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Review Article

Models and frameworks for assessing the value of disaster research

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ABSTRACT

Funders, governments, stakeholders and end-users expect to see tangible evidence that an investment in research is a worthy use of resources. Research has impact if it makes a demonstrable contribution to the economy, society, culture, public policy, health, the environment, or quality of life, beyond academia.

This paper reviews frameworks that assess the impact of research and considers their usefulness in the conceptualisation and measurement of research impact in the disaster domain. Frameworks demonstrate impact through attribution, measurement and quantification of academic, social, and economic impacts in the short, medium and long term. While there is no specific framework in the hazard domain, adaptation of the "pathways to research impact" tool created by Cruz Rivera et al. (2017) provides a well-considered basis for assessing disaster research impact.

Contents

1. Introduction . . . 1
2. Approach . . . 2
3. Defining research impact . . . 2
4. Considerations in assessing research impact . . . 3
4.1. Types of research impact . . . 3
4.1.1. Economic impact . . . 3
4.1.2. Academic impact . . . 4
4.1.3. Social impact . . . 4
5. Frameworks or models to measure research impact . . . 5
6. Discussion . . . 7
7. Conclusion . . . 9
Acknowledgments . . . 9
References . . . 9

1. Introduction

Funders, governments, stakeholders and end-users increasingly expect to see tangible evidence that an investment in research is a worthwhile use of resources, that it informs policy and practice, or justifies current and future funding [76]. This is particularly true for the disasters field, where investment in any ex-ante action is challenging to motivate [1–4]. Additionally, the uncertainty inherent in disaster events means that disaster research is not able to guarantee clear benefits such as are more often available in, for instance, the health field (a new or improved medication) or computing (a new product with economic potential). Despite the challenges it is critical that we understand the value of disaster research, in order to ascertain the extent to which investment in it contributes to saving lives as well as economic and environmental assets. In this paper we provide an overview of the available frameworks for understanding the value of

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research and adapt a framework for assessing the value of disasters research to key stakeholders including emergency agencies, governments, policymakers, and householders.

Research involves the application of physical and social science methods to investigate relationships amongst phenomena or to solve a problem. The purpose of undertaking a program of research in applied fields such as disasters includes influencing policy, improving the efficiency or effectiveness of services, improving individual and community wellbeing or to create environmental benefits [5]. Research may also generate wider, or unexpected outcomes. Expected and unforeseen outcomes create value for researchers, governments, industry and other end-users. The value of research is measured by assessing its impact. Impact is achieved through knowledge generation, capacity building, creation of methods and tools, researcher and end-user network collaborations, and policymaking support.

Research impact assessment is undertaken to make the case for research investment and funding by linking research to evidence informed practice (advocacy); understanding how science works and how it is shaped (analysis); ensuring responsibility to individuals and society (accountability); and assigning resources based on research impact (allocation) [76]. It is also a valuable research planning tool for generating greater impact. Various frameworks have been developed to assess the impact of research. The majority of frameworks have been developed for the healthcare sector so, in applying them to other domains such as disasters, it is necessary to draw parallels between the health sector and the wider research landscape.

This paper reviews the literature on the impact of research and its value with the aim of adapting an appropriate framework for the conceptualisation and measurement of research impact in the domain of disaster research. We first explain our approach to searching the literature for evidence on research impact generally and more specifically in the area of natural hazards. Definitions of the impact of research and the components of the most relevant definitions are presented. Methods to assess how research is used and how value is generated are outlined, focusing on both the process of research and its outcomes and on the users of research including researchers, householders, stakeholders and policymakers. Guidelines for the assessment of research impact are discussed including key elements for consideration in that assessment. The various tools created to assess components of impact are examined. Means of measuring impact are summarised including the valuation and measurement of economic, academic and social impacts. Prominent research impact frameworks and models that create an overall picture of the value of a body of research or of a research institution are presented in summary tables. A discussion of the implications of the evidence on the applicability of research impact frameworks in the assessment of hazard research completes the paper.

2. Approach

An extensive literature review of all available physical and social science literature on the impact or value of research was conducted in February 2019. Criteria for inclusion in the review included peer-reviewed literature and non-peer reviewed publications produced by reputable or authoritative organisations, such as the European Commission and the OECD Global Science Forum, that were published between January 1995 and February 2019 in the English language. Literature searches were conducted of several electronic databases including Google Scholar, EBSCOhost and Web of Science. They were searched between February and March 2019, using pre-identified keywords including research, impact and value; general research impact terms (policy, economic, social); and specific natural hazard and emergency management terms including hazard, bushfire and wildfire.

From this initial search, bibliographies compiled by relevant authors were used in a 'snowballing' strategy to source seminal papers and additional relevant grey literature. Papers were also searched in Scopus to identify recent relevant citations. One hundred and four papers were identified from the initial search and snowballing process. Papers were excluded if: their primary focus was not on research value or impact; they did not include discussion of a model or framework for assessing research impact; they were published prior to 1995; or were supplements, letters or conference abstracts; Following an assessment of the title and abstracts of these papers based on these exclusion criteria, the full text of 40 articles were reviewed. Analysis of the full texts provided data for the summary of pre-imminent research impact frameworks and identification of the framework developed by Cruz Rivera et al. [6] as a robust foundation for the assessment of research impact in the disaster domain.

3. Defining research impact

The review of the frameworks first ascertained how they conceptualised and defined research impact. Alla et al. [5] conducted a systematic review of the 'research impact' field to clarify the definition of the policy impact of public health research. They identified three broad definitions of the impact of research most frequently referenced in health research impact papers. Research Councils UK defines research impact as "the demonstrable contribution that excellent research makes to society and the economy" [5] (p. 4). Higher Education Funding Council for England (HEFCE) shares a definition with the United Kingdom Research Excellence Framework (REF), with an outcome focus that research impact is "an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia"[5] (p. 5). These two definitions differ in their conceptual stance on impact, specifically the emphasis they place on the research process or outcome.

The Australian Research Quality Framework (RQF) and the Australian Research Council (ARC) have the broadest definition encompassing elements of the two previous. According to their definition, research impact is "a demonstrable contribution that research makes to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life, beyond contributions to academia" [5] (p. 5). This definition has been used in this paper, because disasters research has many potential impacts including protecting vegetation and soil (environmental), human safety (health and wellbeing), vital infrastructure (national security) and public and private land and capital (economic).

Kuruvilla et al. [7] note that different types of research are conducted with differing underlying purposes and therefore are expected to show diverse types and extent of impact. There is a lack of consensus in the literature on the terminology used to describe research impact [5], but most recognise the general domains of impact as economic, societal (social or broader impacts) [8], and academic (in its simplest form, measured using bibliometrics). The impact may be achieved via direct or indirect methods [9] and should be viewed from the perspective of the research field in determining whether the overall effect is positive or negative [8]. Nutley et al. [10] discuss various uses of research as being conceptual, symbolic and instrumental [7]. In relation to policy making, research findings are unlikely to be used instrumentally (that is, where it directly influences policy), but for general information or justification of decision making [7,11]. However, the instrumental use of research is easier to measure and is therefore a more obvious component of the value of research [12].

As specific natural disaster outcomes include loss of life, injury, destruction of property and disruption to infrastructure together with generalised social, economic and environmental impacts, any evaluation of research into natural hazards should consider the improvements in each of these areas [13]. As there are many end-users of disasters research, calculations of impact must consider the value created for each of these groups including:

- Emergency agencies that utilise research through training and increasing leadership and management skills [14–16]; in policy development [15,17–20]; to improve emergency response practices [21–23]; and management of prescribed burning and associated land use [20,24];
- Governments at all levels that use research findings to inform policy development [25], funding decisions (for example [26]), implementation; and Monitoring and Evaluation;
- Householders who are more likely to listen to advice when it is supported by credible evidence [27–29].

4. Considerations in assessing research impact

Our literature review found no frameworks to assess the impact of research specifically in the area of natural hazards, however many have been developed for the healthcare sector, so most of the following discussion is drawn from that evidence. We identify several key issues that must be considered when assessing research impact and designing research impact assessment frameworks.

The first key consideration when establishing an approach to assessing research impact is the purpose of the assessment. Adam et al. [76] describe multiple purposes of research impact assessment with four 'A's: advocacy, analysis, accountability, allocation. Indeed, our review finds that assessments of research impact are usually undertaken to demonstrate the nexus between research and evidence-informed policy and practice, to justify the provision of current funds or potential future agreements, or some combination of these [5–7,19,22]. In the case of disasters research, an assessment of research impact might be undertaken in order to trace the relationship between disasters research and improvements in risk or emergency management policy and practice. It might also estimate the return on investment in disasters research in terms of damages avoided and/or increased cost-effectiveness of emergency management provision.

We find evidence that using a research impact assessment tool while planning for dissemination and translation of research is likely to result in greater impact [6]. Managers of research programs are able to better manage limited resources with verifiable assessments of impact [6,7]. Protection of personal safety and property, reflecting concerns for accountability of research to individuals and society, appear central to assessing disaster research impact. The extent that disaster research clarifies returns on investment to disaster prevention, mitigation and response is also likely to be influential in assessments of its impact.

Alston et al. [30] argue that the choice of assessment tool is related to the purpose of research (although this is relevant only when assessing single or associated pieces of research). Assessments may be forward tracing, that is, starting from the research findings and tracing any resulting impacts, or backward tracing, commencing with a known outcome (e.g. a policy change) and tracing backwards to understand what research was at the beginning of the pathway of impact [9].

Second, we find that when assessing research impact, it is important to define the timeframe in which impact occurs. Newson et al. [9] describe how the impact of research can be measured at points along a sequence from research to policy impact. In the short term, process measures may be included as research impacts – that is, steps leading toward a measurable or demonstrable outcome. A policy decision is one demonstrable outcome [31], but longer term measures may be needed to account for changes in population health, behaviour change, socioeconomic change or environmental change arising from the policy impact, or from the research findings in other ways [9,32].Using expert judgement Handmer et al. [33] have defined short term impacts as those accruing within five years of the broad availability of research outputs while long term impacts are those experienced after fifteen years.

The third key consideration for assigning value to research is the question of "attribution", or causality [12,32,34]. In many cases, it is problematic to say with any certainty that specific research influenced an outcome, whether that is policy change, behaviour change, or environmental or economic change. Difficulties in attribution arise from long time lags between the dissemination of research findings, and any potential or perceived impact.

Fourth, we identify data availability and reliability as a key consideration. Data collection to support the assessment of research impact often involves interviewing researchers about the impacts they perceive from their research. This process is subject to potential bias. Corroboration of impact assessment can reduce uncertainty of its veracity and potentially increase the total measured value of the research [9]. Natural hazards research faces some unique challenges in gathering reliable data on the impacts of research. Communities subject to hazards may not be readily identifiable and changes in behaviour not generally researched or documented. Policy and program development in emergency management agencies are somewhat opaque and their development, involving a complexity of influences.

Finally, the issue of quantification is pertinent to many assessment endeavours. Impact can be measured qualitatively or quantitatively, with many approaches opting for mix-methods metrics. Quantitative metrics are often preferred because they can be seen to be more objective than qualitative ones, and monetised assessments are prized because of the primacy of cost-benefit analysis. While it is difficult to estimate the monetary value of all forms of research impact, some elements are amenable to other quantitative measurement. For example, the reach of research may be quantified by counting the number of individuals, agencies or institutions that are directly or indirectly affected by research findings [9].

4.1. Types of research impact

Cruz Rivera et al. [6] conducted a systematic review of methodological impact frameworks in healthcare research. They categorised frameworks as academic-oriented (using qualitative and quantitative methods to measure academic, societal, economic and cultural impact); as productive interaction oriented (between stakeholders and researchers); oriented toward researcher-policymaker partnerships; and toward impact pathway evaluation. In this paper impacts are discussed simply as economic, social and academic however they are inter-related and possibly overlapping descriptors. The pathways to research impact described by Georghiou [35] demonstrate these relationships. Research in the disasters field increases the stock of useful knowledge (academic impact); builds capacity by increasing the skills of workers, creating and strengthening research networks and enhancing user collaboration (academic impact, economic and social impact); improves and creates instrumentation, methodologies and technologies (economic and social impact); and supports current policy or promotes policy change or development (usually measured as social impact). Research makes a vital contribution to the knowledge economy and the innovativeness of society overall by thought leadership that results in innovations [35].

In the sections below we present findings from the literature review on economic, academic and social impacts. We then discuss frameworks or models for measuring research impact from the literature. It is important to note that in many cases reported in the literature, the economic impact of research is the only value assigned. However, often, especially for government investment in research, the purpose is not to create an economic benefit for the government but to generate health, safety, environmental and other benefits [36] so non-economic measures of impact are required to complement the economic measures.

Widely held misconceptions of 'natural' disasters as unpredictable, uncontrollable and having substantial private and public response and recovery costs create a major challenge to demonstrate a clear nexus been disaster research and efforts to predict, control and reduce individual and societal costs. Establishing a reliable estimate of substantial return on investment from disaster research faces challenges including quantification of intangible benefits arising from changes in the behaviour of individuals at risk; attributing costs of and benefits from individual and societal mitigation and response to specific research; and quantifying the extent to which the value of research is diluted in a chain of effect from research to impact.

4.1.1. Economic impact

Direct economic benefits of research may be enjoyed by the researchers and stakeholders themselves (for example increased productivity, new products), and also by others via "spillovers" [35]. Georghiou (citing Adam Jaffe) notes three distinct categories of spillovers - knowledge, market and network spillovers, which are related to the pathways that generate value. Indirect economic benefits can arise from improved operations due to a policy change. This is a major source of economic benefit in the disasters research domain: disasters research on risk management leads to better disaster risk management policies, which in turn result in less disaster damage.

As mentioned above, the literature places considerable importance on the quantification of the economic impact of research to the extent that the economic benefits are often viewed as the only real, tangible or reliable assessment category [37,38]. Bozeman and Sarewitz [12] note that economic assessments are most often categorised as either aggregate analyses (for example the natural hazard mitigation evaluation discussed by Godschalk et al. [39]), or those using social rates of return (most prominently, benefit-cost analysis), which offer a quantitative, monetised evaluation of research. Many governments, such as the Australian Government, mandate use of cost-benefit analysis to support 'better' decision making [40]. In Britain and the US federal government CBA is mandatory for flood mitigation projects.

However, quantitative estimates of economic impact are reliant on a number of assumptions based on subjective and qualitative assessments [11]. A key challenge for monetary estimates of research impact that is particularly pertinent in regards to disasters research, is the monetary estimation of non-market benefits i.e. assets not traded in the market such as environmental and cultural heritage. While there is considerable discussion in the literature on the utility of non-market valuation in research impact assessment, Rogers et al. [38] note that this form of valuation is not well understood, and therefore underutilised, by decision-makers. Pannell et al. [32] provide an explanation of how non-market valuation can be used in an environmental context to quantify changes (potential or real) in a characteristic influenced by research. This analysis can be applied to the disasters context including householder readiness and capacity of first response agencies to deal with a disaster.

Research projects subject to various methods of economic impact assessment and presenting significant themes are reported in Table 2 and summarised here. Greenhalgh et al. [11] note that monetisation models tend to be used at an organisational, institutional, governmental or broad research level rather than at a micro or case study level. Del Bo [50] evaluates various methodologies using case studies (i.e. micro level analysis). Alston et al. [30] discusses case studies of public research and development expenditure in agriculture.

Johnston et al. [51] discussed in Greenhalgh et al. [11] compare monetised health gains from clinical trials, measured in quality-adjusted life years (QALYs) and valued as GDP per head, using cost-utility analyses and actual usage of new interventions. Buxton et al. [52] reviewed all UK public and charitably funded cardiovascular research undertaken between 1975 and 1988 with health gains expressed as monetised QALYs. They note an internal rate of return of 9% per year plus non-health economic spill over effects of 30%.

Estimates from Australia of the societal benefit-cost ratio of investment in disaster research are between $1.17 and $1.40 [53]. In advocating for more investment in quality disaster resilience research, Deloitte Access Economics [54] asserts that by utilising better evidence to inform research investment, the benefit-cost ratio would increase from 1.25 to between 1.3 and 1.5, thereby generating savings for the Australian Government of between $500 million and $2.4 billion by 2050 (see p. 30). In a report of the Australian Business Roundtable for Disaster Resilience and Safer Communities, Deloitte Access Economics [55] provide a method of calculating the economic cost of the social impact of natural disasters. This methodology which is employed to impute a cost of the social impact of disasters, may also be productively applied to the calculation of cost savings resulting in prevention and/or better management of natural disasters that are attributable to research.

Del Bo [50], in her review, reports macro point estimates for the social rate of return to research and development of between 20% and 69% in large research infrastructures in Europe. Limited standardisation of the calculation of these estimates may contribute to the lack of precision. Lateral Economics [56] undertook a benefit-cost analysis of Australian medical and health research, calculating a cost-benefit ratio of 2.17 as reported in their Table 1 below (p. 54).

4.1.2. Academic impact

A narrow definition of academic research impact utilises measures of bibliometric output: primarily citations in the literature. This measure has been and still is the most widely used measure of the impact and value of research [6]. However, bibliometric output is only one component of the academic impact of research.

Cruz Rivera et al. [6] identify four sub-categories of "primary research-related impact" that suggest that academic impact should be measured by more than dissemination. They argue that academic research impact also encompasses advancing knowledge, building capacity and informing decision-making. Consistent with this, knowledge valorisation includes dissemination and knowledge transfer; capacity building, training, and leadership; and academic collaborations, research networks, and data sharing. Academic and research institutions within the disaster domain publish reports, working papers and journals and conduct conferences; provide education and training courses, workshops and seminars; and establish collaborative networks and infrastructure [5].

The Excellence in Research for Australia (ERA) evaluation by the Australian Research Council assesses the quality of research undertaken by Australian Universities and in 2018, assessed how well researchers engaged with end-users of research through the Engagement and Impact Assessment (EI). As part of evaluating academic research impact it examines the extent to which knowledge is advanced, capacity building occurs, and decision-making is better informed. For example, the Australian Research Council found that research work at the University of Tasmania aimed at protecting people and the environment from catastrophic bushfire Research had combined insights and tools from ecology, geography, and health sciences producing three key impacts: 1. On public policy and professional practice of fuel-reduction burning by the Tasmanian Fire Service (TFS) to prevent landscape fires, and use of environmental fire breaks by the Hobart City Council to protect the city; 2. on long-term environmental management of tall forests in the Australian alpine region, to ensure renewal of forests at risk of destruction by extreme fires; and 3. on public health practice, providing vulnerable people with tools to support management of chronic conditions aggravated by bushfire smoke [57].

Research also has an impact on future research by raising fresh research questions, targeting new research and providing knowledge upon which new research can be based; supporting improved capacity to undertake research, for example through the training of young researchers and personnel; ensuring a critical capacity to appropriately absorb and utilise existing research; and informing decisions about future research investment [11].

4.1.3. Social impact

Social impact, referred to in the literature as "societal" [8,58] and "broader" [48,59] impact or benefit, can encapsulate all elements of the domains identified in the research impact definition. Broad social benefits of research include economic growth (if not measured separately), productivity and employment; social values (of the area of research, for example environmental protection or protection of lives or mitigation of property loss); public goods (for example national security); influence on decision-making (including policy); and public behaviours including property preparation and decision-making during a hazard event [60].

Social impacts of research arise through contributions to a nation's social capital such as encouraging social reform, informing public debate, and improving policy making. Research can contribute to cultural capital by enhancing a nation's understanding of how it relates to other societies and cultures and by contributing to cultural preservation and enrichment.

Table 1
Benefit-cost analysis of Australian health and medical research, from Lateral Economics [56]. The economic value of Australia's investment in health and medical research. *Research Australia.*
Source: Lateral Economic simulation.

Item (ratios)	Australia	Rest of world	World
Revenue/costs ratio	1.05	1.06	1.06
Benefits/costs ratio[a]	2.17	2.14	2.14

[a] Simulation inputs adjusted to accord with Access Economics' estimate of this ratio for Australia.

Environmental impacts of research can enhance the natural capital of a nation by reducing waste and pollution and encouraging and facilitating recycling. Research can also contribute to a country's economic capital by strengthening the skills base and improving the productivity of land, labour, capital and enterprise [77,8]. Economic impacts of research are also generated through the development and delivery of standards, regulations, economic assessment and other frameworks dedicated to supporting policy and improvement.

These social impacts may accrue to individuals and organisations far removed from the source of the research. Within the emergency management domain for example, social impact and value through research that improves individual and organisational performance can reduce fatalities and injury and asset loss.

Policy impact, a major component of the broader category of social impact is extensively discussed in the literature. Kuruvilla et al. [7] note several points of reference for research impact assessment including the level of policy-making (at government, professional bodies, or organisational level); type of policy (for example, practice policies, service policies and governance policies); nature of policy use (instrumental, conceptual or symbolic related to direct or indirect influence, mobilisation of support and redefining/wider influence); the extent to which researchers are involved in, or inform, policy networks; and political capital (resulting from researchers' involvement in policy development). Following their systematic review, Cruz Rivera et al. [6] identified three research impact subgroups which incorporate Kuruvilla's assessment points – type and nature of policy impact, level of policy impact, and policy networks.

While various frameworks recognise, for research projects, programs and institutions, the importance of capturing and measuring the impact on policy, it is rare for findings from a single project to directly impact on policy direction [61]. This underlines the importance of research organisations or centres that strategically allocate research resources [62], and collaboration between policy makers and researchers in guiding research to areas of knowledge needed to increase the direct influence of research on policy [63,64].

System or sector-wide impact refers to the impact of research on a domain such as the healthcare or emergency management sector. Most research impact frameworks have been developed within health, so examples and subcategories detailed in the review conducted by Cruz Rivera et al. [6] are specific to that setting. However, there is considerable transferability of measures of system wide impact including evidence-based practice, improved information and information management, cost containment and cost-effectiveness, resource allocation, and workforce (days lost). Similarly, “health-related” impact measures such as knowledge, attitudes and behaviours; improved equity, inclusion and human rights, and literacy (referring to the ability of individuals to make informed decisions and reduce risk) are useful in other domains and particularly transferrable to disasters.

5. Frameworks or models to measure research impact

There is a diversity of frameworks for measuring research impact including those solely with an economic impact focus, and others applying a broader meaning of the value of research to projects, programs or institutions; there is no agreement on which is superior [6]. Table 2 presents the frameworks consistently referenced in the literature, that may be useful in assessing the impact of disasters research, and are discussed in what follows. A more detailed presentation of research impact frameworks identified in this review can be found in the supplementary material.

Frameworks may be constructed in various ways. Some are based on a conceptualisation of impact, focusing on the research process (measuring contributions, for example the Research Contribution Framework or the Contribution Mapping Framework), or on the outcomes (for example the Payback Framework and some of its derivatives). Some emphasise the inter-relatedness of, and map both, contributions and outcomes, at various points within the framework. The Canadian Academy of Health Sciences framework, which is now the ‘Alberta Innovates – Health Solutions (AIHS) Impact framework’, weighs equally, contributions and outcomes of research, illustrating the relationship between investment and impact. The Payback Framework developed by Buxton and Hanney [65], the Canadian Academy of Health Sciences framework described by Frank and Nason [41] and the Research Impact Framework developed by Kuruvilla et al. [7] have featured significantly in the literature. A plethora of contextually adapted frameworks has also evolved since the mid-1990s, using various starting points including the Payback Framework, CIHR framework, the CAHS model and the AIHS framework [6]. Research impact is also assessed without an overarching conceptual framework (for example, see the list in Table 2 of Newson et al. [9]). This may enable the satisfactory assessment of research impact of a single case, but lack of standardisation prevents comparison with other projects or assessment at an institutional or agency level [7].

The Payback framework developed by Buxton and Hanney [65] incorporates a logic model of the research processes and five categories of impact (paybacks). This framework is used in the United Kingdom and Canada [66] and in Australia in a range of health studies [52,67–70]. The resource intensiveness of this framework has led to its modification to reduce resource demands [11].

The Co-produced Pathway to Impact (CPPI) assesses social, economic and health-related impacts of research funded by the Networks of Centres of Excellence (NCE) program [71]. It has evolved to be a flexible tool with broad application to a variety of research areas and institutional environments (http://researchimpact.ca/incremental-changes-to-the-co-produced-pathway-to-impact/). It includes assessment of academic (scholarship and capacity) and social impacts (practice and policy, society and culture, and economy) [72]. Continuous improvement to the framework has resulted in the current version reproduced below (posted January 22, 2019 to researchimpact.ca) (Fig. 1).

The Australian Research Council (ARC) has responsibility for the administration of the Engagement and Assessment framework (ERA) across higher education institutions. The framework assesses various indicators to rank higher education institutions' research impact to encourage continuous improvement and to identify opportunities.

The Research Impact Framework (RIF) presented by Kuruvilla et al. [7] is not an evaluative tool and does not assign priority to any impact. It is a “practical tool to help researchers think through and describe the impact of their work” (p. 3). Table 3, adopted from Kuruvilla et al. [7] lists health related outcomes for each of the broad impact categories - research related, policy, service and societal impacts are applicable to other domains. Service and some societal impacts specific to the health area correspond to similar impacts in other areas of research. Research-related impact is a broader category than applied in other frameworks which tend to simply assess number of citations and other easily identified bibliometrics as the extent of academic impact. The framework has been tested for validity and usefulness however the authors note that, as researchers employ self-assessment of research impact, findings may be prone to bias.

Public value is the value created by governments by making laws and regulations, providing services and undertaking other activities. In a democratic society, this value is defined by the community. Economic and public value overlap. Public values may be interdependent (although not necessarily), and in certain cases, conflicting. This necessitates a contextual prioritisation of values [73].

Public value mapping of science outcomes is described by Bozeman and Sarewitz [12] as a way to consider non-economic and non-scientific measures of the goals of research that are their core values (termed “public values”). It is “an approach to identifying the public value premises of public policy and then tracking their evolution and impacts on policies and, ultimately, social outcomes” (p. 13). It has been proposed as a tool for research and program funding allocation and for measuring the impact of research evidence [73,74]. Case study contextual analysis maps public goals to research activities, impacts and outcomes, using a causal logic theory. Impact and outcome measures are derived from aggregate social indicators or measures of social well-being. Bozeman and Sarewitz [12] recognise limitations of the approach, particularly in measuring innovation

Table 2
Summary of frameworks.

Framework/model	Cited in/used by	Characteristics	Domain(s) of impact	Assessment categories	Methods/description
Payback Framework	Newson et al. [9] Cruz Rivera et al. [6] Wooding et al. (2014)[75] Bowden et al. [26]	Forward tracing Mixed methodology – qualitative and quantitative	Economy Society Public policy or services Health Academia Quality of life	- Knowledge production - Benefits to future research and research use - Benefits to informing policy and product development - Health and sector benefits - Broader economic benefits	Developed by Buxton and Hanney Two elements – logic model of the research processes - Five categories of impact (paybacks)
CAHS (Canadian Academy of Health Sciences)	Frank and Nason [41] Now adapted further to AIHS framework	Mixed methodology – qualitative and quantitative	Economy Health Knowledge Society Capacity building Policy	- Advancing knowledge - Capacity building - Informing decision--making - Health benefits - Broad economic and social benefitsLibrary of 66 indicators	Adapted Payback model – combination of impact category with logic
Alberta Innovates – Health Solutions (AIHS)	Cruz Rivera et al. [6] Table 1 p. 7	Mixed methodology – qualitative and quantitative		- Advancing knowledge - Capacity building - Informing decision--making - Health benefits - Broad socioeconomic impact - Organisational performance	A framework to measure, assess, and illustrate the relationship between research investment and impact. Cruz Rivera p. 7 Table 1
Research Impact Framework (RIF) and Adapted RIF	Kuruvilla et al. [7] Newson et al. [9] Bunn and Kendall [42]	Both forward and backward tracing qualitative	Policy	- Research-related, policy, service and societal impacts - Citations - Mentions of research in policy docs - Interviews –awareness of ways research influenced policy	Adapted from Payback Framework. Documentary review of policy documents, citation analyses, interviews with researchers
Research Contribution Framework	Newson et al. [9] Cruz Rivera et al. [6] Morton [43]	Both forward and backward tracing qualitative and quantitative	Policy	- Final outcome - Policy or practice change - Capacity, knowledge and skill - Awareness, reaction - Engagement, participation - Activities and outputs/inputs	Uses contribution analysis to explain the influence on both policy and practice
Public value mapping (PVM)	Noted in [44] Described in [45] Discussed in [12] Geuijen et al. [46] – public value theory (theoretical base for PVM)	Not applicable	Policy	Public failure criteria [12] (p. 17) - mechanisms for values articulation and aggregation - imperfect monopolies - scarcity of providers - short time horizon - substitutability vs conservation of resources - benefit hoarding	Inclusion of a public value scorecard (like the balanced scorecard but reflective of public value) Public values are non-scientific, non-economic goals (social change); although economic values may in some instances qualify as public values "Put simply, public value mapping is an approach to identifying the public value premises of public policy and then tracking their evolution and impacts on policies and, ultimately, social outcomes" [12], Methods (B&S 2011 p. 19): 1. search for relevant public values 2. application of criteria (expand and refine criteria) 3. value analysis chains incl. relationships 4. graphically display using public values failure grid
Social Impact Assessment Method (SIAMPI)	[47]	Qualitative	"Social" impact Culture Community, health and wellbeing Livelihood and economy Governance and politics	Changes in - Culture - Community, health and wellbeing - Livelihood and economy - Governance and politics - Environment - Fears and aspirations of people [48]	Data collection: survey, in-depth interviews, case studies Evidence of observable and most significant changes to the categories (attribution problem reduced)

Table 2 (*continued*)

Framework/model	Cited in/used by	Characteristics	Domain(s) of impact	Assessment categories	Methods/description
CPPI: Co-produced pathway to impact	[49]	Mixed – qualitative and quantitative	Social Academic Policy Economy	Scholarship Academic capacity Practice and policy Society and culture Economy	Further developed from CAHS model to reflect the impact during the research process on collaborators and stakeholders; and to have broader reach than health. See initial post http://researchimpact.ca/the-co-produced-pathway-to-impact-la-trajectoire-dimpact-codeterminee/ And update with changes http://researchimpact.ca/incremental-changes-to-the-co-produced-pathway-to-impact/
Cooperative Research Centres (CRC) impact model	All Australian Cooperative Research Centres in the application for funding process.	Forward tracing. Mixed methodology – qualitative and quantitative	All domains of impact are monetised.	Production of research outputs Uptake of research outputs by users Impact of user uptake	Articulates process by which research impact/value for end users and/or the community is achieved through measuring inputs, activities, outputs and usage.

and capacity, and value-laden metrics such as quality of life but demonstrate progress toward assessment of goals such as decreased loss of life or cleaner air. The use of market prices is problematic in assessing research impact through public value. They are 'weak partial indicators of the social value of research and research outcomes' (p. 15) and market value is inappropriately used in assessing distribution and equity impacts.

Public value theory is also useful in the planning stages of research, particularly in areas exploring "wicked problems" [46]. Marton and Phillips [22] discuss the need for delivering public value in the specific area of bushfire management and recovery and noted that it is essentially based on individual perception of stakeholders (governments, agencies, householders). Its use in planning or evaluation of research requires prior consensus between those involved. The public value approach can also be used to assess the performance of public service organisations [45]. Private sector accounting does not reflect value-making in the public sector which requires consideration of achievement of public goals through efficient utilisation of resources (money and authority) [73].

Financial proxies may be used to approximate public value and as a starting point for a cost-benefit analysis. The New Economy Manchester unit cost database addresses a range of domains (including fire) and uses a range of social and economic proxies, although only economic costs are currently included for fire. Proxies from this database were used to monetise social outcomes relating to the Citizens Advice services in England and Wales, with a direct return on investment of $1.96 for each $1 invested; and a further $11.98 in wider economic and social benefits and $13.06 for people helped by Citizens Advice [74].

6. Discussion

The value of research is most appropriately defined in broad terms encapsulating economic, social, cultural, environmental and other contributions that are additional to academic outputs through its conceptual, symbolic and instrumental use. Research use and its consequent impact and value in the natural hazards domain is likely to derive from: application to policy and practice, emergency response and training and management; use by hazard prone householders in their risk assessment, personal and property preparation and protective action decision-making; and government policy and program formulation, priority setting and funding decisions.

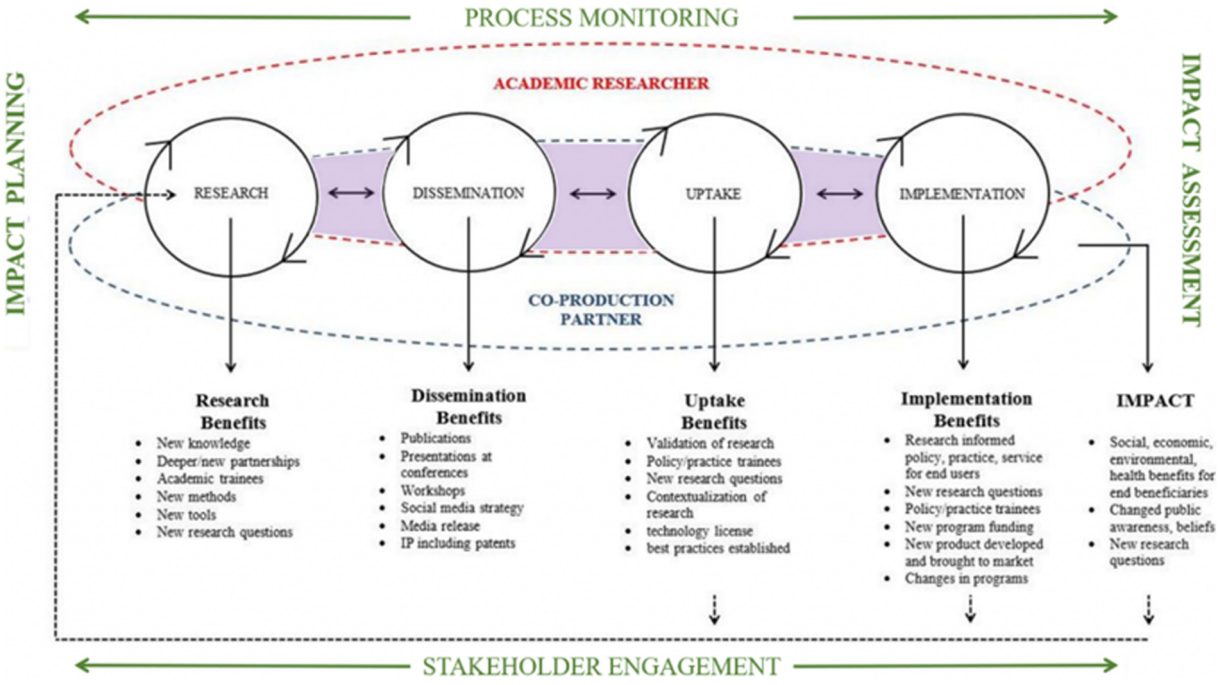

Fig. 1. Co-produced pathway to impact (image reproduced from researchimpact.ca).

Table 3
Research impact matrix.

Research-related impacts	Policy impacts	Service impacts	Societal impacts
• Type of problem/knowledge • Research methods • Publications and papers • Products, patents and translatability potential • Research networks • Leadership and awards • Research management • Communication	• Level of policy-making • Type of policy • Nature of policy impact • Policy networks • Political capital	• Type of services: health/intersectoral • Evidence-based practice • Quality of care • Information systems • Services management • Cost-containment and cost-effectiveness	• Knowledge, attitudes and behaviour • Health literacy • Health status • Equity and human rights • Macroeconomic/related to economy • Social capital and empowerment • Culture and art • Sustainable development outcomes

The literature suggests that an assessment of research impact should take account of the broad parameters of effect over the short, medium and long term. The impact should ideally also be demonstratable, attributable, and quantifiable. Establishing and measuring research impact within these strictures is however extremely challenging and likely to result in underestimation due to the difficulties of attribution and the measurement of intangible benefits.

If well-informed assessments are to be made, means of identifying and attributing effect, measuring outcomes and valuing intangible and other non-market-based outputs must be identified and agreed between stakeholders. This process may be informed by the guideline suggested by Kuruvilla et al. [7] or a similar framework which provides a practical base for identifying the parameters to be considered in assessing research impact.

Economic and societal impacts related to academic research translate into research value depending on the specific circumstances of the research and the context in which it is interpreted and used. The impacts of research suggested by Georghiou's [35] pathways will vary significantly depending on the nature of the research. The stock of knowledge, methodological improvement, skills and capacity building and policy change and development are likely to be differentially represented in total research impact depending on the nature of the research. For example, research on vegetation management or bushfire suppression may contribute to management, training and practice improvement while research on human behaviour in bushfire may produce insights that contribute to the knowledge base, policy development, worker and community capacity improvement and collaboration.

A framework that can capture the diversity of the components of research impact must therefore be broadly based and capable of effective customisation to specific research project(s) or context. An approach that combines logic model development and case study narrative analysis, as described by the most popular of the frameworks is likely to balance the contribution and outcomes approaches [11].

The broad categories of impact assessment - academic impact, economic impact, and social impact should be capable of further refinement into themes, specific criteria or points of assessment, which can be used to assess a particular research area, institution or project. Cruz Rivera et al. [6] pathways to research impact diagram as a basis for the measurement of

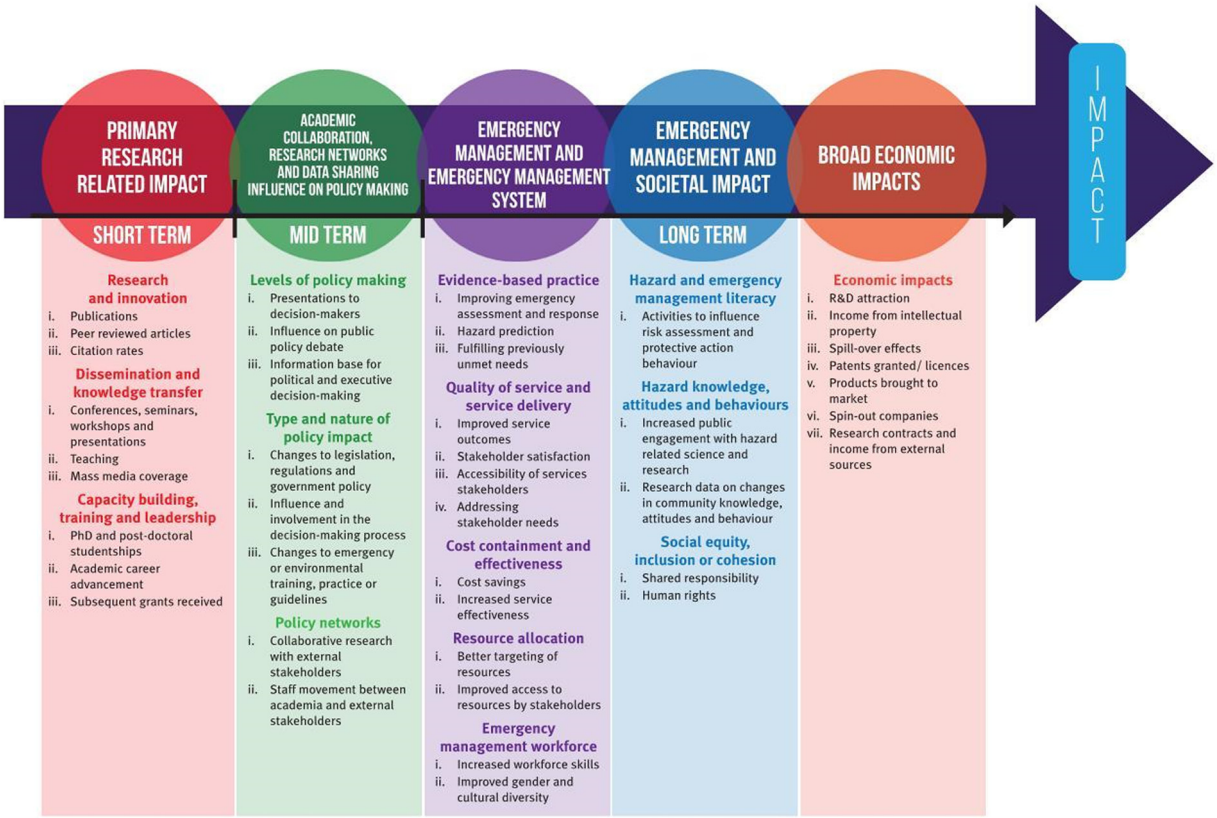

Fig. 2. Pathways to research impact in the disaster domain.
Adapted from Cruz Rivera et al. Assessing the impact of healthcare research: A systematic review of methodological frameworks. PLoS medicine, 14, 2017.

healthcare research impact can assist impact assessment and decision-making in other domains. This framework provides decision-making prompts for measuring research impact in the short, medium and long-term taking account of both the research process and the ultimate outcomes. While research impact is represented as a linear process, it is conceptualised as involving simultaneous actions and outcomes and complex feedback effects along multiple pathways to impact. The pathway diagram is designed to comprehensively trace research impact by combining all the impact metrics in frameworks reviewed by Cruz Rivera et al. [6], assembling those metrics into impact subgroups, and combining these into broader impact categories.

The framework is capable of customisation for research impact assessment in the natural hazard domain. It is likely to be broadly acceptable to governments, government agencies and researchers in the natural hazard domain due to its conceptual and methodological strength, broad applicability to actual research projects, capability in demonstrating impact on the public good, and reflectiveness of availability of data. The pathways to research impact diagram have been adapted for use in the natural hazards area (Fig. 2).

7. Conclusion

This paper reviews the literature on the impact of research and its value with the aim of adapting an appropriate framework for the conceptualisation and measurement of research impact in the domain of disaster risk and emergency management research.

Scientific research involves the application of scientific method to investigate relationships amongst phenomena or to solve a problem. Worldwide, research institutions, governments and funders increasingly aim to assess and to promote maximum research impact to better: make the case for research; understand how science works and how to shape it; ensure accountability to individuals and society; and effectively allocate resources.

Based on widely used definitions, research has impact if it contributes to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life, beyond purely academic outputs.

A diversity of frameworks to conceptualise and measure research impact was identified in our review, especially in the health domain. They variously focus on the research process, for example the Research Contribution Framework or on outcomes (the Payback Framework and its derivatives). Some such as Health Solutions (AIHS) Impact framework emphasise the inter-relatedness of both contributions and outcomes. A few contextually adapted frameworks and their derivatives, that evolved since the mid-1990s, feature significantly in the literature including the Payback Framework, CIHR framework, the CAHS model and the AIHS framework.

These frameworks attempt, to varying extents, to address the challenge of demonstrating an impact, attributing that impact to the research and measuring and quantifying that impact. They need to be broadly based to capture diverse academic, social, and economic impacts in the short, medium and long term. The frameworks must be conceptualised in a way that facilitates the identification, measurement and quantification of process and outcomes. The framework developed by Cruz Rivera et al. [6] is capable of capturing the diversity of the research impact components and has been customised in this paper as a tool for the assessment of research impact in the hazards domain including wildfire.

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.

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