of 26 August 2024: https://odi.org/en/insights/although-shocking-the-rohingya-biometrics-scandal-is-not-surprising-and-could-have-been-prevented/

244 Alzahrani, Mohammed Y., Nayeem Ahmad Khan, Lilia Georgieva, Alawi M. Bamahdi, Omar Ahmed Abdulkader & Ahmed H. Alahmadi. 2023. 'Protecting Attacks on Unmanned Aerial Vehicles using Homomorphic Encryption.' *Indonesian Journal of Electrical Engineering and Informatics* 11(1): 88–96. As of 26 August 2024: https://doi.org/10.52549/ijeei.v11i1.3932

245 The Engine Room. 2023. 'Data sharing in humanitarian Cash and Voucher Assistance (CVA): A look at risks, threats and mitigation technologies.' As of 26 August 2024: https://www.calpnetwork.org/wp-content/uploads/2023/12/DIGID-Interoperability-Data-sharing-in-humanitarian-CVA-A-look-at-risks-threats-and-mitigation-technologies.pdf

encryption was purported to be 'several thousands of times slower' than equivalent low-tech processing approaches.[246]

- **Secure multi-party computation**, which has been theorised in research as a means of enhancing the security of Cash and Voucher Assistance (CVA) programmes.[247]
- Concepts for **portable privacy-preserving Personal Data Stores (PDS)** for refugees and crises-affected communities (e.g. storing information relating to their identity, education and health records) currently being conceptualised in discovery research[248] could be developed and scaled in the long term.

Barriers to and enablers for development

Innovations relating to PDS for refugees are likely to face similar fundamental barriers to those encountered for distribution of other personal electronic devices, such as mobile phones, to these populations, including **mistrust, digital literacy limitations**, and **risks of physical damage and loss**.

New and emerging PETs often come with high costs, which may be a barrier to adoption.[249] However, long-term decreases in **data infrastructure costs, including access to computing centres**, could make PETs more feasible in low-resource contexts where their development is funded by governments or larger donors.

Emerging **international PET certification schemes** that aim to verify the performance of these technologies could be driven by the humanitarian sector in the longer term, as its need for both international coordination and trusted PETs is substantial: a Royal Society report on PETs highlights that 'Humanitarian datasets contain information about some of the world's most at-risk people … The risk of [data sharing] often entails magnified harms in these fragile contexts'.[250]

Risks and opportunities for humanitarian stakeholders

Thinking to the long-term future, the successful adoption of PDS could be an effective means of advancing **data sovereignty** for local communities and refugees where they are more easily able to oversee and control access to their data.[251]

In the case of homomorphic encryption, privacy experts have raised concerns that

246 Internet Society. 2023. 'Homomorphic Encryption: What Is It, and Why Does It Matter?' As of 26 August 2024: https://www.internetsociety.org/resources/doc/2023/homomorphic-encryption/

247 The Engine Room. 2023. 'Data sharing in humanitarian Cash and Voucher Assistance (CVA): A look at risks, threats and mitigation technologies.' As of 26 August 2024: https://www.calpnetwork.org/wp-content/uploads/2023/12/DIGID-Interoperability-Data-sharing-in-humanitarian-CVA-A-look-at-risks-threats-and-mitigation-technologies.pdf

248 Ungar, Michael, & Adam Seymour. 2024. 'Access Without Borders: A Scoping Review to Identify Solutions to Creating Portable Identity, Education and Health Records for Refugee Children.' PREPRINT. As of 26 August 2024: https://doi.org/10.21203/rs.3.rs-3837529/v1

249 Reimsbach-Kounatze, Christian, & Taylor Reynolds. 2023. 'Emerging Privacy Enhancing Technologies: Current Regulatory and Policy Approaches.' *OECD Digital Economy Paper* 351. As of 26 August 2024: https://www.intgovforum.org/sites/default/files/webform/igf_2023_open_forums_town_hall_s/243938/bf121be4-en.pdf

250 The Royal Society. 2023. 'From privacy to partnership.' As of 26 August 2024: https://royalsociety.org/-/media/policy/projects/privacy-enhancing-technologies/From-Privacy-to-Partnership.pdf

251 Ungar, Michael, & Adam Seymour. 2024. 'Access Without Borders: A Scoping Review to Identify Solutions to Creating Portable Identity, Education and Health Records for Refugee Children.' PREPRINT. As of 26 August 2024: https://doi.org/10.21203/rs.3.rs-3837529/v1

these techniques could give false impressions that datasets using this technology are completely private and secure from access by stakeholders, despite still being vulnerable to breaches if encryption keys are compromised.[252] A humanitarian stakeholder such as a government could, for example, still extract information from a dataset if they obtain encryption keys through legal mandates or illegal means. Over the next decades, future developments of generative AI systems that can train themselves autonomously and without human oversight could also disrupt PETs and limit data privacy mechanisms (e.g. data access, anonymisation and deletion).[253]

Based on the risks, opportunities, barriers and enablers discussed in the previous paragraphs, the study team identified some questions that could guide the future adoption of PETs by humanitarians in Box 7.1.

Box 7.1 Considerations for responsible adoption of privacy-enhancing technologies

In response to the potential future development trajectories, risks and opportunities associated with PETs, humanitarian stakeholders could consider addressing the following questions:

- How can LMIC actors be supported to develop and access PET solutions that are currently costly and complex?
- How could personal data stores for crises-affected populations and displaced communities be developed to ensure the trust of those communities?
- How can the humanitarian sector support the development of governance mechanisms such as technical standards and certification schemes to promote trustworthy PETs?

252 Peng, Zhiniang. 2019. 'Danger of using fully homomorphic encryption: A look at Microsoft SEAL.' As of 26 August 2024: https://arxiv.org/pdf/1906.07127

253 Falconer, Sean. 2023. 'Privacy in the age of generative AI.' stackoverflow.blog. As of 26 August 2024: https://stackoverflow.blog/2023/10/23/privacy-in-the-age-of-generative-ai/

Figure 7.1 Future development trajectories, barriers, enablers, risks and opportunities associated with privacy-enhancing technologies in the humanitarian sector

	Horizon 1	Horizon 2	Horizon 3
Development trajectories	• Encrypted and secure messaging • Cryptographic file sharing • Data pseudonymisation	• Zero-knowledge proofs • Private set intersection approaches	• Homomorphic encryption • Cryptographic tools • Secure multi-party computation • Portable Personal Data Stores (PDS)
Barriers to development		• Lack of shared data standards • Use-case specificity • Computational power requirements • Technical complexity • High costs	• Loss and damage risks for PDS • Refugee mistrust and digital literacy
Enablers of development		• Data protection and AI regulation • Integration with identity technologies	• Decreasing data infrastructure costs • Decreasing computing costs • International PET certification schemes
Risks	• Undermining community autonomy • Group privacy risks	• Exclusion of LMIC regions • Power imbalances • Excessive reliance on technology systems	• False impressions of security
Opportunities	• Privacy protection	• Addressing biometric privacy risks	• Promoting data sovereignty

Source: Study team analysis.