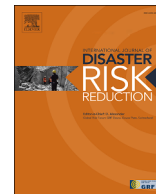


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## International Journal of Disaster Risk Reduction

journal homepage: [www.elsevier.com/locate/ijdr](http://www.elsevier.com/locate/ijdr)

## Living in a pandemic: A review of COVID-19 integrated risk management

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### ABSTRACT

Managing new and complex risks has been one of the greatest societal challenges. At the start of the COVID-19 pandemic, governments all over the world had to make urgent decisions to address a public health crisis. Such decisions had to consider the impacts of alternative options on the public health, citizens' behaviours, and countries' economies. However, most policies undertaken during the first phase of the COVID-19 pandemic were based primarily on health data, with less emphasis given to combining evidence on e.g., social and economic impacts. This resulted in serious consequences at the individual and societal level. In this paper, we conduct a scoping review of the COVID-19 risk management literature focused on integrating evidence from the health, behavioural and economic domains. Using the SPIDER method, we selected the sample of papers using different approaches to integrate diverse types of knowledge and evidence. Examples include multi-criteria approaches to model pandemic responses or geographical information systems supporting preparedness assessment. The results reveal that most of the papers include only two of the three domains considered in the review and the majority of these papers' approach is model based. Also, less than half of the papers integrate all three domains, often providing frameworks that are not tested empirically. Further, we discuss emergent main themes and research gaps including the lack of the Global South perspective and the limited integration of quantitative behavioural data. We conclude by providing recommendations and future research directions to improve COVID-19 integrated risk management.

### 1. Introduction

The world is currently facing crises that will shape our future in ways that are only partly predictable. The climatic, environmental, and socioeconomic crisis is metastasising virtually every sector of the world's economy, impacting human and ecosystems' wellbeing [1]. In addition to this, the global spread of the Coronavirus disease (COVID-19) from the early 2020 has added an additional layer of complexity to the management of multifaceted risks. While scientists warned us about the dangers of a potential pandemic [2], COVID-19 came as a shock globally and is one of the greatest global crises in recent history. Besides, governments showed a lack of comprehensive strategies, plans, and toolboxes to manage COVID-19 (e.g., Refs. [3,4]).

Managing new risks like the COVID-19 pandemic at the governmental level is indeed complex, especially during a crisis when decisions are urgent, the available evidence is changing fast, and public health and economic implications are severe [5,6]. In the case of COVID-19, citizen awareness and preparedness have been low –especially at the beginning– thus requiring considerable efforts in public communication and information campaigns. For example, authorities such as the World Health Organization (WHO) and national governments had to inform citizens not only of the health risks deriving from a SARS-CoV2 infection, but also on how the virus is transmitted, and in turn how to take effective actions to reduce its spread. One of the challenges for governments was to communicate in plain language, without resorting to overly technical jargon [7,8]. The capacity of governments themselves to weigh scientific

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<https://doi.org/10.1016/j.ijdr.2023.104081>

Received 14 December 2022; Received in revised form 10 October 2023; Accepted 22 October 2023

Available online 30 October 2023

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evidence, absorb it, synthesise it, use it to support effective decision-making, and communicate it, was often limited because politicians or civil servants have little familiarity or time to dedicate to synthesising results [6]. Moreover, time pressure has been high, and decisions have often been urgent. As a result, the integration of different types of knowledge and data -e.g., from the health, economic and behavioural domains-has become a major challenge.

To provide a better understanding of the complexity behind the risk management of a global pandemic, this paper reviews the current literature focusing on the integration of health, behavioural and economic aspects for COVID-19 risk management. Particularly, the review assays the approaches, the type(s) of data used, and the common themes emerging from research in this field. Section 2 below provides an overview of Integrated Risk Management (IRM). Section 3 illustrates the methodology adopted to conduct the review and it is followed by the presentation of the main themes that emerged from the review (Section 4). Finally, section 5 discusses the results, limitations and ways forward.

## 2. Integrated risk management

Since the beginning of the COVID-19 pandemic, science advice for policy has revealed strengths and weaknesses of existing models to provide effective decision support and communicate it. Policy decisions have been based primarily on health data such as incidence (e.g., in Italy [9]), case fatality ratio (e.g., in Sweden [10]), or vaccination rate [11], sometimes even with dedicated laws [12]. Gaps were evident in forecasting social, economic, and psychological consequences of mitigation and containment measure implementation, benefits, and costs [13]. Linked to that, there have often been difficulties in integrating evidence from different disciplines, e.g. looking at epidemiological alongside economic models, or modelling the social or psychological effects of different policy choices regarding containment and mitigation measures. One of the reasons is that modelling these interactions or setting assumptions (e.g., about planned behaviours) is extremely difficult [6]; see also section 3 and 4).

Nonetheless, with the succession of multiple pandemic waves, the importance of providing reliable behavioural and economic data (in addition to health data) to support decision-making has become evident. To this end, an Integrated Risk Management (IRM) approach has been advocated because it can provide governments and decision-makers in general with different tools to reduce risk [14–16]. The concept of IRM was originally developed in the late 1990s-early 2000s for organisations (mostly in the private sector) to approach their various risks holistically and to promote a culture of risk awareness [17]. Specifically, the IRM framework was conceived to take into account both financial and strategic uncertainties [18], and to go beyond the set of traditional [17] insurable risks. This approach was then transferred to and adapted for the management of large, complex risks that have the potential of affecting large segments of the population. In this way, the need for integrated approaches to disaster risk management started appearing in international policies and documents. For example, the Sendai Framework for Disaster Risk Reduction 2015–2030 [19] aims to:

*“Prevent new and reduce existing disaster risk through the implementation of **integrated and inclusive** economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that **prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience**”* [p. 12]

Progressively, integration has been conceptualized primarily as a combination of knowledge, methods, evidence, and data from different domains/disciplines. IRM approaches have been called for as a solution for a better understanding of the systemic nature of risks, and they have been implemented successfully for disaster risk management (DRM) and reduction (DRR). Yet, so far, these approaches have especially been applied in the mass-movement and flood disaster domain or to address combined shocks. IRM usually takes a holistic perspective through continuous assessment/monitoring of the risk situation, planning and implementation of protection/risk reduction measures, including measures to deal with residual risks [20–22]. It considers different root causes and drivers of hazard, exposure, vulnerability and risk, and possible options to reduce risk ranging from containment/mitigation<sup>1</sup> measures, to emergency management and risk transfer. Moreover, it uses a variety of approaches for the assessment of risk and evaluation of options, borrowing methods from natural, engineering, economic, ecological, and social sciences [23]. In addition to the design of risk management options, other considerations may come into play when deciding about the implementation of IRM strategies, such as equity, acceptable risk levels and impacts on the environment [1,24,25].

Several authors have pointed out that COVID-19 has highlighted not only key vulnerabilities in our societies, but also the need to promote IRM approaches and/or integration of different types of knowledge and evidence to tackle future crises (e.g., Refs. [14,15, 26–28]). In fact, adopting an IRM approach to manage the COVID-19 pandemic means to take into consideration not only the health, but also the economic, structural, legal, social, cultural, educational, environmental, political, and institutional aspects. The implications for risk management strategies are relevant. For example, by adopting this perspective, COVID-19 cannot be framed exclusively as a health emergency and effective strategies to address it must encompass multiple domains, type of knowledge and evidence.

## 3. Methods

The literature search was conducted between March and April 2022 using the online database Scopus (<https://www.scopus.com/>). Scopus was chosen because it is the largest abstract and citation database of peer-review literature, covering

<sup>1</sup> Measures can be distinguished between containment and mitigation (Ferguson et al., 2020). The former attempt to circumscribe hotspots of the infection and through an aggressive set of quarantine measures and lockdowns of activities and services avoid the spread throughout a region or a country. In the latter, a set of differential measures is taken, focusing on avoiding mass gatherings and situations and activities that constitute a high risk of rapid virus transmission.

more than 43'000 peer-reviewed journals across all scientific disciplines. To structure our search, we used the SPIDER method [29], which is suitable for qualitative reviews:

- Sample: studies focusing on COVID-19 risk management;
- Phenomenon of Interest: Inclusion of evidence from different sectors (health, behaviour, economy);
- Design: any;
- Evaluation: degree of integration (e.g., qualitative vs. quantitative), data types, approach;
- Research type: Qualitative.

The SPIDER method helped defining a clear strategy for searching articles as well as for defining exclusion criteria, and thus minimized the bias when searching for and selecting articles. Based on the structure above, we queried the database with the following criteria (the star indicates that the word should start with the letters before the star but can continue with any letter):

- The abstract should contain the terms “COVID\*” or “SARS-CoV-2”;
- The title, abstract, or keywords should contain the terms “epidemiolog\*”, “behaviour\*” or “behavior\*”, “econom\*”, and “risk manage\*”;
- The language should be English.

Because of the selected topic, the timeframe is limited between 2020 and 2022. The search resulted in 748 entries. At this stage, we screened the abstract to filter out irrelevant articles. These included review articles (127), articles not focusing on COVID-19 (17), articles not focusing on risk management (6), articles on other study species (e.g. bats, 1), and articles discussing evidence only from one sector (e.g. only epidemiological data, 554). This resulted in a final pool of 43 articles. Fig. 1 below summarises the screening and filtering stages of the review process.

After reading the selected 43 articles in full, an additional 25 articles were removed because they were either discussing only one sector or not discussing risk management (which was not clear by just reading the abstract). Finally, the remaining 18 papers were qualitatively analysed to identify common themes.

The limited articles' pool size is justified by two factors: i) the research question is rather specific, as only those studies presenting health, behaviour, and economic factors within risk management were considered for analysis; ii) the time frame is limited, given that the COVID-19 pandemic only started two years prior to the literature search. Further research is needed to monitor and analyse publications on this topic after the literature search was conducted between March and April 2022.

## 4. Results

### 4.1. An overview

Table 1 shows the list of reviewed articles, including bibliographical information such as authors, year published, and title, in addition to the main aim of the article.

The final paper pool spans several disciplines, namely epidemiology, public health, medicine, biology, behavioural science, sociology, psychology, physical and human geography, governance, law, business and economics, operations management, computer science, mathematics, and engineering. While this may indicate high interdisciplinarity among the authors, only in 50 % of papers the authors belong to different disciplines (based on their affiliation).

Fig. 2 shows that most of the papers include only two of the three sectors considered in the review, i.e., health, behaviour, and economy, and the majority of these papers' approach is model-based. Half of the papers that include all three domains present a framework. The other half uses often Geographical Information Systems (GIS) to integrate data quantitatively (see section 3.2.6 for details). Only papers merging health and economic aspects also use multi-criteria analysis as an approach, likely because it is deriving from operations research within the economic and medical sectors (e.g. Ref. [15]). Another emerging approach is multi-criteria analysis. For example, Ekenberg and colleagues (2022) use a multi-criteria approach to modelling pandemic responses under strong uncertainty in Jordan. Yet, it seems that the use of quantitative data from the social domain (e.g. behavioural data) poses some challenges to multi-criteria analysis.

The reviewed studies use various types of data (see Fig. 3), including clinical/epidemiological (e.g., the number of infected individuals), demographic (e.g., total population, population in urban areas, age distribution), economic (e.g., GDP), environmental (e.g., air quality, temperature), behavioural data (e.g. adherence to protective behaviours).

Most of the papers (almost 70 %) integrate the data quantitatively. However there are considerable differences across the types of domain integration. For example, all papers integrating the “health and economic” domains, do so quantitatively, while the same is true for less than a half of the papers in the “health and behaviour” domain. An in-depth analysis of the papers reveals that the inte-

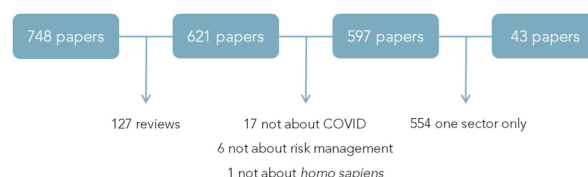


Fig. 1. Summary of filtering stages.

**Table 1**  
Information on the final articles pool.

Authors	Year	Title	Aim
[30]	2021	Optimal shutdown strategies for COVID-19 with economic and mortality costs: British Columbia as a case study	To formulate a model with both epidemiological and economic content to assist COVID-19 management
[31]	2021	Science-based environmental conservation to answer the risk of pandemic, with a focus on the Republic of Korea	Perspective on the interaction between COVID-19 and conservation management
Božek, F. & Tušer, I.	2021	Measures for ensuring sustainability during the current spreading of coronaviruses in the Czech Republic	To identify serious risks and to propose priority measures that can lead to their significant mitigation
Chan, E.Y.Y. et al.	2022	Challenges of Data Availability and Use in Conducting Health-EDRM Research in a Post-COVID-19 World	To discuss the challenges of data availability within the Health-EDRM framework
[32]	2022	Political decision making in the covid-19 pandemic: The case of Germany from the perspective of risk management	To present a tool from the entrepreneurial and management decision making field to be used as a benchmark for political decisions
[33]	2022	Vulnerability to COVID-19 in Pernambuco, Brazil: A geospatial evaluation supported by multiple-criteria decision aid methodology	To present an innovative application to identify areas vulnerable to COVID-19 considering both spatial analysis and a multi-criteria learning approach
[26]	2021	Multiple hazards and risk perceptions over time: the availability heuristic in Italy and Sweden under COVID-19	To examine and compare how global crises and local disasters influence public perceptions of multiple hazards by comparing mortality data and risk perception
[14]	2021	A Multi-Criteria Framework for Pandemic Response Measures	To apply a multi-criteria framework to evaluate different combinations of pandemic response measures
[15]	2022	A multicriteria approach to modelling pandemic response under strong uncertainty: A case study in Jordan	To apply an integrated decision-making framework under ambiguity of the COVID-19 spread
[34]	2022	Decision-making framework for identifying regions vulnerable to transmission of COVID-19 pandemic	To propose a hybrid fuzzy decision-making framework to identify transmission factors and conduct proactive decision-making
[35]	2021	A spatial interpretation of Australia's COVID-vulnerability	To develop a risk prediction model based on demographic vulnerability and economic vulnerability
[36]	2022	GIS-based spatio-temporal analysis and modeling of COVID-19 incidence rates in Europe	To analyse the spatio-temporal distribution of COVID-19 incidence and mortality rates using a set of 40 demographic, socioeconomic, environmental, transportation, health, and behavioural indicators as potential explanatory variables
Lu, X. & Lin, Z.	2021	COVID-19, Economic Impact, Mental Health, and Coping Behaviours: A Conceptual Framework and Future Research Directions	To conceptually analyse how the pandemic affects individual mental health and coping behaviours from the perspective of individual economic status, individual context, and social context
[37]	2021	Managing the COVID-19 emergency: A coordination framework to enhance response practices and actions	To define a framework for modelling activities, actors, and resources coordination in the epidemic management scenario
[38]	2022	Prioritizing Global Public Health Investments for COVID-19 Response in Real Time: Results from a Delphi Exercise	To employ a multi-step, interactive Delphi process to reach consensus on a "menu" of priority COVID-19 responses
[39]	2021	COVID-19 disaster risk reduction and interdisciplinary education and training	To introduce the EmTASK course, aimed at raising awareness and improving education on disaster risk reduction needs both within experts and the general public
[40]	2022	Assessing Response Readiness to Health Emergencies: A Spatial Evaluation of Health and Socio-Economic Justice in Pakistan	To propose a Geographic Information Systems-based framework in the context of public health-related hazards and pandemic response; to compute a response readiness index (RRI) by using indicators relevant to health system and socio-economic conditions
[41]	2022	The Assessment of COVID-19 Vulnerability Risk for Crisis Management	To determine COVID-19 vulnerability risk and its change over time in association with health care system, turnover, and transport to support the crisis management decision-making process

gration of quantitative behavioural data is one of the main problematic issues, also in the case of the integration of all three domains (see also section 5).

All the reviewed papers using empirical data made use of epidemiological, demographic, and economic data, mostly as model input data. This is not surprising, as clinical/epidemiological data was readily available since the beginning of the pandemic and, in most countries, demographic and economic data is often provided by national statistical institutes and agencies. Only papers discussing health and economy, or health, behaviour, and economy, on the contrary, employed surveys and environmental data. A number of papers discussing all three domains also do not use any empirical data, which is also not surprising given that some of them present frameworks.

Most of the reviewed papers present case studies in the European continent (see Fig. 4), followed by two in Asia (Jordan and Punjab, Pakistan), one in Oceania (Australia), one in North America (British Columbia, Canada), and one in South America (Pernambuco, Brazil).

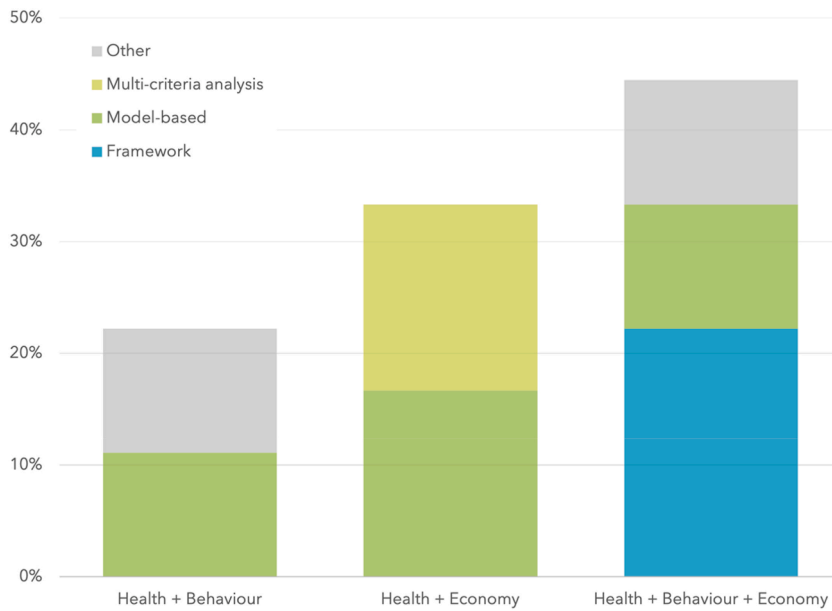


Fig. 2. Type of approach used, by domain.

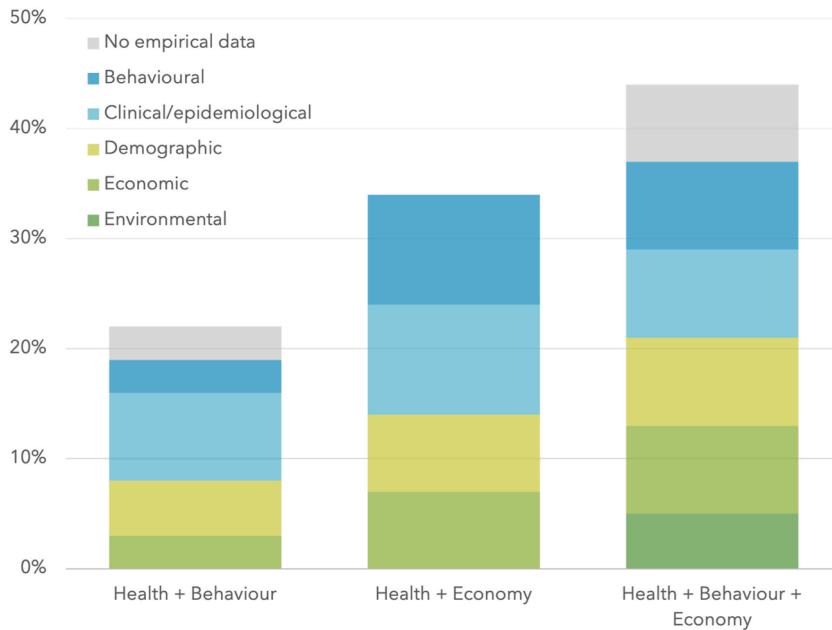


Fig. 3. Type of data used, by domain.

#### 4.2. Main themes

This section presents the main themes that emerged from the selected literature. They include the role of uncertainty in affecting policy and decision making, the importance of context, the adoption of knowledge co-production approaches, the political costs of measures, feedback mechanisms, and emergent tools.

##### 4.2.1. Uncertainty

Two types of uncertainty emerge prominently from this review. The first one is affecting the basis on which we make decisions. For instance, this includes lack of data at the beginning of the pandemic, such as case fatality rate or the number of asymptomatic cases [14], scattered data [32], i.e., data that are available only in certain areas or for certain periods of time, and the limited availability of “microlevel” data [42], i.e., data for specific contexts vs. macro-level data (e.g., national, or global level data). In fact [42], argue that while global-level platforms for knowledge sharing continue to be of importance, regional-level platform will gain more



Fig. 4. Location of case studies presented in the reviewed papers.

ground and become central to improve data collection. The study of [35] is a prime example (see Table 1 for an overview of papers considered in the review). They used data disaggregated at the regional level, because considering only data at the national (macro-) level would have not allowed the federal government to take into account the demographic differences among the various Australian states, potentially resulting in worsen outcomes for particularly vulnerable communities.

The second type of uncertainty concerns the unknown or un-expected consequences of making a particular decision over another. In our case, this would be for example the uncertainty in the outcome of a risk reduction measure [15,32]. For example, when some governments decided to close down schools to limit the spread of infections among pupils, there was a certain degree of uncertainty regarding the effect(s) this would have on the pupils themselves. In fact, while on one hand this allowed education to be conducted remotely, with a lower risk to physical health, on the other hand it took a toll on mental health and exposed more children to difficult family environments [13].

#### 4.2.2. Context matters

The second theme, the importance of context, is inevitably tied to the first one. Indeed, even if there are data available for a certain region that we can use as a benchmark for another region, the different contexts in the two areas can affect the transferability of data and practices. Several authors maintain that there is no “one-size-fits-all” approach to COVID-19 risk management, and - to be efficient and beneficial - policies need to adapt to the social, economic and cultural context [42]. While the WHO emphasised the lack of consistent policies among nations [35,43], evidence suggests that this may not work. For example, [35]; showed how in Australia, a federation of states and territories, the states have taken different approaches and measures to address the pandemic. For instance, part of the Northern Territories region experienced stricter measures, such as the ban of movements in and out of the region, due to the high percentage of Indigenous people in the area, who are generally more prone to chronic illness and thus more vulnerable to COVID-19, compared to the population in other regions of the country [35]. Thus, the adoption of different/context specific policy instruments should not be considered negative “in principle”: rather, it may be justified by the different socio-economic and geographical characteristics of each area.

#### 4.2.3. Co-production approaches

The importance of context is also relevant when it comes to the adoption of co-production approaches that, drawing on contributions from public health authorities, individual citizens and community groups, can augment traditional public health approaches [44]. It has been argued that these approaches can be effective especially during the long term phase of a pandemic that typically has growing societal impacts in comparison with the initial acute onset (ibidem). Indeed, when local actors are involved in the decision-making process, the resulting policies and measures have better chances to be tailored to the relevant target group, i.e., the local population. Some of the reviewed articles adopted a co-production approach to investigate potential risk management strategies together with local actors in the respective case study areas. [37]; for instance, involved a hospital nurse, a sociologist, a psychologist, a civil engineer, an economist, a public manager, and two management engineers to develop a framework for modelling activities, actors, and resources coordination in an epidemic scenario. With an iterative process, the authors drafted a framework (first stage) which was then submitted to the various experts for review (second stage). In the third stage, the feedback was incorporated into the original draft. Similarly [14], involved relevant stakeholders from various sectors, including policymakers, the private sector, academia, civil society, banks, and representatives from local communities to assess and give a preference to various mitigation measures presented to them. In their interactive Delphi process [38], involved close to 30 health security experts from different backgrounds, including national governments, academia, technical agencies, as well as bilateral and multilateral organisations and non-governmental organisations to develop a set of priority COVID-19 response interventions, agreed upon by all involved.

Co-production approaches may be an essential steppingstone towards the acceptability of measures but are not easy to implement when decisions are urgent and time is of essence. One aspect that became relevant during the unravelling of the pandemic is compliance with imposed, top-down measures. While, during the first weeks, fear kept people at home, after some time the cost of isolation

became unbearable for several people experiencing severe lockdowns (e.g., in China, Italy, or the UK). The decision to impose strict lockdowns was taken only considering one side of the risk (i.e., the spread of infections). From an integrated risk management perspective, many aspects were indeed overlooked, such as impacts on mental and physical health and repercussions on the economy of the country. Furthermore, as discussed by [30]; it is unlikely that people will comply with measures that are considered overly restrictive for a long period of time. [15] propose the use of strategic narratives as a way to present these measures in a different light, while not hiding the uncertainty behind them. In fact, such stories also have explanatory power, and thus reduce the overload of information that has characterised the initial phase of the pandemic [15].

#### 4.2.4. Acceptability and political cost of measures

The acceptability of measures is inextricably tied to their political cost. The decision to impose a strict lockdown, for instance, comes with political costs because imposing limitations to citizens' perceived freedom could potentially matter at the next election. At the same time, policy priorities have changed and evolved over time, e.g., saving lives, preventing the collapse of the health system, avoiding economic meltdown [27]. Thus, governments have to constantly find a balance between saving lives and the economic, social and political costs of it [30]. Indeed, democratic governments not only have to deal with and manage risk in the present but also have to ensure keeping the public's consensus in view of the next elections. As a result, some leaders decided to adopt less stringent measures in terms of the spread of infections to avoid a large toll on their country's economy [30], thus potentially avoiding discontentment among their citizens. In addition, governments tend to have the capacity to operate for a limited period, usually around 5 years, and with obviously limited resources. This makes governments more likely to focus on short-term fixes that may yield results more quickly, and makes it harder to focus on long-term policies [32]. [26]; discuss the differences between two countries that adopted opposite responses to the emergence of COVID-19: Italy, which prioritised limiting the spread of infection, and Sweden, which prioritised preserving public health as a whole ("physical, mental and social well-being" according to the WHO). The Italian response was characterised by governmental decrees that introduced stringent national policy responses, including a national lockdown and prolonged school closures. The Swedish response was primarily based on soft measures (recommendations) relying on trust between people and authorities [26]. In this sense, the Swedish response may have been driven also by a fear of the political cost of stringent measures.

#### 4.2.5. Feedback mechanisms

Because governance does not exist in a vacuum, the adoption of different risk reduction measures inevitably triggers feedback mechanisms in the societal and natural systems. Lockdowns in the initial stage of the pandemic, for instance, resulted in improvements in air and water quality in various areas of the world [31]. However, while short-term solutions may be beneficial at the initial stage of a crisis, they could result in what are known as "fixes that backfire" [45]. For instance, while at the beginning of the pandemic a strict lockdown was beneficial to reduce the spread of infections and alleviate the pressure on the healthcare system, it resulted in a series of long-term negative consequences. These include, for instance, reduced access to education [13], which may exacerbate child labour, teenage pregnancies, socioeconomic and gender disparities [26], decreased tourism and consequent risk of poverty for tourism-reliant communities [31], poorer mental health and weaker social relationships [46], among others. This review reveals that the adoption of IRM approaches generally allowed a better understanding and analysis of feedback mechanisms.

#### 4.2.6. Emergent tools

Another theme that emerged from a number of papers is the use of Geographical Information Systems (GIS) as an emergent tool in COVID-19 IRM. In fact [40], argue that GIS can be an effective decision support system to aid risk management because of its ability to deal with multidimensional and complex data. Spatial data and analyses also allow us to determine where and which interventions are most needed [41]. [33] for instance, used a geospatial evaluation to create a vulnerability map for the state of Pernambuco, Brazil, pairing it with a set of demographic, economic, and infection data. While GIS, and satellite data in general, can aid in the development of new tools for disaster risk management and reduction, it is important to notice that they still only provide macro-level data, which then needs to be integrated with data at the local or regional level (see Section 3.2.1).

## 5. Discussion

At the beginning of the COVID-19 pandemic, most efforts around the world were directed towards reducing the spread of infections to save lives. As such, the risk to human life was prioritised, while other risk factors were overlooked, and their management received less attention [27,28]. These factors include, for instance, mental health and economic stability. Within the time span of two years since the beginning of the COVID-19 pandemic, the scientific community has produced a large amount of literature on the risk management of this expected – yet unknown for its scale – phenomenon. This review covered a small but significant part of this literature, focusing on those studies that integrated two or more sectors, namely health, behaviour, and economy for improving risk management practices. Including these three main sectors into integrated risk management would result in strategies with either reduced side effects, or at least with plans in place to mitigate them.

The results highlight the benefits (e.g., better appraisal of feedback mechanisms), potential good practices and innovative tools (e.g., co-production or multi-criteria approaches, and GIS based tools), but also limitations of the adoption of IRM approaches (e.g., difficulties to integrate behavioural data quantitatively).

For example, a co-production approach is a promising way forward to implement integrated risk management strategies. Examples from the reviewed literature show the positive effects of including not only experts from various disciplines (i.e., not only public health experts or epidemiologists), but also representatives of the communities at risk. [15] for instance, show that the input from

stakeholders was fundamental to “reach compromise-oriented policies” (p. 17). Arguably, policies that have been designed and agreed upon by all stakeholders have a higher chance to be abided by in the long term, as opposed to top-down, imposed solutions. This would also mitigate the political cost of the policy, as it becomes more difficult to blame a single entity (such as a party) when the decision was discussed with most – and preferably all – stakeholders. Undoubtedly, with such a process, reaching an agreement would require a longer timeframe, a luxury that was not available at the beginning of the COVID-19 outbreak. This stresses the importance of preparedness. Policies would be better designed if they were conceived prior and not during the crisis they were supposed to address [15]. This also stresses the importance of dedicating resources to collaboration and communication: good practices include hot-lines for disseminating information, giving advice and analyse public needs; surveys to collect feedback on the regional approaches; dashboards tracking key indicators to evaluate the effectiveness of selected policy instruments [44].

Designing plans, strategies and policies in advance would also allow for factoring in potential feedback mechanisms. Every policy will have a number of expected consequences, but what happens with the unexpected, or unintended, ones? An integrated risk management approach would minimise the occurrence of unintended consequences because the inclusion of more than one perspective widens the horizon of potential policy effects. For instance, considering a lockdown purely from a physical health perspective makes sense, but if the policymakers would factor in the consequences of such measures on people's behaviours or on the economy, it becomes clear that it is not a measure that is sustainable if taken alone. Pairing it with additional measures to mitigate its adverse effects, such as, for instance, continued education for children and young adults [13], would reduce the risk. This can also prepare the community for the inevitable cascading effects of certain measures, which could then be mitigated and reduced.

The most evident gap the review highlighted is the difficulty in quantitatively integrating behavioural, health, and economic data. Integration across these three domains is often conceptualized with frameworks but hardly empirically tested, especially using quantitative data about public attitudes and behaviours. This may be partly due to data availability, but we also argue that it is rather complex to merge all these different kinds of information quantitatively. However, while frameworks are essential to push research forward in the long-term, in the short-term they may not be an effective tool to support decision making. In this sense, a multi-criteria analysis seems to be a less time-consuming method, but the review showed that most of the papers conducting such analysis do not include behavioural data. This type of data may be indeed difficult to include because, unless already present, collecting data on communities' behaviours in real time is complex and time-consuming, especially during a time-sensitive crisis like COVID-19. Yet, there has been considerable research collecting behavioural data, e.g. about COVID-19 related attitudes and behaviours, factors affecting COVID-19 risk perception and adoption of protective behaviours, changes in adherence to COVID-19 protective behaviours (e.g. [47–53] but with limited attempts of quantitative integration of and with other domains.

The review also highlighted additional gaps. The limited focus on risk communication strategies resulted sometimes in fear or lack of knowledge in the affected population, especially during the first weeks. This then caused a mistargeted expenditure of resources in activities that were irrelevant for risk reduction (an example is the disinfection of streets in Italy [54]). Another gap is the limited literature available (at the time of this writing) to compare and contrast government policies and response with respect to the adoption of IRM approaches [55]. developed a global panel database of pandemic policies, but this includes little information on if and how integration of knowledge from different domains has been conducted. Thus, a systematic analysis of these aspects is needed, together with a better understanding of the role played by the multi and inter-disciplinary expert committees supporting COVID-19 risk management in different countries. Finally, the review shows a near absence of the Global South in studies investigating COVID-19 IRM. The lack of such studies translates into a lack of perspective from different contexts and cultures that could provide additional insights and best practices.

Last but not least, it is also important to highlight two methodological limitations of this study. First, as illustrated in section 3, we analysed journal articles listed in Scopus, within a selected time frame and with a specific research question. As such, this study did not include COVID-19 IRM studies published in grey literature, as book publications, in other languages, or unlisted scientific journals. Second, we may also have missed relevant articles due to the terms used for the search and the fact that we considered only those mentioned in the abstract, title and keywords. As a result, potentially relevant articles on IRM were not included if COVID-19 was not explicitly cited. These limitations, which are often encountered with literature reviews [56], should be considered as a qualifying boundary condition of our findings.

## 6. Conclusions

The COVID-19 pandemic is one of the greatest global crises in recent history. After an initial framing of COVID-19 as an exclusively medical emergency, it has become evident that a combination of medical, social, economic, and environmental knowledge and data was necessary to address the crisis effectively [27]. In parallel, there have often been difficulties in integrating evidence from different disciplines, e.g., looking at epidemiological alongside economic models, or modelling the economic and social effects of different policy choices regarding containment and mitigation measures. Nonetheless, with the succession of multiple pandemic waves, the importance of providing reliable behavioural and economic data (in addition to health data) to support decision-making has clearly emerged. To improve COVID-19 risk management, an integrated approach has been often advocated, i.e., an approach able to combine knowledge, methods, evidence, and data from different domains/disciplines.

In this paper, we conducted a review of the COVID-19 IRM literature where different types of evidence were integrated. Specific attention has been dedicated to the integration of health, economic and behavioural evidence. The review assays the approaches, the type(s) of data used, and the common themes emerging from research in this field.

The results reveal that most of the papers include only two of the three domains considered in the review and the majority of these papers' approach is model-based. Less than half of the papers integrate all three domains, often providing frameworks that are not



tested empirically. Moreover, six main themes emerged from the analysis: the role of uncertainty and context in affecting COVID-19 IRM; the benefits deriving from the adoption of IRM approaches, including e.g., understanding and analysis of feedback mechanisms; the importance of and challenges in the adoption of co-production approaches for integrating different types of knowledge and evidence; the acceptability and political cost of different measures and the emergent tools for COVID-19 knowledge integration.

For governments to adopt IRM strategies for systemic crises like COVID-19, more research is needed that integrates quantitative data about public attitudes and behaviours into standard risk assessment practices, and plans. Not only quantitative but also quantitative and qualitative data integration should be promoted. Our results reveal that a key component of these IRM strategies is the adoption of co-production approaches that bring a plurality of knowledge sources, types, and stakeholders together for policy, decision making or problem-solving purposes. These approaches also integrate qualitative and quantitative evidence and have proven effective to co-define priorities in policy objectives for long term crises like COVID-19. Thus, new methodologies to promote formal involvement of residents, civil society organisations and other stakeholders within the management strategies should be developed and tested. The same is true for the development of risk communication campaigns that should be an integral part of IRM strategies, together with risk assessment, assessment of impacts and risk propagation, warning systems, preparedness, emergency and recovery plans. Concurrently, more creative work to shape options that cut across the three analysed domains (health, economy, and society) should be identified, including using formal and informal models to capture feedbacks, trade-offs, and synergies across policy and financial instruments to reduce COVID-19 risk. While governments and local authorities may reduce data collection and risk management efforts when outside of an emergency (i.e., after a pandemic is over), it is during these times that it becomes essential to invest in integrated risk management efforts to be prepared for the next crisis.

### Ethical approval

Not applicable.

### Consent to publish

All authors have read and agreed to the submitted version of the manuscript.

### Authors contributions

Conceptualization A.S., E.M., M.S.; Methodology, E.M.; Formal Analysis: E.M.; A.S.; Writing and original draft preparation: E.M.; Writing-review and editing: A.S., G.D.B., E.M., M.S.; Funding acquisition: A.S., M.S.; Resources: M.S.; Supervision: A.S., G.D.B., M.S.

### Funding

This research was funded by “Shaping resilient societies” Initiative supported by the University of Geneva (UNIGE) and the University of Zurich (UZH) in the framework of the project “Integrated Risk Assessment and Management in times of Pandemic: IRAM2.0”.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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