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THE VALUE OF DISASTER RESEARCH: A REVIEW OF THE LITERATURE

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Cover: Fire emergency services respond to the 2011 Christchurch earthquakes. Picture: John McCombe, Fire and Emergency New Zealand

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EXECUTIVE SUMMARY

Increasingly, funders, governments, stakeholders and end-users expect to see tangible evidence that an investment in research is a worthy use of resources; that it informs policy and practice; or to justify the provision of current and future funding. The value of research is measured by assessing the extent to which research has impact. Research impact is defined as "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" (Alla et al.). These value-outcomes are achieved via the pathways of knowledge generation, capacity building, creation of scientific methods, researcher and end-user network collaborations, and policymaking support. Bushfire and natural hazard research evidence is utilised by emergency and fire agencies, governments, policymakers, and householders and landowners.

Research impact assessment is undertaken with the aim of addressing advocacy, analysis, accountability and allocation. It is also a valuable tool for use whilst planning research to ensure a greater impact. A major problem associated with research impact assessment is that of attribution: it is extremely difficult to assign causality for any outcome to a specific piece of research. This difficulty is exacerbated by the usually large time lag between research findings and policy impact, behaviour change, or change in environment or economy.

Various frameworks have been developed to assess the impact of research; whilst the majority of those reviewed were developed for the healthcare sector, there are more broad frameworks which have evolved to encompass a breadth of research areas and level of research. Impact has generally been categorised as economic (direct influence on the economy of the researcher, agency, population, or government as well as knowledge, market and network spill overs); academic (influence within academia, researcher and end-user collaborations, capacity building, training and leadership); and social or societal (a broad category including social values, national security, influence on policy and decision making).

Economic impact has largely been measured using cost-benefit analysis or a return on investment approach (including a social return on investment). Over the effect life cycle, public research is valued at 3 to 8 times the initial investment. Median annual rates of return are between 20% and 50% but this varies considerably between sectors. (Georghiou (2015)) . At an aggregate level, the return on investment in Australian disaster research has been estimated at between $1.17 to $1.40 for each dollar invested (Access Economics, 2003, Access Economics, 2008) . As most of the research within the natural hazard sector does not produce goods or services which pass through a market, a non-market method of valuing outcomes is required. The application of public value theory has created methodologies including public value mapping to understand the non-economic and non-scientific goals of research; that is, the core values (public values) of the research.

There is no specific framework for assessing the value of research in the bushfire and wildfire context, however adaptation of the "pathways to research impact" tool created by Cruz Rivera et al. (2017) may be helpful in achieving appropriate impact measurement.

DEFINING THE VALUE OF RESEARCH

Alla et al. (2017) conducted a systematic review to understand the definition of the policy impact of public health research. They identified three broad definitions of the impact (aka value) of research that are most frequently referenced in health research impact papers; which are also applicable to other research domains and in a more general sense than policy impact. The first two definitions differ in their conceptual understanding of impact; that is, in placing a greater emphasis on the research process or on the outcome; and the last is a hybrid definition.

1. Research Councils UK defines research impact as "the demonstrable contribution that excellent research makes to society and the economy" (Alla et al.).
2. 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" (Alla et al.).
3. The Australian Research Quality Framework (RQF) and the Australian Research Council (ARC) have the broadest of the most popular definitions, encompassing elements of both of the two previously stated definitions. 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" (Alla et al.).

Kuruvilla et al. (2006) note that different types of research are conducted with differing underlying purposes and therefore are expected to show diverse types and degree of impact. Whilst there is a lack of consensus in the literature on the terminology used to describe research impact (Alla et al., 2017), most of the literature recognises the general domains of impact to be economic, societal (aka social or broader impacts (Bornmann, 2013)), and academic (in general, measured using bibliometrics). The impact may be achieved directly or indirectly (Newson et al., 2018); and should be viewed from the perspective of the field of research when determining whether the effect is positive or negative (Bornmann, 2013). Nutley et al. (2007) discuss various uses of research as being conceptual, symbolic and instrumental (Kuruvilla et al., 2006). In policy making, the use of research findings is less likely to be instrumental (that is, where it directly influences policy) and is more often used for general information or for justification of decision making (Greenhalgh et al., 2016, Kuruvilla et al., 2006). It is likely that the instrumental use of research is easier to measure and is therefore a more obvious component of the value of research (Bozeman and Sarewitz, 2011).

Georghiou (2015) identifies pathways to generate value from research, which align loosely to the outcomes noted in the most popular definitions:

- Increasing the stock of useful knowledge (through publications, commercialisation, and creation of intellectual property)
- Capacity building (training skilled people)
- Creating scientific methods and methodologies
- Collaboration in further research projects and creating networks with end-users of the research
- Supporting current policy or impacting on policy change or development

As natural disaster outcomes include loss of life, injury, destruction of property and disruption to infrastructure; together with social, economic and environmental impacts, any evaluation of research into natural hazards should consider the improvements in each of these areas (Hemingway and Gunawan, 2018). The end-users of bushfire and natural hazards research are numerous including emergency and fire agencies, all levels of government, non-government organisations, business and households; and any value calculations must consider the value created for each of these groups.

- Emergency and fire agencies may utilise research in many ways, including training and increasing leadership and management skills (Granito, 2016, Owen, 2017, Owen and Martin, 2017); in policy development (Ruane, 2018, Owen, 2017, Haque et al., 2018, Gibbs et al., 2018); and to improve emergency response practices (Plucinski et al., 2017, Marton and Phillips, 2005, Adams et al., 2013, Kerber, 2015).
- Governments at all levels may use research findings to inform policy development (Pannell and Roberts, 2009) and funding decisions (for example Bowden et al. (2018)).
- Decision-making around management of prescribed burning and associated land use has been informed by research findings (Ruane, 2018, Altangerel and Kull, 2013).
- Householders and land owners are more likely to take heed of advice when it is backed by evidence (Liu and Jiao, 2018, Maddock, 2014, Gibbs et al., 2016).

ASSESSMENT OF RESEARCH IMPACT

Assessment of research impact is usually undertaken to demonstrate the value of research to evidence-informed policy and practice, or to justify the provision of current funds or potential future agreements (Alla et al., 2017, Haque et al., 2018, Kuruvilla et al., 2006, Cruz Rivera et al., 2017, Marton and Phillips, 2005). It has also become evident that using a research impact assessment tool whilst planning for dissemination and translation will likely result in greater impact (Cruz Rivera et al., 2017). Managers of research programs can better manage limited resources with verifiable assessments of impact (Kuruvilla et al., 2006, Cruz Rivera et al., 2017). Adam et al. (2018) describe the purposes of research impact assessment with four 'A's: advocacy, analysis, accountability, allocation. Alston et al. (2000) 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). There is a paucity of framework development in the area of natural hazards however much work has been done in the healthcare sector, so most of the following discussion is drawn from this literature.

Assessments may be forward tracing, i.e. starting from the research findings and tracing any impacts, or backward tracing, commencing with a known outcome (e.g. a policy change) and tracing backwards to understand the pathway of impact (Newson et al., 2018).

Newson et al. (2018) describes the impact of the research can be measured at various points along a chain 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 (Collins et al., 2017), 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 (Pannell et al., 2018, Newson et al., 2018).

Adam et al. (2018) developed a 10-point guideline for considerations when undergoing a process of research impact assessment, which can be utilised in all areas of research; and which provide

direction in evaluating models to undertake assessment. These are:

- Context
- Purpose
- Stakeholders' needs
- Stakeholder engagement
- Conceptual frameworks
- Methods and data sources
- Indicators and metrics
- Ethics and conflicts of interest
- Communication
- Community of practice

Quantifying the impact

When assessing the impact of research, the reach can be quantified – how many people (or agencies or institutions) have been directly or indirectly affected positively by the findings and translation (Newson et al., 2018)? Where policy impact is measured, the value is affected by the significance or importance of policy change (or support for existing policy).

One of the major problems in assigning value to research is that of "attribution", or causality (Pannell et al., 2018, Bozeman and Youtie, 2017, Bozeman and Sarewitz, 2011). In many cases, it is extremely problematic to say with any certainty that a certain piece of research influenced an outcome, whether that is policy change, behaviour change, or change in environmental or economic circumstances. This is especially difficult where there is often a large time lag between conducting the research and disseminating the findings, and any potential or perceived impact. In addition, data collection to assess impact often involves interviewing researchers about the impacts they believe have occurred and this is prone to bias. Where possible, corroboration of impacts will reduce this uncertainty and increase the value of the research (Newson et al., 2018).

Authors have categorised impact under various headings. Cruz Rivera et al. (2017) 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), productive interactions (between stakeholders and researchers), researcher-policymaker partnerships, and impact pathway evaluation. For ease of discussion, we have described various impacts under the headings of economic impact, academic impact and social impact; however, these are inter-related and, in some cases, overlapping descriptors. The pathways described by Georghiou (2015)demonstrate these relationships.

- Increasing the stock of useful knowledge (academic impact)
- Capacity building through increasing skilled workers, research networks and user collaboration (academic impact, as well as economic and social impact)
- Creating scientific methods and methodologies (economic and social impact)
- Supporting current policy or impacting on policy change or development (usually measured as social impact)

Economic impact

In many cases in the literature, the economic impact of research is the only value placed on it. However, especially for government investment in research, the purpose of the research is often not to create an economic benefit for the government but rather for other public benefits relating to health, safety, and environment (du Plessis and Krüger, 2018); and therefore non-economic measures of impact should be employed to complement the economic measures.

Evidence on public investment in research that links research and innovations in the market across a variety of industries demonstrate high rates of return. Over the life cycle of effects, the value of public research is 3 to 8 times the initial investment and median annual rates of return are between 20% and 50%. Rates of return vary between industries, types of innovations, and by type of sponsor (Georghiou (2015)) .

Australian calculations of net benefits to society from every dollar invested in disaster research are between $1.17 and $1.40 (Access Economics, 2003, Access Economics, 2008). In an argument for more investment in good research, Deloitte Access Economics (2014) assert that by utilising better evidence to inform hazard resilience investments, the cost-benefit 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 to 2050 (see p. 30). Del Bo (2016) reports point estimates at a macro level for the social rate of return to research and development of between 20% and 69% although limited standardisation in calculation of these results may contribute to the lack of precision. Lateral Economics (2010) conducted a cost-benefit analysis of Australian medical and health research, with the results reported in Table 1 below (p.54)

Table 1: Cost-benefit ratios of Australian medical and health research

Table 3.1: Cost benefit analyses of Australian health and medical research

(Ratios)

Item	*Australia*	*Rest of World*	*World*
Revenue/Costs ratio	1.05	1.06	1.06
Benefits/Costs ratio (a)	2.17	2.14	2.14

Notes: (a) Simulation inputs adjusted to accord with Access Economics' estimate of this ratio for Australia.

Source: Lateral Economics simulation (Attachment A).

The importance of quantifying the economic impact of research is well documented in the literature; in fact, in many impact assessments, the economic benefits are viewed as the only "real" assessment category. Economic benefits may be enjoyed by the researchers and sponsors (for example increased productivity, new products); but there are "spill overs" which ensure that not only the researchers and stakeholders benefit (Georghiou, 2015). Georghiou (citing Adam Jaffe) notes three distinct categories of spillovers – knowledge, market and network spillovers; which are related to the pathways to generate value. It is important to note that whilst a quantitative estimate of economic impact may be calculated, it is reliant on a number of assumptions which are made via subjective, qualitative assessment (Greenhalgh et al., 2016).

Bozeman and Sarewitz (2011) note that economic assessments are most often categorised as either aggregate analyses (for example the natural hazard mitigation evaluation discussed by Godschalk et al. (2009)), or those using social rates of return (most prominently using benefit-cost analysis), which

offer a better practical evaluation of research. The Australian Government mandates use of cost-benefit analysis to support better decision making, but also allows an estimation of non-market benefits (discussed below) (Australian Government, 2007). Adams and Morse (2019) propose that cost effectiveness ratios and bibliometric citation counts can be seen as rough proxies of the rate of return to public investment in research infrastructures.

Whilst there is much discussion in the literature surrounding the utility of non-market valuation in research impact assessment, Rogers et al. (2015) note that it is not well understood, and therefore underutilised, by decision-makers. Pannell et al. (2018) provide an explanation of how non-market valuation can be used to quantify changes influenced by environmental research (potential or real) in a key characteristic, which can be translated to the natural hazard context (for example, householder readiness, or capacity of first response agencies to deal with a disaster).

Research evaluated for economic impact

Greenhalgh et al. (2016) note that monetisation models tend to be used at an organisational, institutional, governmental or broad research area level rather than at a micro, case study, level. Del Bo (2016) discusses many case studies (i.e. micro level) and evaluates various methodologies while Alston et al. (2000) also reports case studies of public research and development expenditure in agriculture.

Johnston et al. (2006), discussed in Greenhalgh (2016), compares monetised health gains from clinical trials, measured in Quality Adjusted Life Years (QALY) and valued at GDP per head, using cost-utility analyses and actual usage of new interventions.

Health Research Impact (2008) examines all UK public and charitably funded cardiovascular research 1975-1988. Health gains are expressed as monetised QALY's and an internal rate of return of 9% per year plus non-health economic spill-over effects of 30% are reported.

Access Economics and Deloitte Access Economics mentioned earlier – quantified returns from all Australian health R&D spending

Academic impact

A very narrow definition of research impact utilises bibliometric measures (primarily citations in the literature), which historically were most widely used to demonstrate the value of research and remain the most common measurement of impact (Cruz Rivera et al., 2017). However, the most commonly used definitions of research impact acknowledge that impact in academia is only one component of the value of research. [See discussion of Research Impact Framework under Frameworks in relation to the extension of academic impact]

Cruz Rivera et al. (2017) include four sub-categories under the major impact heading of "primary research-related impact", which reflect the need to measure academic impact beyond dissemination metrics (the narrower definition of academic impact), and which encompasses the concept of knowledge valorisation (Alla et al., 2017). These sub-categories are:

- research and innovation outcomes
- dissemination and knowledge transfer
- capacity building, training, and leadership
- academic collaborations, research networks, and data sharing

Social impact

Social impact is referred to in the literature under various designations, including "societal" (Bornmann, 2013, Suk et al., 2018) and "broader" (Dames et al., 2015, Hiruy and Wallo, 2018) impact or benefit. No matter the nomenclature, the concept covers 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, protection of lives or mitigation of property loss), public goods (for example national security), and the influence on decision-making (including policy) and public behaviours including property preparation and decision-making during a hazard event (National Research Council, 2011). In a report of the Australian Business Roundtable for Disaster Resilience and Safer Communities, Deloitte Access Economics provide a method of calculating the economic cost of the social impact of natural disasters (2016). The methodology employed by Deloitte Access Economics to impute a cost to the social impact of disasters, may be relevant to the calculation of cost savings attributable to research resulting in prevention and/or better management of natural disasters.

Policy impact

Policy impact is one of the major components of the broader category of social or societal impact, and is extensively discussed in the literature. Kuruvilla et al. (2006) note several impact assessment issues: 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 the direct or indirect influence, as well as 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. (2017) identified three impact subgroups which include Kuruvilla's assessment categories– type and nature of policy impact, level of policy impact, and policy networks. It is noteworthy that while various frameworks (discussed later) recognise the importance of capturing and measuring the impact of research projects, programs and institutions on policy, it is rare for findings from a single project to directly impact on policy direction (Boa et al., 2010). This underlines the importance of a boundary organisation such as a Centre for Research Excellence, to assist in the allocation of research resources (Beaven et al., 2017). Policy makers and researchers should collaborate to increase the direct influence of research on policy, by guiding research to areas of knowledge need (Dovers et al., 2004, Ismail-Zadeh et al., 2017).

Systems impact

Systems (Sector wide) impact refers to the impact on the service area under assessment, for example the emergency management sector or the healthcare system. As most frameworks have been developed within the health setting, the examples and subcategories detailed in the review conducted by Cruz Rivera et al. (2017) are specific to health. However, there is some transferability of sub-categories to other areas of research; for example, evidence-based practice, improved information and information management, cost containment and cost-effectiveness, resource allocation, and workforce (days lost). Similarly, measurement is possible for some sub-categories under "health-related" impact: 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. In the emergency management sector literacy relates to householder preparedness.

FRAMEWORKS OR MODELS TO MEASURE RESEARCH IMPACT

There are many frameworks developed to measure research impact in various areas of research. In addition to those listed in the Economic Impact section which have focussed on measuring solely the economic impact, there are several which have been developed and tested in an attempt to elicit a broader understanding of the value of projects or of research programs or institutions. However, as Cruz Rivera et al. (2017) state, "Currently, there is a debate surrounding the optimal methodological impact framework, and no tool has proven superior to another"(p.19). Among other frameworks is the "Cooperative Research Centres Impact Tool" which estimates the expected net benefit of the CRC and a benefit-cost ratio (Department of Industry, Innovation and Science, n.d.).

The frameworks may be aligned to the conceptual understanding of impact; whether they focus on the research process (measuring contributions, for example the Research Contribution Framework or the Contribution Mapping Framework) or the outcomes (for example the Payback Framework and some of its derivatives), or recognise the inter-relatedness of these measures and map both contributions and outcomes at various points on the framework.

The frameworks developed by the Canadian Academy of Health Sciences, which evolved into the Alberta Innovates – Health Solutions (AIHS) Impact framework is a good example in the health sector of giving similar weight to the contributions and outcomes of the research; ultimately illustrating the relationship between investment and impact. Cruz Rivera's "pathways to research impact" diagram reproduced on page 17 of this paper was developed as a tool to provide decision-making prompts around measuring the impact of research over the life time of effects and draws on the AIHS framework and others in recognising the importance of both the research process, and the ultimate outcomes.

Whilst there are frameworks which have featured more significantly in the literature (for example Payback Framework developed by Buxton and Hanney, Canadian Academy of Health Sciences described by Frank and Nason (2009), Research Impact Framework developed by Kuruvilla et al. (2006)), a plethora of adapted frameworks has evolved (Cruz Rivera et al., 2017). Table 2 summarises several frameworks that may be suitable for assessing impact in hazard and bushfire research. However there are many examples in the literature where research impact has been assessed without the benefit of utilising an overarching conceptual framework (for example, see the list in Table 2 of Newson et al. (2018)). This may result in a satisfactory assessment of the impact of research in a single case study, however does not allow for a standardisation of assessment for comparative purposes, or to assess impact at an institutional or agency level (Kuruvilla et al., 2006).

A better approach appears to be the combination of the logic model and case study narrative analysis, as described by the most popular of the frameworks and which is more likely to balance the contribution and outcomes approaches (Greenhalgh et al., 2016).

Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
Payback Framework	Described by Newson et al. (2018) and Cruz Rivera et al. (2017) - reviews Wooding et al. (2014) - cardiovascular research translation Bowden et al. (2018) -Australia: cancer funding (Also see list of references in Table 1 of Reale et al. reproduced below)	Forward Mixed – qual and quant	Economy Society Public policy or services Health Academia Quality of life	Single project (case studies)	-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) To assess knowledge production – publications audit Bowden et al also surveyed recipients of funding to assess the other categories Economic valuation: -attracting further funding -innovations to reduce cost or produce income -length or quality of life
CAHS (Canadian Academy of Health Sciences)	Development described by Frank and Nason (2009), cited in Rivera review Now adapted further to AIHS framework	Mixed – qual and quant	Economy Health Knowledge Society Capacity building Policy		Categories -Advancing knowledge -Capacity building -Informing decision-making -Health benefits -Broad economic and social benefits Library of 66 (validated)	Adapted Payback model – combination of impact category with logic See Fig 1 (p,530) for schematic compared to Payback model Can use impact frameworks such as Balanced Scorecard for specific program and project comparisons, to evaluate progress against targets; but then also is able to explain how impacts occurred (and how to improve them) “Framework focused on evaluating how research activity influences decision making in order to improve health, the economy, and

Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
					preferred indicators - select	social benefits", Cruz Rivera p.7 (Table 1)
Alberta Innovates – Health Solutions (AIHS) impact framework	Described in Cruz Rivera et al. (2017) Table 1 p.7	Mixed – qual and quant			Categories -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. The ultimate goal is to contribute to the most societal benefit among the people." Cruz Rivera p.7 table 1
CPPI: Co-produced pathway to impact **Used by (Phipps et al., 2016) Canada: bullying**		Mixed – qual and quant				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/
Contribution mapping framework	Described by Kok and Schuit (2012) Used by Kok et al. (2016) - Netherlands and Ghana	Forward Qualitative	Fit for purpose – for accountability, learning or improvement	Single project (case studies); unless for learning may use multiple cases or cross-case analyses	-Change in actors (eg skills and training for investigators) -Knowledge products -contributions	Kok used interviews and document analysis Assesses the contribution instead of impacts - to eliminate the issue of attribution Three-phases (research formulation, production and knowledge extension) -

Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
					through linked utilization (eg policymakers) -utilization at a distance (those not involved in or interacted with research) – difficult to corroborate and analyse	process map and contribution map developed to show main actors, activities and alignment efforts (contributions) Benefit – can be used for learning and improvement in future research efforts
Logic model	Described by Newson et al. (2018) (review) Orians et al. (2009) -US (health)	Forward tracing (grantees) and backward tracing (end-users)	Some economic, broader impacts		-Funding -Dissemination -Product development and commercialisation - research utilisation -recommendations future research	Oriana – survey of grantees and key informant interviews with end-users of research
Overseas Development Institute RAPID Framework	Described by Newson et al. (2018) (review) (Hutchinson, 2011) -Malawi, Uganda (health) (Overseas Development Institute, 2004)	Qualitative Backward (from policy)	Policy			More a tool to increase the impact of research, not to assess impact per se Used as a basis, a framework developed to focus on developing countries. (by Crewe and Young, Court and Young – in Hutchinson references) 3 interrelated elements – process, links (networks of actors), evidence; with overarching impact of context
Research Impact Framework	Kuruvilla et al. (2006)				-research-related impacts -policy impacts	Adapted from Payback Framework. "Conceptual framework to describe the possible impacts of health research outcomes"

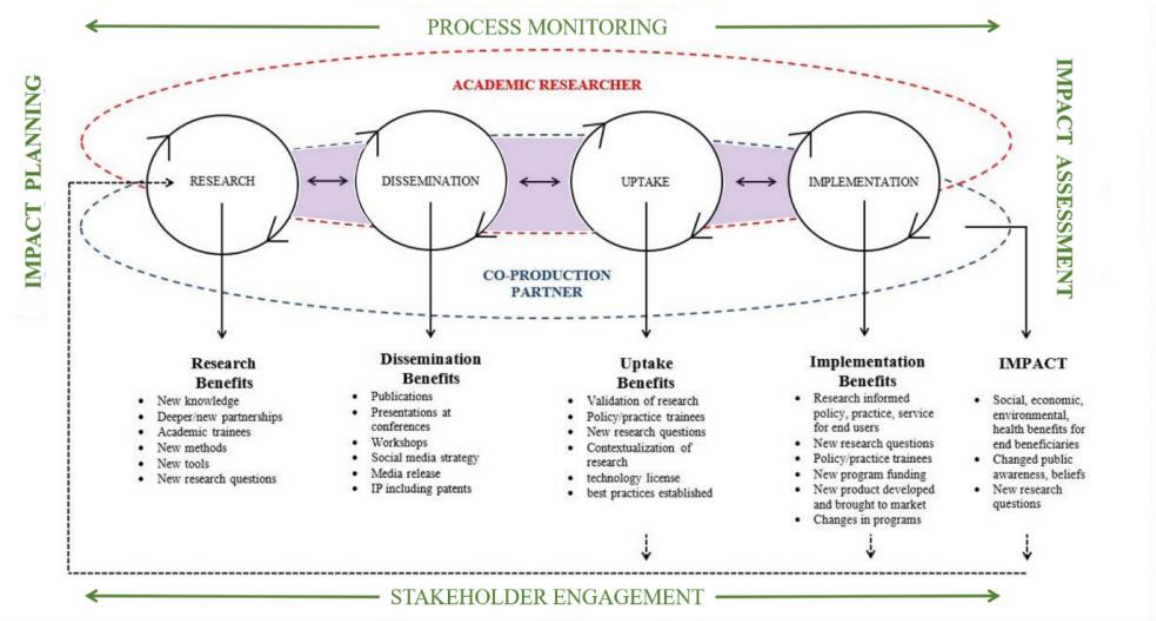
Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
					-service impacts -societal impacts	Cruz Rivera p.7 Table 1
Adapted Research Impact Framework	Described by Newson et al. (2018) (review) Bunn and Kendall (2011) -UK: health	Both – forward and backward	Policy		-citations -mentions of research in policy docs -interviews – asked if aware of any ways research influenced policy	Documentary review of policy documents, citation analyses, interviews with researchers
Research Contribution Framework	Described by Newson et al. (2018) (review) and Cruz Rivera et al. (2017) Morton 2015 -UK: health (NB no free access to this article – not downloaded)	Both – forward and backward	Policy	Single project	-Final outcome -Policy or practice change -Capacity, knowledge and skill -Awareness, reaction -Engagement, participation -Activities and outputs -Inputs	"Assessment of research impact using contribution analysis to explain the influence in policy and practice" Table 1 Cruz Rivera (2017) p.11
ASIRPA	(Joly et al., 2015) -France: research institutions (agriculture)	Forward tracing (ex-post) Mixed – qualitative and quantitative	Economic Environmental Social Health Political (including policy) Territorial	Single projects, standardised so can scale up to analyse impact at institutional level		Socio-economic assessment of public sector research institutions
Public value mapping	Noted in (Joly et al., 2015) Described in Talbot (2008)		Policy	Case-based (single project)	Public failure criteria (Bozeman and Sarewitz, 2011, p.17) -mechanisms for	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

Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
	Discussed in (Bozeman and Sarewitz, 2011) (Geuijen et al., 2017) – public value theory (theoretical base for PVM)				values articulation and aggregation -imperfect monopolies -scarcity of providers -short time horizon -substitutability vs conservation of resources -benefit hoarding	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" Bozeman and Sarewitz (2011, p.13) 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)	Spaapen and Van Drooge 2011 -Australia: fisheries	Qualitative	"social" impact Culture Community health and wellbeing Livelihood and economy Governance and politics Environment Fears and aspirations of people (Hiruy and Wallo)	Single project (case studies)	Changes in -Culture -Community, health and wellbeing -Livelihood and economy -Governance and politics -Environment -Fears and aspirations of people (Hiruy and Wallo)	Data collection: survey, in-depth interviews, case studies Evidence of observable and most significant changes to the categories. (Attribution problem reduced)
Excellence in Research for						

Framework / model	*Cited in / used by*	*Forward or backward tracing* *Quantitative/qualitative*	*Domain(s) of impact* *Economic* *Environmental* *etc*	*Unit of analysis*	*Assessment categories*	*Methods / description*
Australia (ERA) framework						
ARC Engagement and Assessment Framework	https://www.arc.gov.au/engagement-and-impact-assessment/ei-pilot-overview See Framework and Submission Guidelines: https://www.arc.gov.au/engagement-and-impact-assessment/ei-key-documents	Qualitative, with some quantitative aspect	Economic Environmental Social Other	Two-digit Institutional Field of Research (FoR)		Measure of how universities are translating their research into economic, environmental, social and other benefits Universities provide information following the impact study template -who or what has benefitted -nature or type of impact and how -extent of impact, referencing cost-benefit analysis, quantity of those affected, reported benefits etc -approaches to impact (i.e. processes of collaboration, stakeholder involvement, translation mechanisms and utilisation strategies) Assessors use 3-point rating scale (high-medium-low) for both engagement and impact. Impact: 1. Approach to impact 2. Impact (significant and clear link)

The Payback framework developed by Buxton and Handley (1996) includes the development of a logic model of the research processes and five categories of impact (paybacks). These include knowledge impact, research impacts, and political and policy impact. Quantitative and qualitative data is collected to provide ex post and ex ante (prospective) measurement of research impact, although no monetary impact is calculated. According to Searles et al. (2016) this framework is used in the United Kingdom and Canada [Banzi et al. (2011); Buxton and Handley (1996, 1998, 2000); Handley et al. (2000, 2007); Handley et al. (2003); and Milat et al. (2013)].The resource intensiveness of this framework has led to its modification to reduce resource demands ((Greenhalgh et al., 2016)).

The Co-Produced Pathway to Impact (CPPI) is a Canadian framework developed to assess social, economic and health-related impacts of research funded by the Networks of Centres of Excellence (NCE) program (Pepler et al., 2017). 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/). The categories of impact described by this framework are academic impacts (scholarship and capacity); and social impacts (practice and policy, society and culture, and economy) (Federation for the Humanities and Social Sciences, 2017). Continuous improvement to the framework has resulted in the current version (posted January 22, 2019 to researchimpact.ca) and reproduced below.



(Image reproduced from researchimpact.ca)

Public value mapping of science outcomes is a framework described by (Bozeman and Sarewitz, 2011) as a way to consider non-economic and non-scientific measures of the goals of research, that is, the core values (termed "public values") of the research. Moore (2013) provides a thorough discussion of public value theory, on which the public value mapping framework is based. The Barber Review in the UK proposed the introduction of the Public Value Framework as a tool to underpin the allocation of funding to research and programs (but which could also be used to measure the impact of research evidence (O'Connor, 2018), Moore (2013)). The definition of public values recognises the overlap of economic value with public value, as discussed in earlier sections relating to overlap of impact categories. Public values may be interdependent (although not necessarily) and may conflict in certain cases.

Bozeman and Sarewitz (2011) draw on well-tested economic approaches and tools and note the benefit of evaluating products of research while recognising that there are limitations, particularly related to shortcomings in measuring innovation and capacity, and value-laden metrics such as quality of life. They note that "Market prices are viewed as weak partial indicators of the social value of research and research outcomes. Even as a partial indicator, market value is considered in terms of not only magnitude but also distribution and equity criteria". They argue that progress toward widely adopted goals such as decreased loss of life or cleaner air, can be measured and assessed. 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", (p.13). Public value mapping uses a case study contextual analysis method to map goals to research activities, impacts and outcomes, using a causal logic theory. Impact and outcome measures are linked to aggregate social indicators or other appropriate measures of social well-being.

Public values criteria were initially developed to measure public values failure, a concept somewhat parallel to the economic theory of market value failure; in that goods and services are not provided to enable public values to be achieved (Bozeman and Sarewitz, 2011). Bozeman and Sarewitz list the criteria for assessing public failure (p.17):

- Mechanisms for values articulation and aggregation
- Imperfect monopolies
- Scarcity of providers
- Short time horizon
- Substitutability vs conservation of resources
- Benefit hoarding

Public value theory is also useful in the planning stages of research, particularly in areas exploring "wicked problems" (Geuijen et al., 2017). Marton and Phillips (2005) discuss the need for delivering public value in the specific area of bushfire management and recovery. It is noted that as public value is essentially based on the perception of the individual, the perception of what encompasses "public value" differs between different stakeholders (governments, agencies, householders). Where this method is used in planning or evaluation of research, consensus between those involved must be reached prior to implementation. Talbot (2008) notes that the public value approach can also be used to assess the performance of public service organisations. Moore (2013) discusses several case studies which quantify public value, in order to allow bottom-line value of agency activities; and notes that private sector accounting is not a good reflection of value-making in public sector agencies. Rather, this "bottom-line" is whether the public goals are reached, by the most efficient utilisation of resources (money and authority).

Moore developed a "public value account form" roughly mirroring a profit and loss account; whereby income streams are reduced by costs to arrive at net value. He notes that many of the conceptual categories of public value (mission achievement, unintended positive consequences, client satisfaction, justice and fairness) are not easily monetized, and does not offer solutions for quantifying these values.

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 (New Economy) encompasses many areas (including fire) and includes a range of social and economic proxies, although only economic costs are currently included for fire (http://neweconomymanchester.com/our-work/research-evaluation-cost-benefit-analysis/cost-benefit-analysis/unit-cost-database). 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 (O'Connor, 2018). This estimation is of public value gained by a public sector service agency, but the same principles could be applied to valuing research investment.

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; in order to encourage continuous improvement and to identify opportunities.

The **Research Impact Framework** (RIF) presented by Kuruvilla et al. (2006) is not an evaluative tool and does not assign priority to any impact; rather it is a "practical tool to help researchers think through and describe the impact of their work" (p.3). Table 2 from Kuruvilla (inserted below) lists categories pertaining to health for each of the broad categories; each of which would serve as a checklist that researchers can use to determine their impact. For research impact assessment in a different area, these impact categories would be drawn from the literature as known areas of impact. For example, the service impacts and some of the societal impacts listed are very specific to the health sector but correspond to similar impacts in other areas of research. Research-related impact is a broader category than in other frameworks which tend to assess the number of citations and other easily identified bibliometrics as the extent of academic impact. Possibly owing to the "public value" nature of health research, the economic impact does not have its own broad category under this framework and is instead addressed as a societal impact (macroeconomic level) and service impact (cost-effectiveness). The framework was tested for validity and usefulness. The authors note that as researchers employ self-assessment of research impact, findings may be prone to bias.

Table 2: Research Impact Framework

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 the economy • Social capital and empowerment • Culture and art • Sustainable development outcomes

Within each of the major frameworks, broad categories of assessment are identified which directly or indirectly reflect the headings created in this document as academic impact, economic impact, and social impact. For example, the Research Impact Framework (Kuruvilla et al., 2006) has four broad areas of impact, being research-related, policy, service, and societal. Within each of the broad categories, the frameworks are further broken down into themes, and specific criteria or points of assessment, which can be used to assess a particular research area, institution or project. Cruz Rivera et al. (2017) developed a "pathways to research impact" which provides a detailed description of measurement of healthcare research impact. It was developed after their systematic review and analysis of healthcare research impact frameworks and models. It is a useful tool to assist in decision-making around appropriate impact measurement for research areas other than healthcare including bushfire, natural hazards and emergency management. Figure 4 draws extensively on the work of Cruz Rivera et al. (2017) in outlining the pathways to research in the

natural hazards and emergency management domain. We have adapted the pathways model by changing some of the content to apply to natural hazards and emergency management research.

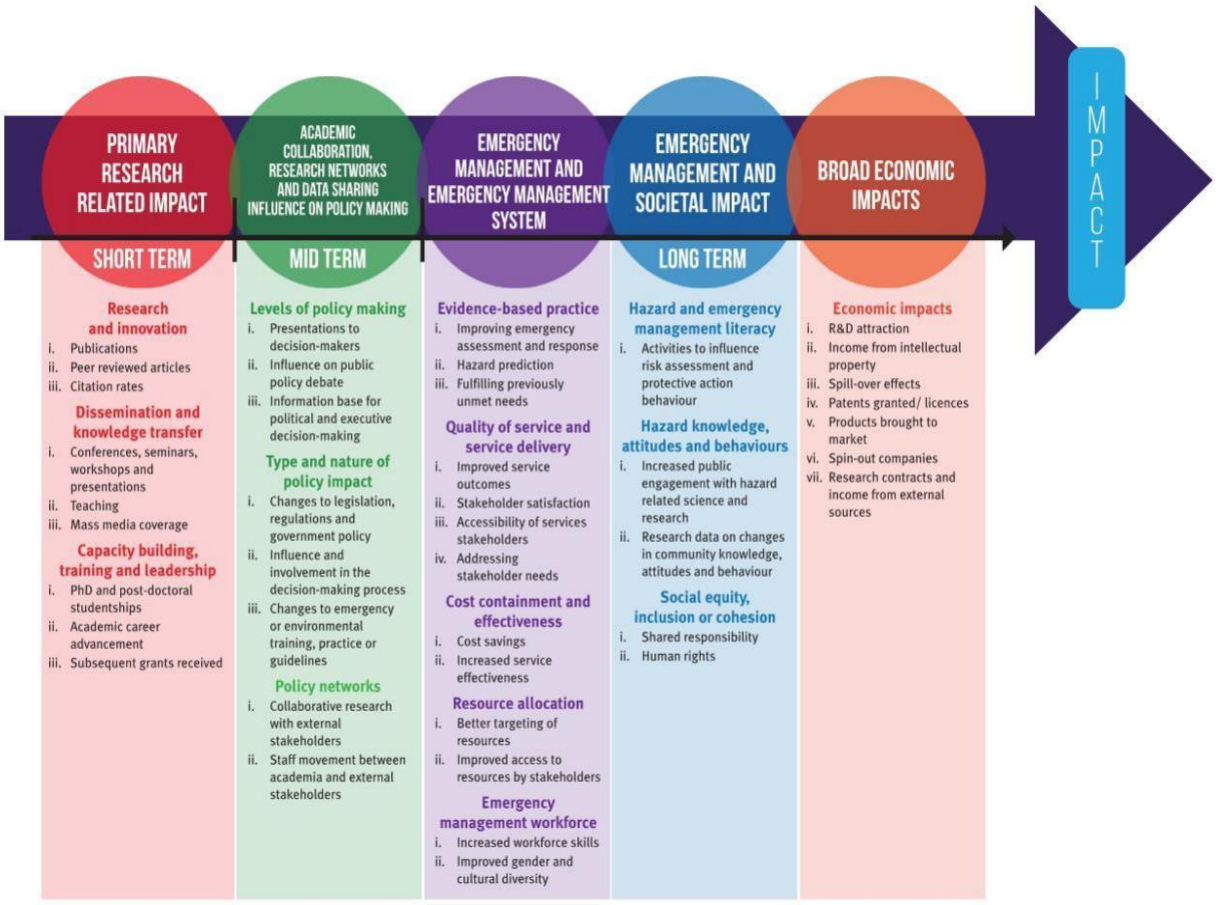


Figure 4. Pathways to natural hazards and emergency management research. Adapted from Cruz Rivera et al. (2017) *Assessing the impact of healthcare research: A systematic review of methodological frameworks.* PLoS Med*,* 14**,** e1002370.

CONCLUSION

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 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.

These frameworks attempt to address the challenge of demonstrating an impact, attributing 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 facilitate the identification, measurement and quantification of process and outcomes. The framework developed by Cruz Rivera et al. (217) 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 bushfire, natural hazards and emergency management domain.

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