NSW GOVERNMENT

Transformation in farm livelihoods: Impacts on the work health and safety of farming communities

Centre for WHS

UTS Institute for Sustainable Futures

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Executive summary

Employment in agriculture embodies a range of work health and safety (WHS) risks that most directly affect farmers, their families and farm workers (Farmsafe Australia, 2020). The dynamic nature of these factors ensures that farming communities continuously innovate and adapt their operations in pursuit of rural livelihoods (i.e. ways of making a living). The agriculture sector in Australia and New South Wales (NSW), as elsewhere in the world, is increasingly facing a range of disruptions (social change, new technology, international commodity prices, biosecurity threats) that affect farmers' ability to remain financially viable with the business models under which most of them currently operate. Among the range of drivers of change, agricultural systems are particularly vulnerable to increasing climate variability and extreme weather events. In response, farmers make changes to the way they operate by adopting new approaches to food and fibre production within their current farming system, by adopting a different farming system altogether (e.g. organic farming), or by exploring novel uses of agricultural land (e.g. energy generation). Such changes are likely to change the WHS risk profiles of farming communities. This report forms the first stage of research which is to identify the current impact of disruptors, increased climate variability in particular, on the WHS of farming communities.

The report will, firstly, briefly present the climatic and economic context in which farming communities are adapting to change, and draw on theories of vulnerability, resilience and adaptive capacity to explain the need for transformation. This will require alterations in agricultural livelihoods that will likely involve a spectrum of responses spanning adjustment of current farming practices (coping), incremental changes in enterprise mix of farming systems (incremental) and novel uses of land for non-agricultural enterprises (transformation). Secondly, the report will review the literature, through bibliometric and qualitative analysis of existing research globally and identify those practices that may be suitable for application in NSW agricultural sectors.

The literature review identified several research gaps with implications for WHS of farming communities:

1. Currently the WHS literature focuses mainly on the mental health impacts of drought, and does not consider physical WHS impacts.
2. The changes in farming systems and business models discussed in the scholarly literature focus mostly on the 'persistence' of existing systems (coping), through the implementation of changes in practices 'at the margin'. However, transformational responses through fundamental changes to livelihoods and novel uses of agricultural land are beginning to emerge. Some 'novel uses' of agricultural lands are already being implemented in the agricultural landscape, such as those related to conservation, recreation, and to a lesser degree, alternative commercial uses. The potential effects of transformational changes to land use on agricultural industries and rural communities remain speculative but evidence

suggests they could potentially alter the value of agricultural production and land value, the style and function of buildings, the viability of family-farm businesses and the loss of ecosystem services. Discussions of the WHS impacts of novel uses of land have not yet appeared in the literature and have not been linked to climate change possibly because their link to climate change adaptation might be indirect and involve complex, context-specific changes in exposure and sensitivity to climate drivers.

3. The link between changes in farming systems, business models and WHS risks has been the subject of only limited research interest (e.g. adjustment to risk profiles through adoption of organic farming systems). Changes in risk profiles due to adoption of transformational responses (novel uses of agricultural lands) have not been explored.

The findings of the literature review indicate that the way farming communities interact with the establishment of novel activities in farming environments, may create different risks and/or require a different way to communicate about those risks that require further research. Farming entrepreneurs are likely the principal actors in the transformation. This constitutes, according to us, the main research gap. While the WHS risks of the types of activities that constitute 'novel uses of agricultural lands' might be already known in other industry sectors; for example, in warehousing (Waters, Putz-Anderson, & Baron, 1998); hospitality (Sharma, 2019), and solar energy systems (Aman et al., 2015), for farmers, these represent emerging risks. In light of the already high rate of WHS incidents among farming communities, and their distinct physical and cultural environment, the way they manage WHS risks becomes an important issue in the development of sustainable rural livelihoods in NSW.

Table of Contents

List of Tables and Figures

Introduction

Employment in agriculture embodies a range of work health and safety (WHS) risks (Farmsafe Australia, 2020) that most directly affect farmers, their families and farm workers, which we define here as 'farming communities'. Traditionally, exposure to risk in agriculture is a function of the set of practices employed by the farmers in the production of food and fibre, which in turn vary geographically and across industry sectors in response to a range of biophysical (e.g. climate and agronomy), socioeconomic (e.g. farmer demography and industry viability) and cultural (e.g. values, world views) factors (Pannell & Vanclay, 2011). The dynamic nature of these factors ensures that farming communities continuously innovate and adapt their operations in pursuit of rural livelihoods (i.e. ways of making a living) (Nelson, et al., 2010).

The agriculture sector in Australia and New South Wales (NSW), as elsewhere in the world, is increasingly facing a range of disruptions (presented later in this report) that affect farmers' ability to remain financially viable with the business models under which most of them currently operate (e.g. Tubb & Seba, 2019). A disruption of particular note is increasing climate variability and the additional challenges it will pose to farmers' ability to remain profitable. Disruptors like this might lead farmers to make changes to the way they operate by adopting new approaches to food and fibre production within their current farming system, by adopting a different farming system altogether (e.g. organic farming), or by exploring novel uses of agricultural land (e.g. energy generation).

The changes farmers are making to their operations are likely to change their risk profiles in terms of WHS.

This report outlines how changes in the enterprise mix on farms, particularly to non-traditional uses of agricultural land, in pursuit of more 'climate-durable' livelihoods might influence the WHS of farming communities, based on the published literature.

The report is structured as follows. Firstly, we provide the contextual background for this research. Secondly, we provide an overview of the current literature on the connections between climate variability, changes in the enterprise mix on farm, and WHS risks as identified by a thematic and bibliometric analysis of the literature. Thirdly, we offer a discussion of existing gaps in the literature, and how future phases of this research project will aim to bridge these gaps.

Contextual background

Agriculture in the NSW Economy

Agriculture is a major driver of the NSW rural economy, providing between $10-16 billion in agricultural output per year. In 2016, NSW agriculture contributed $14 billion to the economy (of which 50% is from cropping industries; the Agriculture Census, 2016) and in 2018-2019, the livestock industries dominated the highest value commodities, with cattle and calves ($2.6 billion), wool ($1.2 billion), and sheep and lambs ($1.1 billion) being the largest (Figure 1) (Department of Agriculture Water and the Environment, 2020). As a contributor to employment, in May 2020, agriculture, forestry and fishing employed 83,300 people (2% of the NSW workforce), representing about 30% of all farm business in Australia (Figure 1) (Department of Agriculture Water and the Environment, 2020).

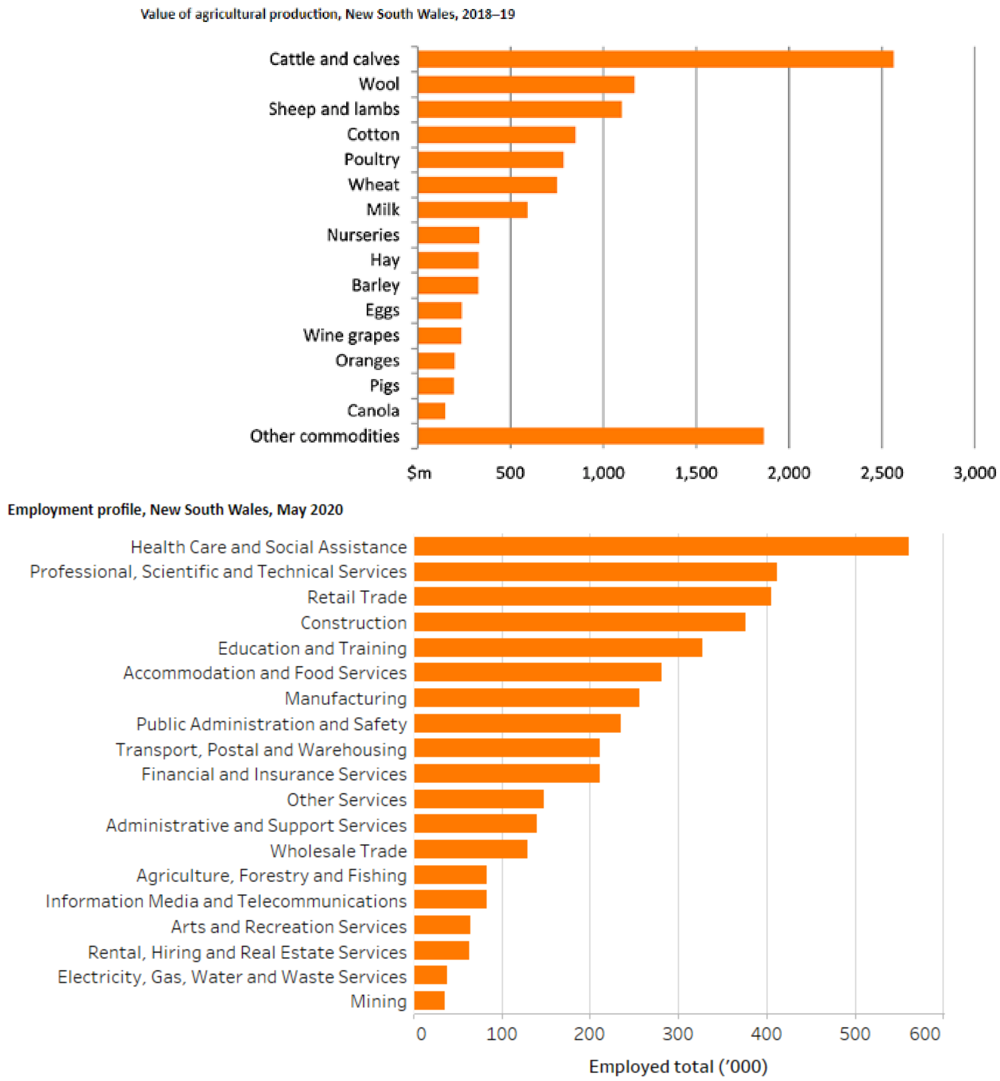


Figure 1: Value of agricultural production, New South Wales, 2018-19 (Top); NSW employment profile 2020 (Bottom). Source: (Department of Agriculture Water and the Environment, 2020)

Potential disruptors of agricultural systems

In the relatively near future, the agricultural sector is likely to undergo radical transformations that will disrupt current agrifood systems. Stringer et al. (2020) identified five potential scenarios: global carbon pricing mechanisms, the fourth agricultural revolution, vertical farming, universal basic income, and production of alternative protein sources.

- *Global carbon pricing mechanism* is an example of a market-based mechanism to internalise the negative environmental costs (or externalities) of carbon emissions from farming (and other activities). For agriculture, a carbon pricing mechanism would influence energy intensive farm practices that generate significant levels of greenhouse gases placing pressure on the use of nitrogen fertilisers, transport of agricultural produce, the production of animal protein and the rate of land clearing.
- *The fourth agricultural revolution* is predicted to occur through the rapid adoption of a range of new technologies in food production and farming systems. These technologies include genetic engineering, robotics and automation, artificial intelligence, data analytics and internet-enabled remote sensing.
- *Vertical farming* represents an attempt to decouple food production from environmental risk by growing plants in protected and highly controlled, indoor environments. There is potential to site vertical farms adjacent to manufacturing facilities, particularly in urbanised areas, to use waste heat from the manufacturing to heat and power the farm.
- *Disruption via Universal Basic Income* is probably of lesser significance in the context of NSW farming systems. Stringer et al. (2020) speculate that providing every member of society with a regular sum of money could encourage some small-scale producers to exit farming.
- *Production of alternative protein sources:* growing consumer interest in vegetarian-based diets coupled to a recent rise in the availability of non-protein products (e.g. meat substitutes) has the potential to transform agriculture over the next 20-30 years.

These disruptors, among others, have the potential to alter substantially the relationship between the production of food and fibre and the use of agricultural land. For example, Tubb and Seba (2019) produced a deep analysis of an economic disruption to the US livestock sector from the production of alternative proteins (e.g. from precision fermentation using micro-organisms) and their widespread incorporation into consumer diets. Although Tubb and Seba (2019) recognise there are significant uncertainties in their predictions, the analysis presents a sobering picture for commercial livestock production systems in developed countries (Figure 3). In summary, Tubb and Seba (2019) suggest alternative proteins will be:

- Five-times cheaper by 2030, and 10-times cheaper by 2035 than existing animal proteins.
- Superior in every key attribute – more nutritious, healthier, better tasting and more convenient.

- By 2030, modern food products will be higher quality and cost less than half as much to produce as the animal-derived products they replace.

The consequences for animal farming in the US could therefore include (Figure 3):

- By 2030, the number of cows will have fallen by 50% and the cattle farming industry will be all but bankrupt due to a fall in demand for cattle products of 70%.
- Severe knock-on effects for other livestock and crop farmers and businesses throughout the agrifood value chain.
- By 2035, about 60% of the land currently used for livestock and feed production will be available for other uses.
- Farmland values will collapse by 40%-80%. The outcome for individual regions and farms depends on alternative uses for the land, amenity value, and public policy choices.

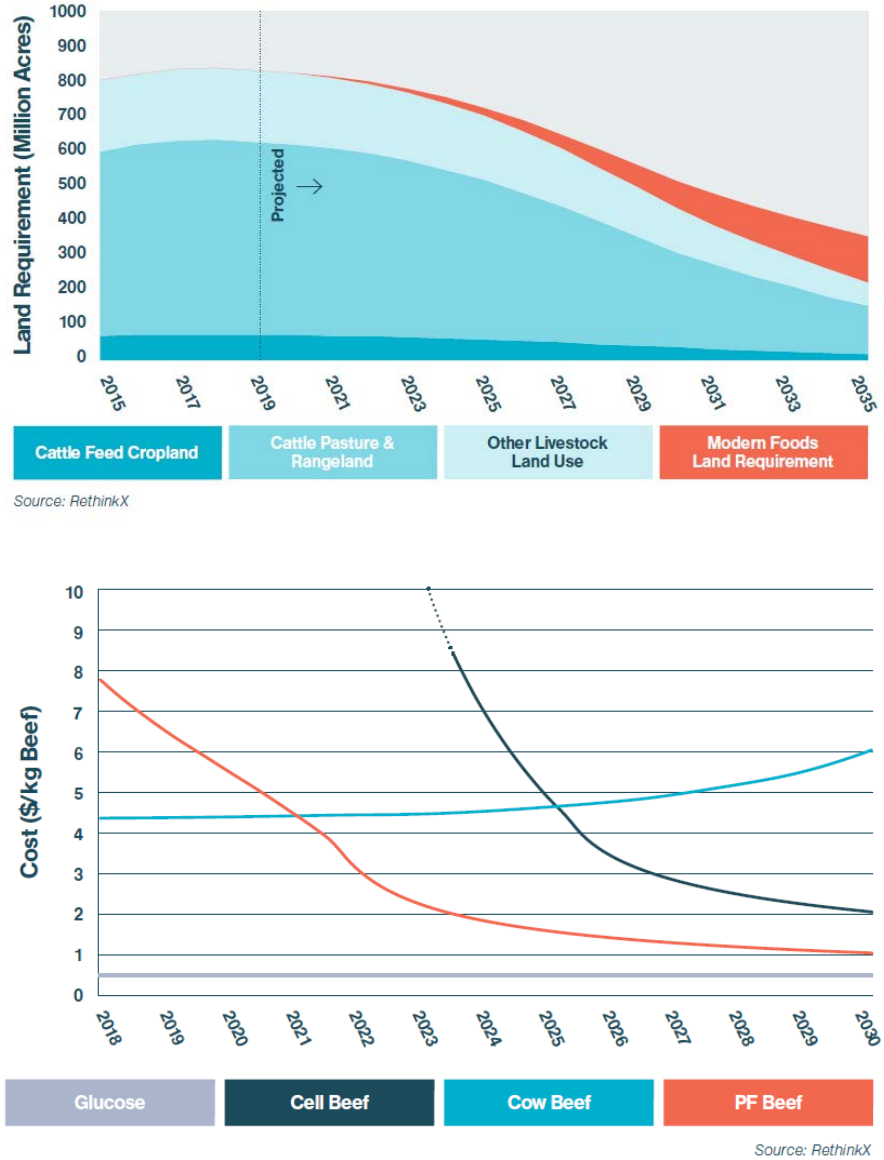
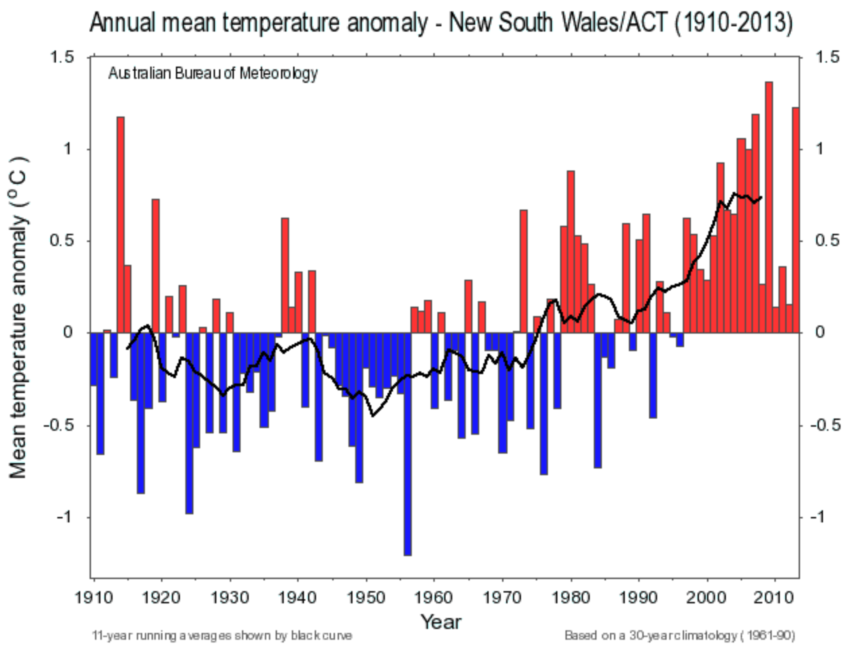


Figure 2: Land requirement (Top) and relative cost curve projections (Bottom) for US beef production.
Source: Tubb and Seba (2019).

Climate variability as a driver of change

Other factors that have not been mentioned in the previous section also affect the economic output from NSW agriculture. Those include commodity prices (e.g., livestock products, wool, and grains), biosecurity threats (e.g., livestock), international trade relations (e.g., wine and horticulture) and the changing agro-climatic conditions of NSW.

Changes in agro-climatic conditions, either through the occurrence of extreme weather events (e.g. drought, bush fires, floods) or long-term incremental changes (e.g. average temperature) are recognised as significant drivers of change for farming communities (Office of Environment and Heritage, 2014).



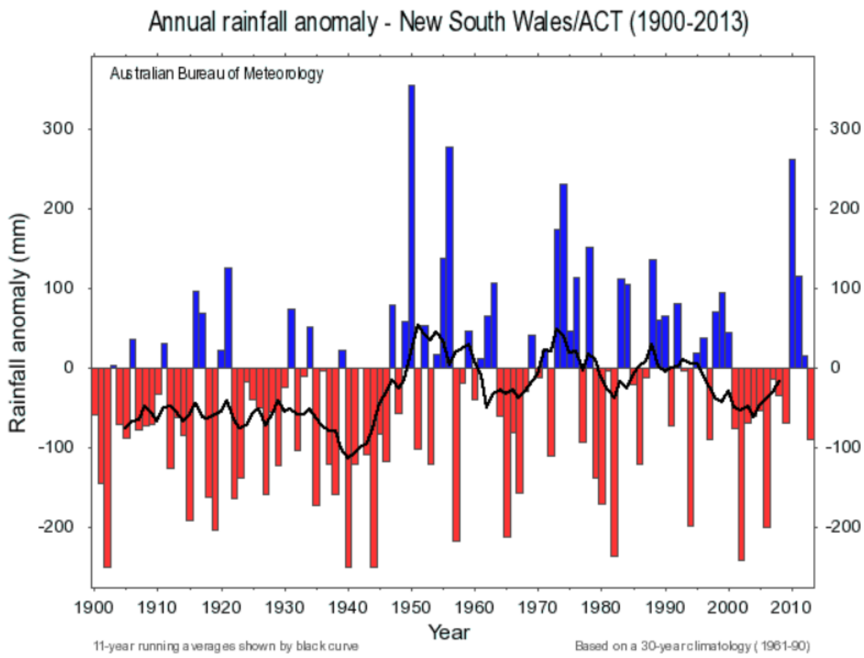


Figure 3: Temperature (Top) and rainfall (Bottom) anomalies for NSW. Source: (Adapt NSW, State Government, 2020)

According to long-term records, NSW has been warming since the 1950s and will continue to warm into the future (Office of Environment and Heritage, 2014). NSW is projected to warm on average by 0.7°C in the near future (2020-2039) and by 2.1°C in the far future (2060-2079) (Office of Environment and Heritage, 2014). NSW Government projections (Office of Environment and Heritage, 2014) also indicate that maximum temperatures will increase by 0.4 - 1°C (near future) and 1.8 - 2.6°C (far future); minimum temperatures are projected to increase by 0.0 - 0.5°C (near future) and 1.4 - 2.6°C (far future); thus increasing the number of hot days while the number of cold nights will decrease. Rainfall is projected to decrease in spring and winter and increase in summer and autumn with increased regional variation.

Long term changes in temperature and variations in rainfall are expected to result in flow-on impacts to other aspects of the agricultural production environment in NSW. For example, average fire weather and number of days with severe fire danger are projected to increase in summer and spring along with associated risks to lives and properties. The changes to cold nights will have an impact on horticultural species that require vernalisation to trigger flowering (Office of Environment and Heritage, 2014). Heat waves can also be detrimental to human and animal health. Reduction in water availability, which is likely the most important biophysical determinant of productivity, is likely to affect agricultural systems. Analyses by the Australian Bureau of Statistics (ABS) indicate there is a close correlation between the gross value of agriculture and NSW state-wide average rainfall over time (Figure 2) (Campbell & Scarlett, 2014), while the Department of Primary Industries shows that ongoing periods of low rainfall and drought affected the agricultural sector with an economic decline of 48% ($2.5 billion) in 2018-19 (Deparment of Primary Industries, 2019).

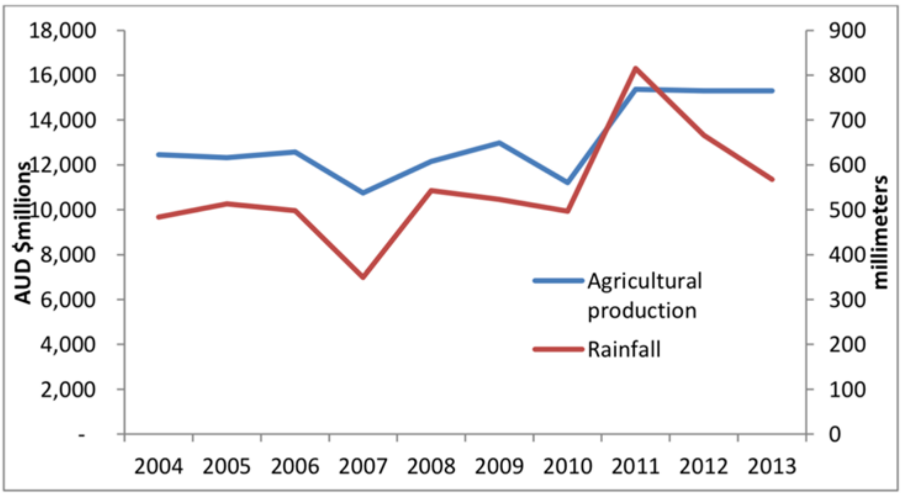


Figure 4: Measuring agricultural production and rainfall over time
Source: Campbell and Scarlett (2014, p.3)

The majority of agricultural industries in NSW are located in inland regions: Northern, Murrumbidgee, North West, Central West, and Murray. These regions have diverse exposures to climate risks, which inevitably influence the changing landscape management practices throughout the state.

Processes of change

Generally, change occurs in response to the awareness of a hazard (Pelling, 2010) or the perception of risk (van der Linden, 2015). For farming communities, the hazard may be defined as geographical exposure and sensitivity of agricultural activities to shocks or stresses imposed on farming systems by the external environment. For farmers, the capacity for change, often termed their adaptive capacity (Nelson, Adger & Brown, 2007), depends on:

- Their ability to access, combine and transform a range of resources (human, social, natural, physical and financial capital; Ellis 2008) in pursuit of adaptation (Jacobs, Nelson, Kuruppu, & Leith, 2015).
- The socio-political context in which they operate (e.g. formal regulatory environment), often termed the enabling environment, which sets external limits on their use of resources (e.g. water access licencing, and land clearing regulations) (Jacobs & Brown, 2014).
- Their personal psychosocial characteristics (such as culture, worldviews, attitudes to risk, and aspirations in life), which can influence how they respond to and navigate the need for change.

These three elements form a dynamic context that variously constrains and enables change in farming communities (Leith, Jacobs, Brown, & Nelson, 2012). Together with adaptive capacity, exposure and sensitivity comprise vulnerability.

Typically, farmers respond to vulnerability by changing aspects of their operations through alterations of farming practice. The pace of practice change, or the diffusion of an innovation among farmers (Rogers, 2003) can be rapid - e.g. adoption of reduced tillage in Australian cropping systems (D'Emden, Llewellyn, & Burton, 2006; Llewellyn, D'Emden, & Kuehne, 2012). In the past, farmers have been classified by terms such as 'early adopters' and 'laggards', as indicators of how rapidly they adopt an innovation, although as Pannell and Vanclay (2011) observed, farmers may have sound and rational reasons for non-adoption that are not immediately obvious to the promoters of the change (often the scientific community). A number of properties of a practice influence its likelihood of adoption including trial-ability (i.e., ease of moving from non-adoption to adoption through a learning phase) and its relative advantage (i.e., perceived net benefits to the farmer). These two key attributes are, in turn, dependent on a range of economic, social, and environmental factors. These factors include: the costs and possible outcomes of adoption; the riskiness of the innovation; impacts on other parts of the farming system; compatibility with existing technologies and practices; its complexity; government policy settings; impacts on farmer lifestyle, self-image and brand loyalty; as well as the perceived environmental credibility of the practice (Pannell et al., 2006).

Contingent on dimensions of their adaptive capacity, the extent of the response among farming communities to drivers of change will depend also on the intensity (magnitude and duration) of the shock or stress. We suggest there are four potential response options available to farmers to maintain their livelihoods. Farmers may:

- Option 1: Adjust their farming practices to suit the new context within the current enterprise mix (e.g. adoption of reduced tillage in cropping systems).
- Option 2: Change their farming systems by altering their farm enterprise mix (e.g. shifting business emphasis from cropping to livestock) or adopting a new a radically different approach to their existing enterprise mix (e.g. shifting from conventional to organic vegetable production).
- Option 3: Remain in agriculture and transform their use of livelihood resources to encompass business opportunities outside the agriculture sector while continuing to farm adaptively depending on seasonal conditions.
- Option 4: Exit the agricultural industry (Rickards & Howden, 2012).

Examples of Options 1, 2 and 3 are embedded within a model of transformational change (Figure 5) in grazing systems for the New England-North West region of NSW (NSW Government, 2016). Options 1 and 2 mainly involved changes for which WHS risks are already well defined and understood, despite ongoing high levels of injury related to some practices. The focus here primarily will be on Option 2, where broad farming system change occurs, and Option 3, as it involves speculation about the range of potential future enterprises that might emerge under drivers of change on farming communities. These enterprises will likely involve practices unfamiliar to farmers and transformational uses of available livelihood resources.

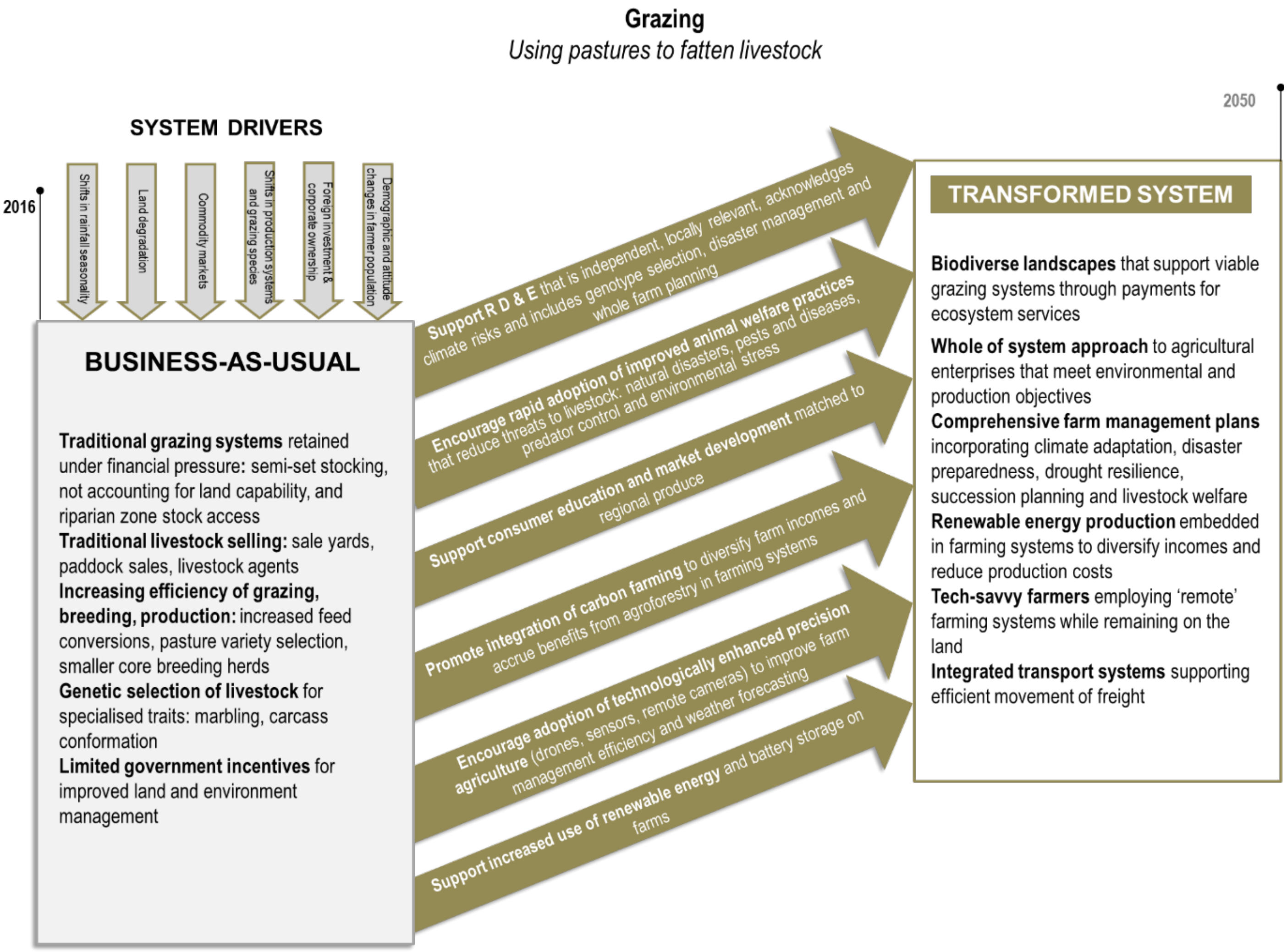


Figure 5: A model of transformative change in New England-North West region grazing systems (NSW Government, 2016)

Livelihood transformation

Transformation may be defined as an essential alteration of the nature of a system once the current ecological, social, or economic conditions become untenable or are undesirable (Ajulo, Von-Meding, & Tang, 2020). This process creates a fundamentally new system, which results from technological or social innovation crossing ecological or social thresholds (Figure 6). The model depicts drivers of change, such as extreme weather events or economic disruptions, as triggers for adaptive responses in farming systems (coupled biophysical and social systems) that draw on the capacity (resources) for adaptation that goes beyond coping and requires innovation that leads to fundamental changes in technology, society and governance (including policy).

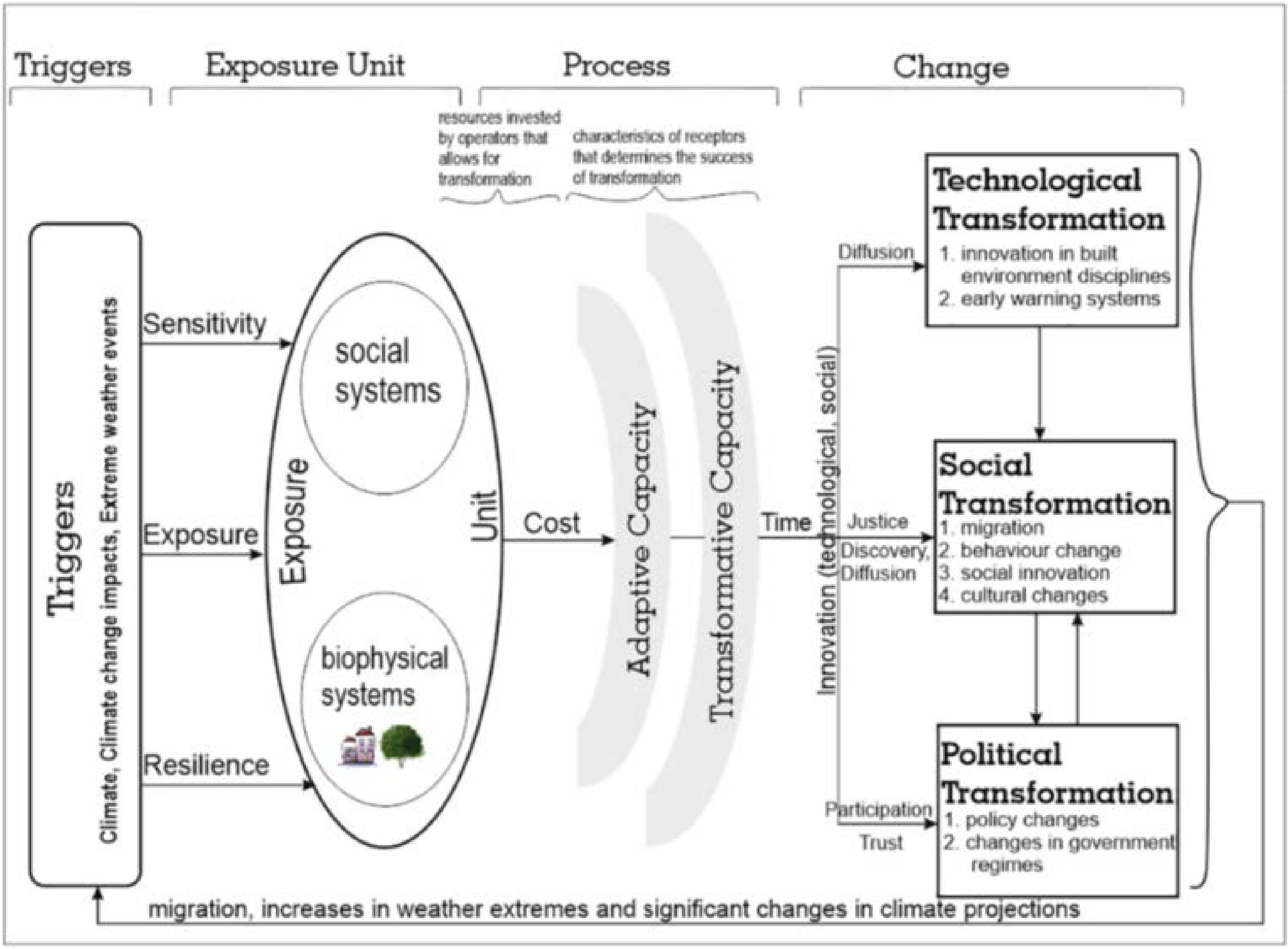


Figure 6: A model of transformational change that links vulnerability of systems to triggers (e.g. climate variability) with their capacity for change leading to transformations in technology, society and governance. Source: (Ajulo et al., 2020)

For farming communities, Rickards and Howden (2012) defined migration from the land and exit from farming as transformational changes under the impacts of an increasingly variable climate. However, transformation in place (i.e. without leaving the land) is undoubtedly a more desirable option provided farming communities could maintain viable livelihoods despite climate variability. Such transformation would require significant innovation in the use of available resources (livelihood capitals) by farmers.

Natural resource dependent livelihoods, such as farming, involve making a living from the conversion of natural capital to other forms of capital (F. Ellis, 1999). In agricultural systems, natural capital (land and associated resources, such as soil fertility) is managed for the production of food and fibre. These products are then converted, through markets, to financial capital, which is easily convertible to many other forms: physical capital in the form of purchased farm inputs, machinery and improved genotypes of plants and animals; human capital in the form of skills improvement and educational opportunities for farming communities; and, social capital by supporting involvement in Natural Resource Management (NRM) networks, sports clubs and other organisations (Jacobs et al., 2015). Climate is an aspect of natural capital that can fundamentally alter the use of other natural assets. For example, high soil fertility is of little use for crop and pasture production during a prolonged drought. This issue becomes a central consideration under an increasingly variable climate and suggests that novel uses of land, a farmer's principal asset, will become intrinsic to transformed rural livelihoods.

Novel use of agricultural land

The five most common uses of land are recreational (provision of amenity), transport (roads, airports, train stations), agriculture (production of food and fibre), residential (sites for permanent or temporary human dwellings and settlements), and commercial (businesses, warehouses, shops and any other infrastructure related to commerce) (Land.com Network 2020). To this list, we add conservation (e.g. natural resource protection, Indigenous or western cultural heritage conservation) as it is already a significant alternative land use for agricultural landholders (NSW Government, 2020a; NSW Government, 2020b). The potential uses of agricultural land encompass activities and enterprises drawn from these six categories leaving enormous scope for adaptation. Conceptually, changes to land use may include above and/or below ground applications (Figure 7).

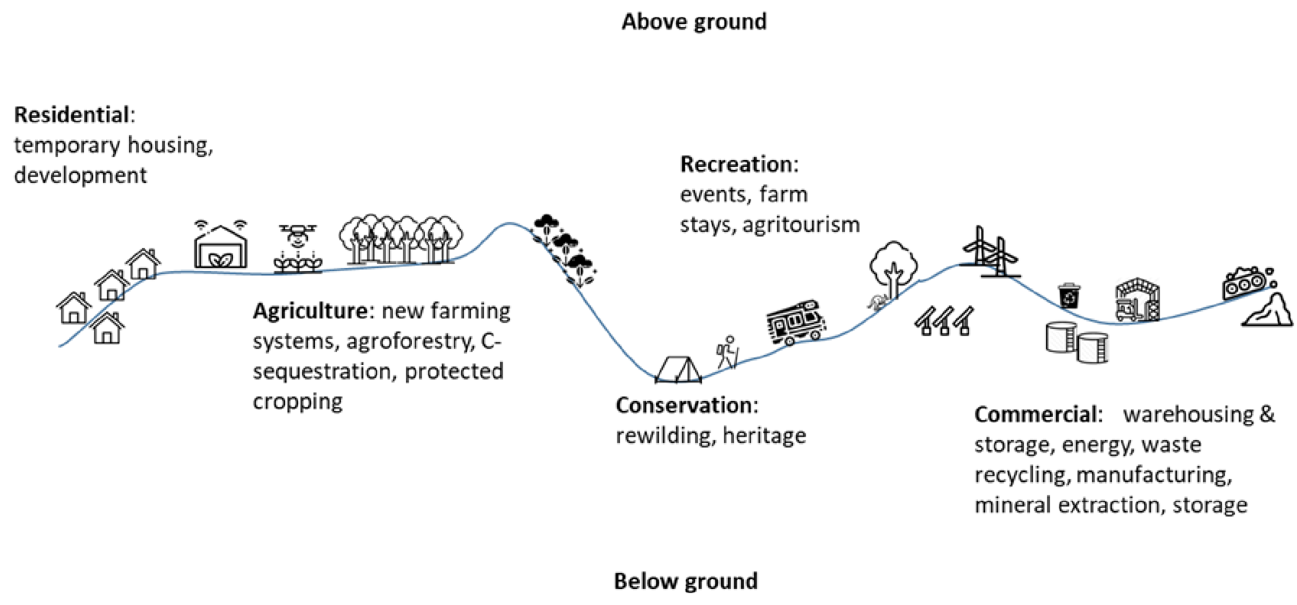


Figure 7: Examples of the potential range of uses for agricultural land (graphic developed by the authors).

The options for farmers to respond to drivers of change while remaining on the land are consistent with a spectrum of adaptation pathways to vulnerability reduction (Béné, Cornelius, & Howland, 2018) (Figure 8):

- Persistence: coping through adjustment to farming practices within the current enterprise mix.
- Incremental adjustment: changes in farming systems
- Transformation: the pursuit of non-agricultural livelihoods.

As farmers move across this spectrum of change, WHS risks move from known risks entailed in conventional farming practices to emergent risks from activities not widely practiced in the agriculture sector (Figure 8).

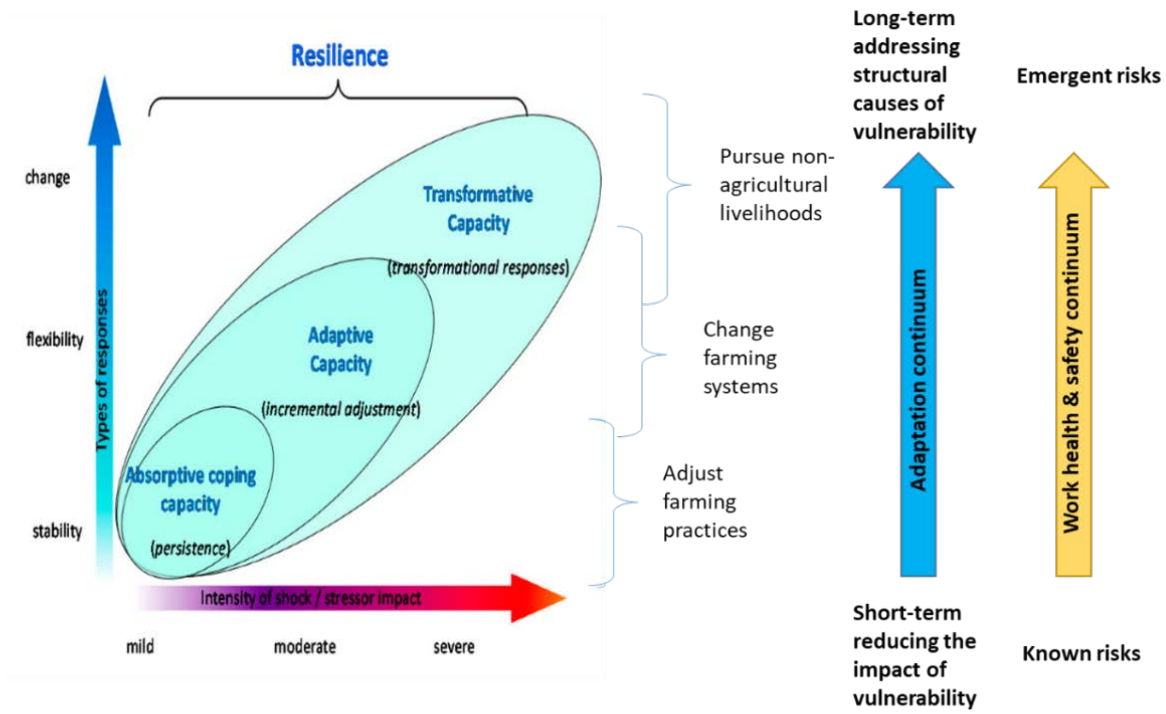


Figure 8: Conceptual model of the options available to farming communities to respond to disruptions, their effect on vulnerability and work, health and safety risk (Adapted from Béné et al., 2018).

Work health and safety risks

Current WHS risks in farming communities are relatively well-understood and information is available on the causes of fatalities and injuries among farmers. Farmsafe Australia recently reported that in the past 12 months there were a total of 58 fatalities and 133 non-fatal injuries in the sector Australia-wide; within NSW there were 7 fatalities and 20 non-fatal injuries (Farmsafe Australia, 2020). Across Australia in the past 18 months, the most common agents for fatal injuries were quad bikes (22%), tractors (13%), animals (8%), side-by-side vehicles (8%), motorbikes (3%) and farm dams (3%) (Farmsafe Australia, 2020).

In addition to published statistics, the specific physical and cultural environment in which farming occurs and how it interacts with WHS risks is also well-understood. Agriculture takes place in a distinctive physical environment. Farming communities are often isolated from health services, tasks involving manipulating animals and heavy machinery are frequently performed by solo workers, and farm families live and raise children in their place of work (i.e. their farm). This poses some difficulty in managing work/life balance, as farm work is a 24/7 365 workplace (Farmsafe Australia, 2020), and poses unique WHS risks seldom experienced by workers in other sectors of the NSW economy. To those risks associated with the physical environment, strong traditions and cultural influences also affect WHS. For example, Safe Work Australia identified four key insights as to why it is difficult to improve WHS on farms (Farmsafe Australia, 2020, p.6):

- *Time is money and money is tight* – there are significant economic imperatives related to the viability of farming enterprises.
- *It will never happen to me* – familiarity with farming activities results in discounting risks
- *It's common sense and it's not my place to tell them their business* – isolation and independence leads to a culture of non-interference.
- *My Dad did it this way and his Dad did it this way* – maintenance of tradition can be an impediment to change.

While these themes speak to WHS risks, and how the physical, financial and cultural factors affect farming communities' WHS risks, they do not explicitly take into account any changing or additional risks induced by changes in practices or reconfiguration of farm businesses to enterprises that might offer alternative livelihood opportunities for farming communities under an increasingly variable climate.

The overall aims of this research are to fill that gap in knowledge by:

1. Identifying the current impact of disruptors, increased climate variability in particular, on the WHS of farming communities

2. Identifying the changes farmers are already implementing or likely to implement in the future in response to climate variability, and how that might lead to a change in the WHS risks they will be exposed to.

3. Identifying how to best communicate with farming communities about these new sets of risks and influence the adoption of practices that minimise WHS risks.

This report constitutes the first step towards these objectives. It specifically focuses on reviewing existing literature that looks at how climate variability is, and will continue to affect, many farmers if no changes are made to their farming enterprises. It also explores the consequences of farmers' adaptation of their enterprises mix on WHS risks.

Methods

For this report, we developed a bibliometric and a qualitative thematic analysis of the literature. The bibliometric review is a descriptive evaluation of publications that enabled us to provide an overview of the types of journals in which papers that tackle our topic of interest are published, who is authoring them (see if clusters of authors emerge), in which countries research on those topics is concentrated, and the key topics on which they focus (analysis of keywords). To complement the overview provided by the bibliometric review, we also conducted a qualitative thematic review. Thematic analyses are more analytical in nature and aim at identifying the main themes that have been tackled by the articles selected, to identify what is already known and what the knowledge gaps are.

In this section, we will detail the process followed to conduct both the bibliometric (landscape and targeted) and qualitative thematic analyses. By landscape we mean broad explorations of domains, whereas the targeted analysis allows for deeper understanding of the articles utilized within the qualitative thematic analyses. We will first explain the process used to identify primary domains and keywords for the bibliometric and qualitative thematic analyses. Secondly, we will describe the process used to conduct our keyword searches and select articles in two major peer-reviewed literature databases, Scopus and PubMed. Finally, we will present the process followed to conduct both reviews.

Selection of keywords within primary domains for the bibliometric and qualitative thematic analysis

In order to select our keywords, we first defined the three thematic domains of interest for this research:

1. Climate change
2. Changes in farming systems and business models
3. Farm WHS risks

We then identified search terms or "keywords" for each of the three domains. Table 1 outlines the lists of keywords identified per domain.

Table 1: Keywords for three primary domains

DOMAIN	KEY WORDS
Climate change	climate change, global warming, climatic variability, extreme climatic events, extreme weather events, disasters, drought, water availability, heat, on-farm heat adaptation, heatwaves, bushfire, flood, storms, precipitation patterns, desertification, land degradation, biosecurity (biodiversity migration - livestock and crop diseases, weeds, feral animals)
Changes in farming systems and business models	organic agriculture, regenerative agriculture, regenerative farming, agro-ecology, agroforestry, sustainable farming practices, farming diversification, diversified production, pluriactivity, servitisation, 'farming cooperative groups', adaptation, land use change, resilience, 'farm management', technology, automation, farming management model, farming practice model, business management model, farm ownership model, farm leasing model, share farming, contract farming
Farm WHS risks	health, mental health, suicide, depression, anxiety, disease, safety, accidents, incident, injuries, death, fatality, chemicals, pesticides, 'work health and safety' (WHS), 'occupational health and safety

Keyword searches for the bibliometric and qualitative thematic analysis

Searches were applied in the Scopus and PubMed databases to identify relevant articles (details of the searches can be found in Appendix A). Each search brought together two (or three domains) in order to identify what we will call a 'nexus theme':

- Climate change & work health and safety, which focuses on the already observed impacts of climate change on farming communities' WHS risks in Australia (search 1 on Scopus, search 6 on PubMed)
- Farming systems and business models & climate change, which focuses on the farming systems and business models adopted by farming communities in response to climate and weather effects in Australia and elsewhere (searches 2 and 3 on Scopus, search 7 and 8 on PubMed).
- Farming systems and business models & work health and safety, which focuses on the impacts of farming systems and business models on WHS on farm (Search 4 on Scopus, search 9 on PubMed).
- Nexus, which focuses on the three dimensions at the same time (Search 5 on Scopus, search 10 on PubMed)

A final query put together the keywords related to the three domains in order to identify any publication that would have considered all at once: how climate change can lead to changes in farming systems and business models, which will then lead to changes in WHS risks.

Scopus keyword searches & selection of relevant articles

Scopus was selected because it is a comprehensive database of academic literature. For each search in Scopus, we initially looked for keywords situated in the 'titles, keywords, abstracts' sections. This allowed us to capture as much of the relevant literature as possible, and including abstracts, enabled us to select articles in which their relevance might not have been obvious from the title. However, for certain searches (searches 1 and 4) over 7000 references were identified for each. For logistical reasons and time constraints, we conducted searches focusing only on 'titles' for those two searches (see Table 2 for a summary of the location of search terms for each search on Scopus). While the search based on 'titles, keywords, abstracts' for search 5 provided over 1000 results, we assessed the relevance of those references manually, as the search based only on 'titles' did not provide any results.

Table 2: Location of search terms for each search on Scopus (full list see Appendix A)

Searches	Location of search terms	Number of articles
Search 1: Climate change & farming systems	Titles	165
Search 2: Climate change & business models	Titles, keywords and abstracts	30
Search 3: Climate change & work health and safety	Titles, keywords and abstracts	169
Search 4: Farming systems and business models & work health and safety	Titles	41
Search 5: Nexus	Titles, keywords and abstracts	1552
TOTAL NUMBER OF ARTICLES IDENTIFIED		1957

Once the five searches were completed, we selected relevant articles. We conducted a first selection of articles that would enable us to do a 'landscape' analysis of the literature on the nexus themes. By 'landscape' analysis, we mean a broad scale analysis of the literature published on the topic worldwide. To conduct this first analysis, we selected every article that was specifically focusing on the nexus of at least two of the thematic domains identified, regardless of the country the study was set in. We did not take into account any article that was not focusing specifically on the nexus of at least two of the thematic domains of interest. Out of the 1957 articles identified in Scopus, 933 were selected for this analysis.

We then continued our selection of articles in order to identify the articles that are more specifically focusing on the Australian context, or on developed country contexts where farming systems are similar to Australia's. In this second selection process, we identified 103 articles. Out of those 103 articles, 51 proved to be relevant to our research, after a qualitative appraisal of their content. We were unable to find the full text of two of the 51 articles selected, bringing the number down to 49. The reasons to exclude the 52 articles were that they were only tangentially focusing on a nexus area, were approaching the issues surrounding a nexus area in a way that was not relevant for our research or were focusing on a different topic (e.g. focusing on animal health rather than human health).

Based on our first search, we noticed that very little emerged for some nexuses, particularly regarding the nexus of climate change and changes in farming systems and business models. We also saw that some potentially relevant keywords had been omitted from this first search. For example, we looked for the keywords 'organic agriculture', 'regenerative agriculture' and 'regenerative farming', but not for 'organic farming'. Finally, we also observed that some of our climate change related keywords were too broad and led to many irrelevant results in the first search. As a result, we conducted a second search where we simplified the search terms related to farming systems and business models (e.g. 'farming management model' became 'farm*' AND 'management'), used only limited climate change-related keywords, and added the missing keyword: 'organic farming'. This second search was specifically focusing on identifying missed references that focused on the Australian context or a developed country context in order to inform the targeted bibliometric review and the qualitative thematic analysis. From this second search, we obtained 189 results, out of which 68 were selected based on reading the title. The selection criteria remained the same as for the previous search: they needed to focus on a nexus theme and to be situated in Australia or in a developed country with a similar context. Those 68 articles were then assessed through reading the full-text articles. Out of those 68, 16 were identified as relevant for our project. The reasons to dismiss were: 1. Only tangentially focusing on a nexus area, 2. Were approaching the issues surrounding a nexus area in a way that was not relevant for our research, or 3. Were irrelevant (e.g. focusing on animal health rather than human health). The 65 relevant articles (49 in the first search and 16 in the second search) identified in our two Scopus searches were used for both the bibliometric analysis and the qualitative thematic analysis focusing more narrowly on the Australian and developed country context. The selection process for articles retrieved from Scopus is detailed in Figure 8 below.

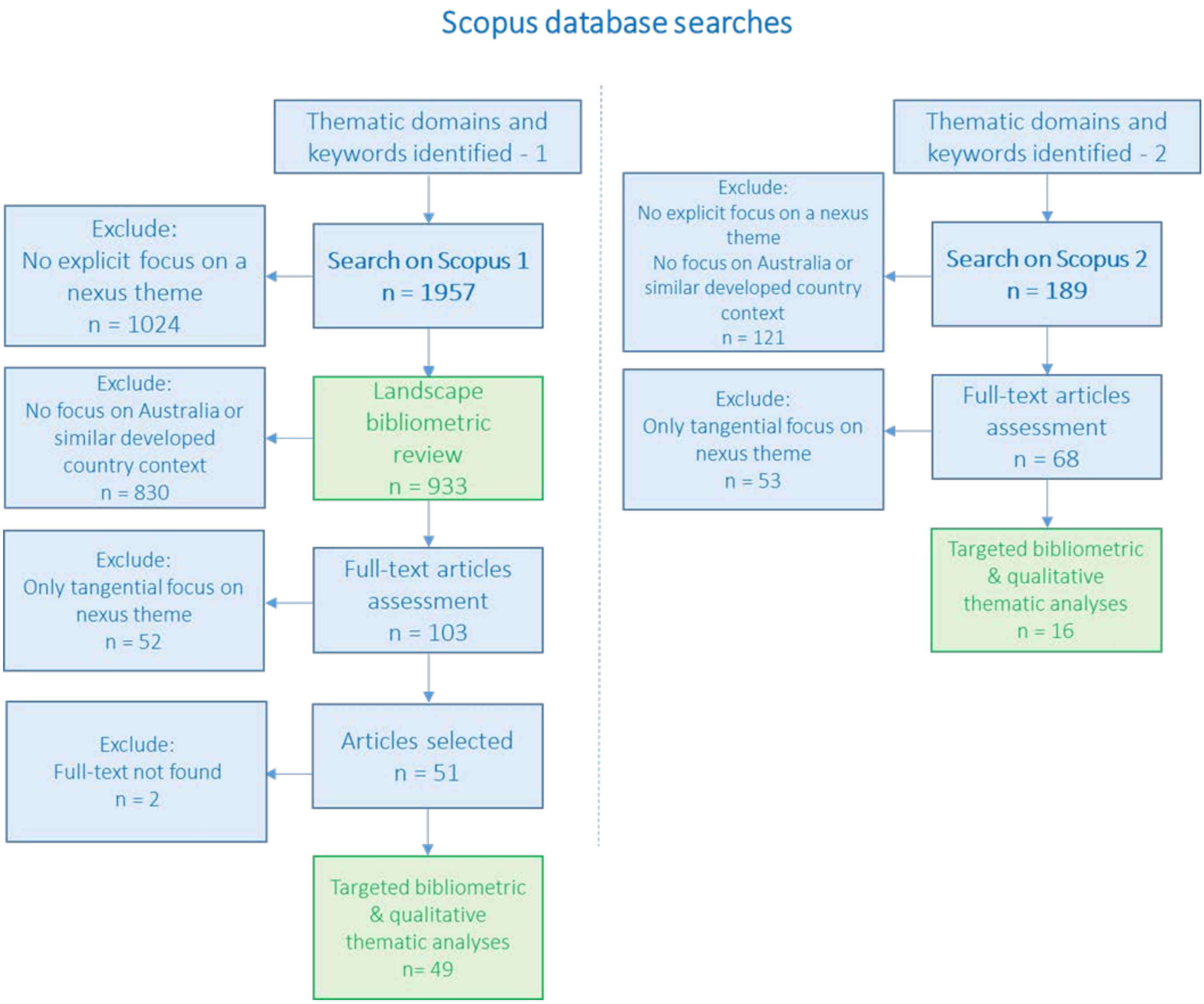


Figure 9: Selection process for the Scopus database searches

PubMed keyword searches & selection of relevant articles

In addition to Scopus, PubMed was selected as a complementary database due to its focus on medical research. Our objective here was to see if additional references tackling one of the nexus areas (particularly the nexus areas where one of the components is WHS). For this search, we specifically focused on the Australian context. In a similar fashion as for the Scopus search, we initially looked for keywords situated in the 'titles and abstracts' sections (keywords are not included as an option in PubMed; see Table 3 for a summary of the location of search terms for each search on PubMed). For the 'search 9', 978 references were selected under the 'titles and abstracts' section and 541 under the 'titles' section. In this case, we selected the 541 references in the 'titles' sections, as we assessed that they were likely to provide a comprehensive list of the relevant articles, as well as many non-relevant articles. If all the 541 articles were to be relevant, then we would have looked at the 437 remaining references in the 'titles and abstracts' section to ensure that we would not overlook relevant references. For all the other searches, we selected the 'titles and abstracts' sections as they provided a substantial number of references, while the searches under the 'titles' sections only provided a very limited amount of references.

Table 3 Location of search term for each search on PubMed

Searches	Location of search terms	Number of articles
Search 6: Climate change & farming systems	Titles and abstracts	504
Search 7: Climate change & business models	Titles and abstracts	1
Search 8: Climate change & work health and safety	Titles and abstracts	1019
Search 9: Farming systems and business models & work health and safety	Titles	541
Search 10: Nexus	Titles and abstracts	130
TOTAL NUMBER OF ARTICLES IDENTIFIED		2195

Out of the 2195 articles identified, we only looked at those that were clearly tackling a nexus area and were situated in the Australian context. Out of this search, no additional articles were identified. We then conducted a second search on PubMed, based on the refinement of the keywords put in place for the second Scopus search. This search identified 2054 references. Of these, 2046 references were excluded based on the fact that they were not clearly tackling a nexus area and were not situated in the Australian context, or were duplicates from the Scopus searches. Eight articles were selected during this second search. The selection process for articles retrieved from Scopus is detailed in Figure 9 below.

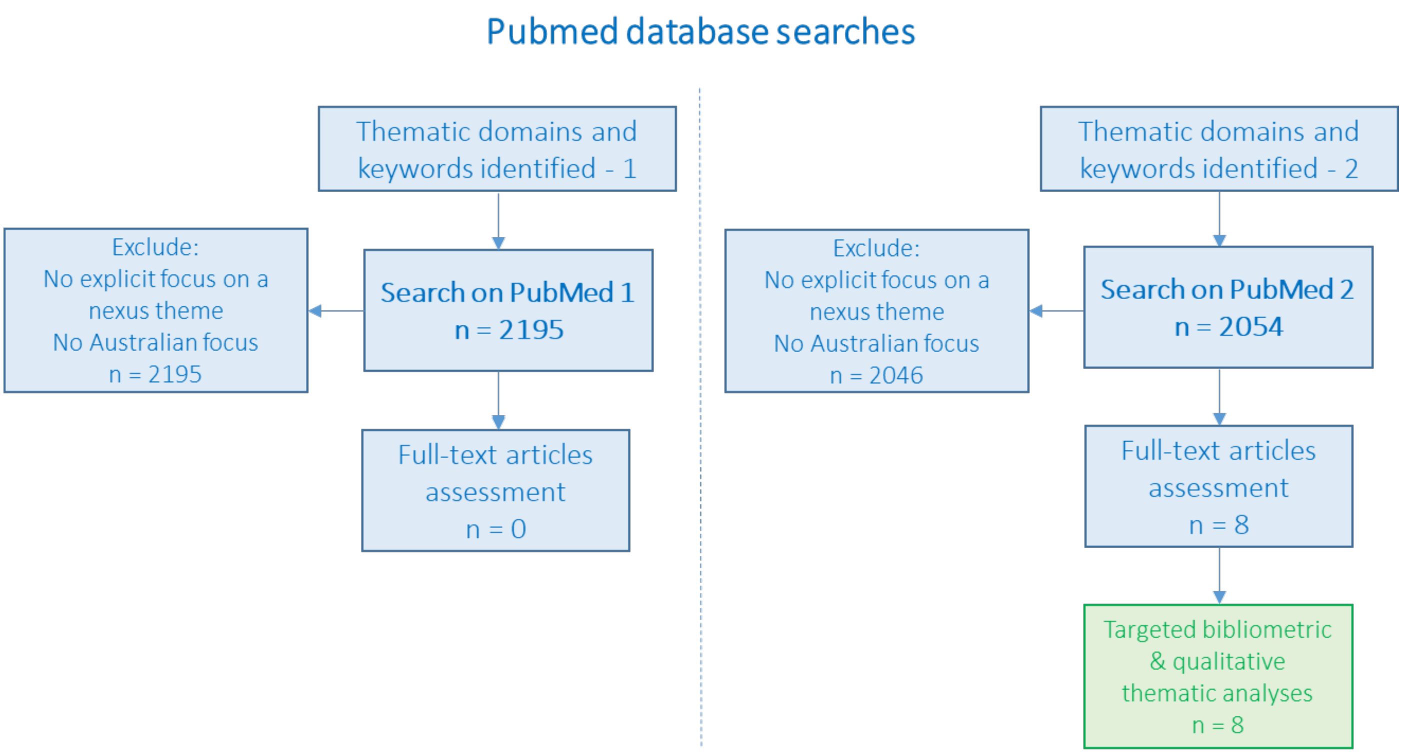


Figure 10: Selection process for the PubMed database searches.

Overall, 73 articles belonging to the different nexuses were identified for the targeted bibliometric and the qualitative thematic analyses (Figure 10).

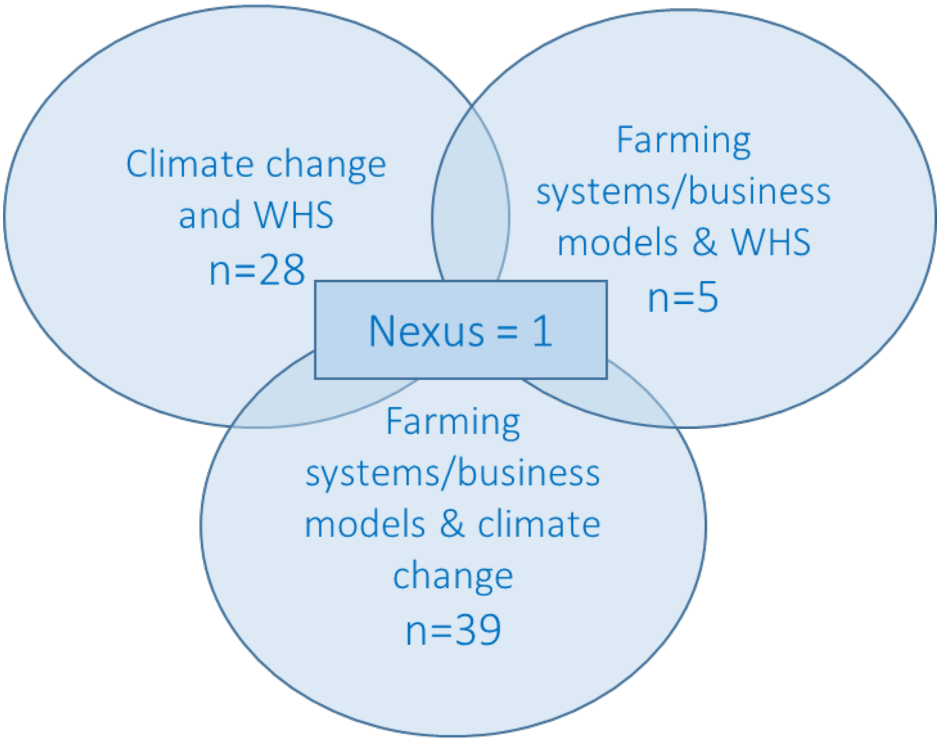


Figure 11: Number of articles per nexus theme (the nexus to which articles belong were determined during the analysis rather than based on the nexus themes in which they appear during the database searches. Total papers = 73

Landscape and targeted bibliometric analysis method

The landscape bibliometric analysis was undertaken to ensure that no essential material was omitted from the scope of the nexus queries. To understand the trends of research within each of the distinct research spaces, we used the Scopus Sci Val "Trends" function to run a trend analysis within four topic domains which are themselves made up of a variable number of sub-topics. The full methodology of the landscape analysis and findings can be found in Appendix C.

The targeted bibliometric analysis was undertaken in order to provide a deeper understanding of where the articles were situated within the broader literature and complements the qualitative thematic analysis of these articles. Data from the Scopus database was gleaned to understand the number of articles per journal, the articles with highest levels of citation, and co-authorship networks. In order to visualise the co-authorship networks, the software VoSviewer was used which allowed for greater interrogation of co-authorship, patterns of the use of key words, and geographical locations of co-authors.

Qualitative thematic analysis method

The process to conduct the qualitative thematic analysis is as follows. An excel spreadsheet was created to analyse the content of the 179 articles selected for 'full-text articles assessment' in our iterative queries in Scopus and PubMed. The different categories that were to be filled in are presented below:

- Title
- Authors
- Year
- Journal
- Purpose of the paper/research question(s)
- Methodology
- Sector (e.g. livestock, cropping etc)
- Location
- Main findings
- Additional comments

Based on this qualitative assessment of the content, 73 papers were selected to thematically discuss each nexus. The content of each article is discussed in the qualitative thematic analysis section below. As it is a qualitative analysis, we do not provide the numbers of articles that discuss each theme nor do we prioritise the topics that are more discussed, but rather provide a comprehensive overview of all the topics tackled in the articles.

Quantitative targeted bibliometric results

The following bibliometric results are based on the targeted repository of 73 articles found in Scopus. Interrogation of journal titles yielded a total of 54 unique journals titles and conference proceedings within this selection of 73 articles. This indicates that these topics of query are published in a broad range of journals. Of these, the top journals that published 3 or more papers included Agricultural Systems (n=7), Proceedings of the National Academy of Sciences of the USA (n=3), and Social Science and Medicine (n=3) (see Figure 10). The scope of this selection of journals encompasses topics of relevance to our search.

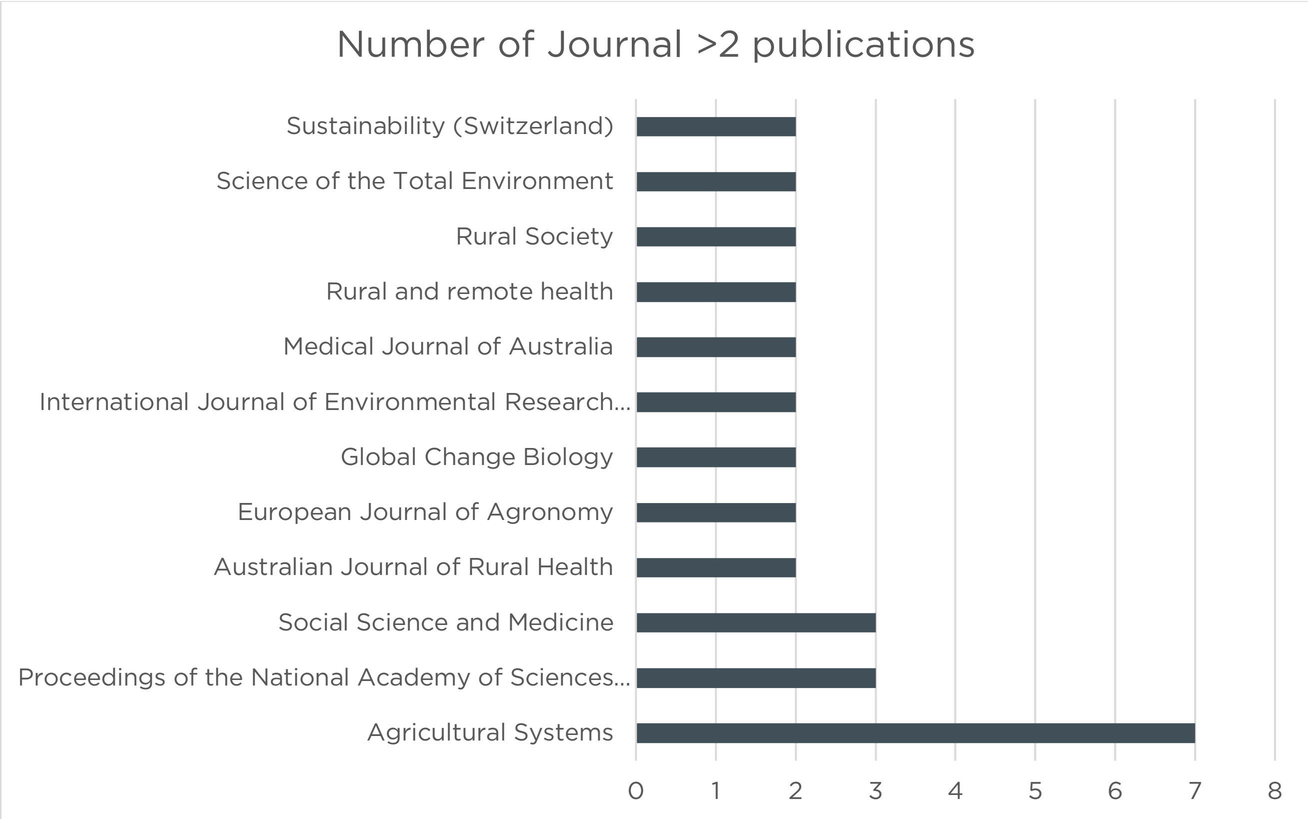


Figure 10: Most highly published journals (Articles N = 73)

In addition to understanding where the articles were published, the database was examined to identify the key journals and articles with the highest level of citation. Table 2 lists the ten most highly cited papers, while Appendix F includes the whole dataset.

Table 4: Articles N=73 Top 10 Highest cited papers

No.	Nexus theme	Authors	Year	Title	Source title	Cited by	Author keywords	Document type
1	T 2	Bradshaw B., et al	Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies	2004	Climatic Change	181	*(Nnone recorded)*	Article

No.	Nexus theme	Authors	Year	Title	Source title	Cited by	Author keywords	Document type
2	T 2	Scialabba N.E.-H., et al	Organic agriculture and climate change	2010	Renewable Agriculture and Food Systems	146	Adaptation; Carbon sequestration; Climate change; Diversification; Mitigation; Organic agriculture; Resilience	Review
3	T 1	Alston M.	Rural male suicide in Australia	2012	Social Science and Medicine	113	Australia; Climate; Farming; Gender relations; Masculinity; Men; Rural; Suicide	Article
4	T 1	Hanigan I.C., et al	Suicide and drought in New South Wales, Australia, 1970-2007	2012	Proceedings of the National Academy of Sciences of the United States of America	103	Depression; Rainfall; Self-harm; Weather	Article
5	T 1	Alston M., Kent J.	The big dry: The link between rural masculinities and poor health outcomes for farming men	2008	Journal of Sociology	101	Drought; Masculinities; Mental health; Resilience; Rural	Article
6	T 1	Berry H.L., et al	Climate change and farmers' mental health: Risks and responses	2011	Asia-Pacific Journal of Public Health	80	Adaptive strategies; Australia; Climate change; Farmers; Mental health; Rural	Review
7	T 2	Hochman Z., et al	Prospects for ecological intensification of Australian agriculture	2013	European Journal of Agronomy	76	Climate risk management; Crop-livestock integration; Deficit irrigation; Nutrient use efficiency; Precision agriculture; Water use efficiency	Article
8	T 2	Nicholas K.A., et al	Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in Northern California	2012	Global Environmental Change	76	Agriculture; Climate change; Climate change adaptation; Frost; Heat; Pests; Resilience; Vulnerability Scoping Diagram	Article
9	T 2	Zhao G., et al	Impact of agricultural management practices on soil organic carbon: Simulation of Australian wheat systems	2013	Global Change Biology	58	Agricultural management practice; APSIM; Australia; Carbon sequestration; Climate change; Crop model; Soil organic carbon; Wheat	Article
10	T 2	Leclère D., et al	Farm-level Autonomous Adaptation of European Agricultural Supply to Climate Change	2013	Ecological Economics	55	Agriculture; Autonomous adaptation; Climate change; Europe; Modeling; Residual impact; Water use efficiency	Article

Figure 11 shows the co-authorship network of the 73 papers (from VOSviewer software), wherein they had published a minimum of 2 papers. The figure indicates that there are 12 cliques within this co-authorship network. In particular, the cluster in the bottom of the image has developed over time, while other authors have appeared more recently (e.g., Wheeler S.A.). Figure 12 demonstrates that Australia has been involved in publishing in this space for almost 20 years, while more recently authors from the United States of America, China and Spain have begun to publish.

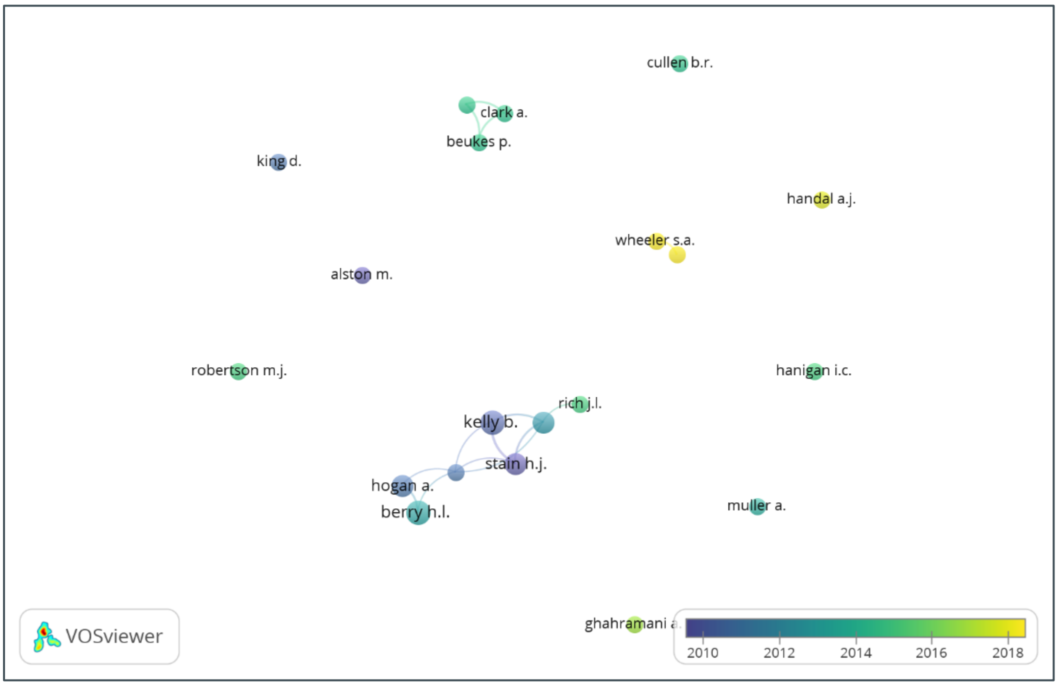


Figure 11: Co-Authorship network of authors with > 2 papers published. Papers: N=73, Authors: n = 281 Clusters = 12

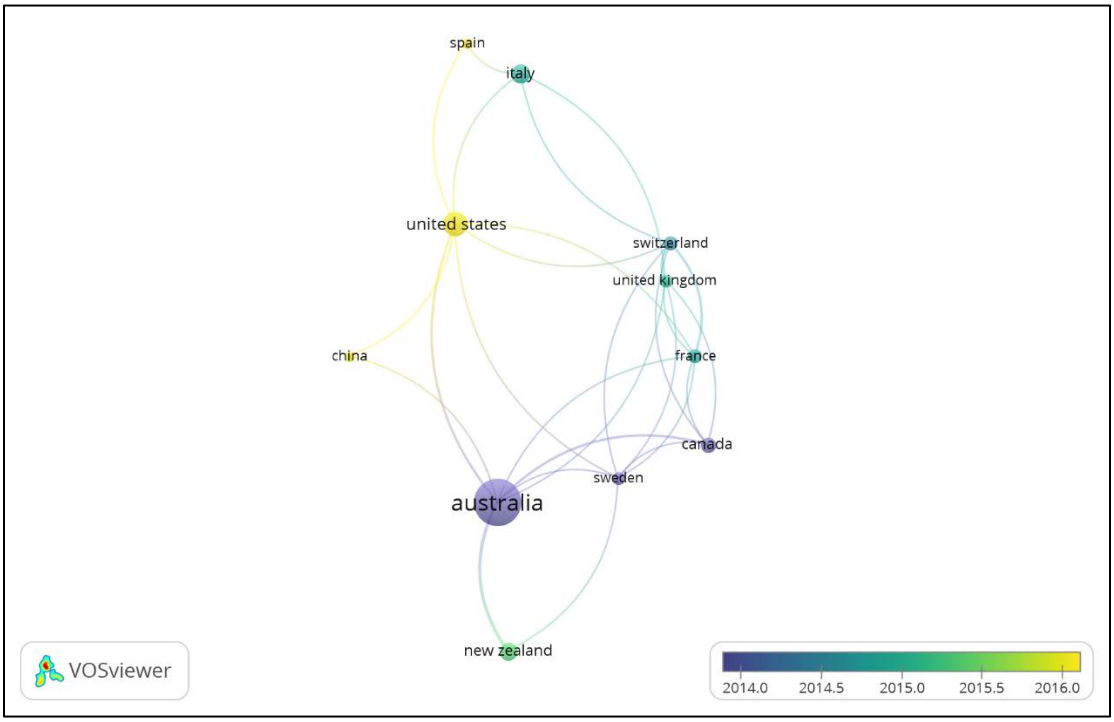


Figure 12: Co-Authorship network time scale by Country. Papers: N =73, Countries: n= 24 Clusters = 4. Isolated node – Germany (not depicted)

To understand how keywords were utilised by authors, a keyword analysis was undertaken on this database. Figure 13 and 14 visualises the author keyword networks appearing in the network when the word occurred more than twice. Figure 13 highlights the clustering of co-keywords which are ordered by colour. 'Climate change', 'adaptation', 'drought', 'agriculture' and 'organic agriculture' were among the highest nominated keywords, while Figure 14 demonstrates how the co-keywords have developed over time with "drought" and "resilience" appearing earlier in the record, and "organic farming", "farming systems" and "greenhouse gas emissions" appearing later.

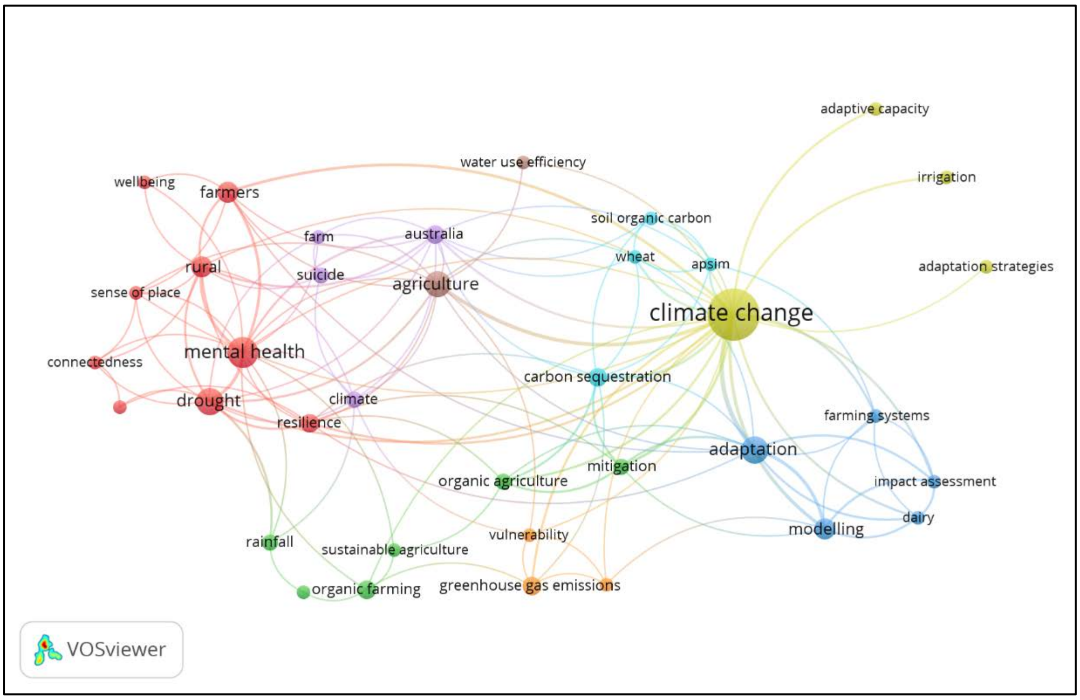


Figure 13: Author Keyword occurrence >2 network. Papers: N=73 Keywords n=247, Items = 37 Clusters = 8

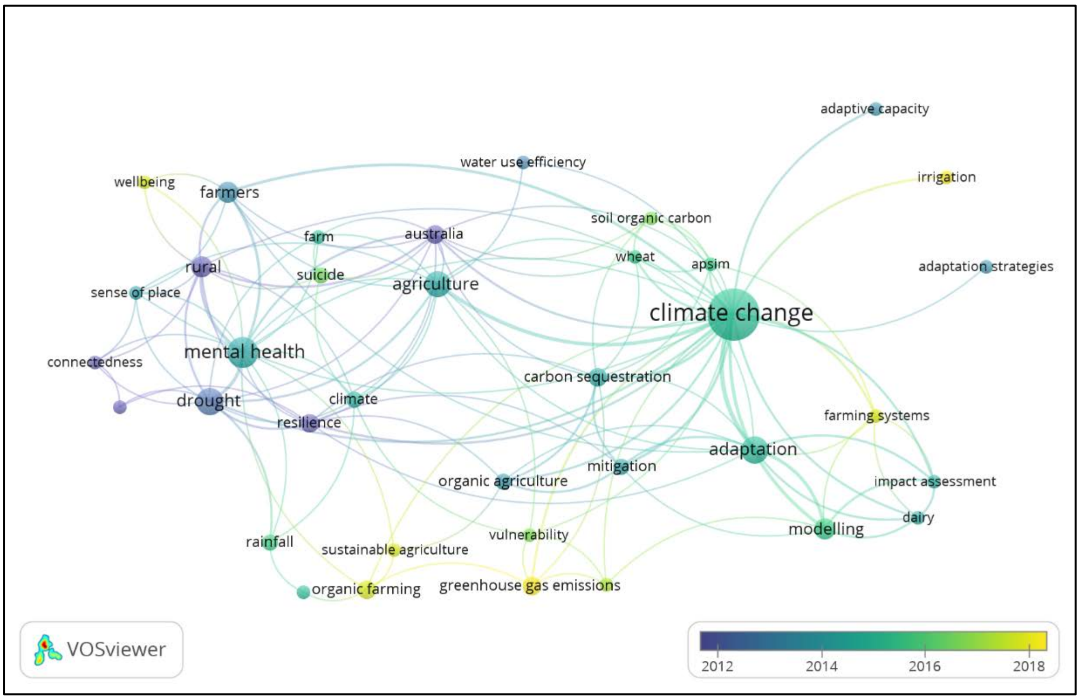


Figure 14: Author Keyword occurrence >2 network time scale. Papers: N=73 Keywords n=247, Items = 37, Clusters = 8

Qualitative thematic results

A baseline: Observed impacts of climate change on farming communities' work health and safety

The academic literature questioning the observed impacts of climate change on WHS in farming communities focuses mostly on mental health, with less attention paid to physical health and safety.

Mental health as a major impact of climate change on farming communities

The question of the impact of climate change on farming communities' mental health is debated. Some studies do not find a connection between climate change related events and farmers' mental health or suicide. A study by Beautrais (2018) found that financial problems and climate impacts were not leading factors in farming suicide[1]. Another study by Guiney (2012) in Victoria during six years of drought (2001 to 2007) found that there was no indication of an increased incidence of suicide during the drought. In contrast, other studies found that climate variability and extreme weather events, such as drought and floods, had an impact on farmers' mental health and, in some cases, suicide rate (Acharya, Kalischuk, Klein, & Nyende, 2007; Daghagh Yazd, Wheeler, & Zuo, 2019b; I. C. Hanigan, Butler, Kokic, & Hutchinson, 2012; Perceval, Kõlves, Ross, Reddy, & De Leo, 2019). In a review of the risk factors regarding farmers' mental health, climate variability (in particular drought) appears as one of the most cited risk factors, along with pesticide exposure, financial difficulties, and poor physical health or past injuries (Daghagh Yazd, Wheeler, & Zuo, 2019a). Acharya et al. (2007) in a study of the health-related impacts of flood events on feedlot farms in Alberta, found that, while physical health problems were rarely reported (3% of participants), mental-health impacts were mentioned by a large part of the participants (63%). Regarding suicide, a quantitative study by I. C. Hanigan et al. (2012) found that the relative risk of suicide increased by 15% for rural males (it was assumed in the study that a large portion of the cohort are farmers) aged between 20 and 49 when the drought index increased from first to third quartile. In a qualitative study focusing on the identification of the social and environmental factors related to farmers' suicide in Australia, Perceval et al. (2019) identify eight determinants of suicide, among which two are related to climate change: extreme climatic events (e.g. drought and floods) and distress of animals. Other factors are isolation, lack of adequate

[1] Leading factors identified were instead conflicts or arguments, physical health problems, legal charges or issues, acute alcohol or drug intoxication, life 'struggles' or accumulated problems, work problems and recent death of a family member or friend

service availability[2], access and familiarity to firearms, government policy and legislation[3], technology[4], and property values[5]. As such, climate change in general, and extreme weather events, such as drought and floods more specifically, are identified in the literature as impacting farmers' mental health and suicide rate. It is described by Sartore, Kelly, and Stain (2007) as a potential multiplier of existing mental health issues. The Australian literature, which is our priority, puts particular emphasis on drought (H. L. Berry, Hogan, Owen, Rickwood, & Fragar, 2011). Indeed, the Millenniam Drought led to an important number of studies focusing on the impacts of drought on mental health in Australia (Daghagh Yazd et al., 2019b). Only one study identified flooding, but the focus was on the general population rather than on farmers specifically (Matthews et al., 2019).

When it comes to understanding how climate change impacts mental health, H. L. Berry et al. (2011) identify three potential pathways:

1. damage to landscape and agriculture due to climate change-related disasters leads to economic and social impacts (loss of livelihood, isolation etc.)
2. increase in disease and injuries (e.g. smoke, burns) and lack of water and food availability due to climate change-related disasters can lead to poor physical health
3. stress and trauma due to climate change-related disasters can lead to poor mental health

The third pathway is direct (stress and trauma directly lead to poor mental health), the two others are indirect. The negative economic and social impacts triggered by climate change-related disasters might worsen mental health impacts through, for example, loss of livelihoods, or separation of family. It might also lead to decreased physical health. Poor physical health due to climate change-related disasters might also negatively impact mental health. In turn, poor mental health due to climate change-related disasters might lead to decreased physical health. The first pathway between climate change-related disasters and mental health have been illustrated in Australian irrigators, where drought and water scarcity contributed to psychological distress through the degradation of the financial capital of farmers (Daghagh Yazd et al., 2019a).

The focus of this first section of the literature review will be about understanding how climate change-related disasters (and its various pathways) can cause differentiated mental health

[2] Interviewees talked about the lack of availability of primary health and other services in general, as well as of the transient nature of service provision (service providers working in regional areas often do so to meet their professional services requirements, and would go back to work in cities once they have met the requirements) and the lack of face-to-face services with someone understanding their circumstances.

[3] Interviewees often felt that government policy and legislation were often affecting farmers negatively (e.g. changes to water licensing, extensive red tape to obtain grants during hardship etc.) and were taken by politicians in capital cities who did not understand farmers' circumstances.

[4] Interviewees perceived technologies as detracting from interpersonal relationships and adding stress in an already overloaded work environment.

[5] Property values drop due to the global financial crisis, drought, fall in commodity prices, and market shocks increasing farmers' feeling of being trapped.

impacts based on: farming status (e.g., farmer or non-farmer and type of farming), age and gender (M. Alston & Kent, 2008; Congues, 2014; Sartore et al., 2007).

Farming status

Contrasting findings are found when it comes to identifying whether farmers face a higher level of distress than the general (rural) population. While some studies found that the farming population has a higher level of distress during drought than the Australian population and the rural Australian population more generally (Gunn, Kettler, Skaczkowski, & Turnbull, 2012; Stain et al., 2008). Others (I. Hanigan, 2018) did not find a difference in distress due to drought between farming and non-farming individuals living in rural Australia. H. L. Berry et al. (2011) report on the life satisfaction of farmers and farm workers during drought in comparison to the general rural population. This study found that, while farmers report that they feel safer, have better personal relationships, are healthier and feel more part of their communities than general rural Australians, they also report feeling less satisfied with their lives and levels of achievement, their security about their future and their spirituality. This lack of sense of a future is of importance as lack of hope for the future is potentially linked to depression and suicide (H. L. Berry et al., 2011). As such, while farmers might not appear more distressed than the general population, and might even have higher levels of life satisfaction regarding aspects of their lives (i.e. feeling safer, having better personal relationships), their hopelessness regarding the future is important to consider individually, as it might strongly be linked to mental health issues, such as depression and self-harm, particularly suicide.

Within the farming community, differences have been identified between irrigators and dryland farmers (Wheeler, Zuo, & Loch, 2018). In the year 2015-16, irrigator farmers were the most psychologically distressed nationally, more than dryland farmers. Within the category of irrigators, horticulturalists were the most distressed, followed by broadacre, dairy and livestock farmers.

The reasons why farmers might be more psychologically impacted by climate change than the general rural population seem twofold. Firstly, farmers are financially dependent on the land. A study by Stain et al. (2011) found that the degree of worry about drought was linked to the pragmatic impact of the drought on livelihood. When identifying the pathways to mental health impacts from drought, Stain et al. (2011) saw that the financial impact of the drought on farming operations was one pathway. Beyond the financial impact, it has also been argued that connection to the land and a strong sense of place can also contribute to degraded mental health and well-being, due to a loss of identity in periods of low rainfall (M. Alston & Kent, 2008; N. R. Ellis & Albrecht, 2017; Stain et al., 2011; Stain et al., 2008). N. R. Ellis and Albrecht (2017)'s study showed that family farmers feel a strong sense of place for their farm properties that they consider as a site of work as well as a place of home and family, and thus a central aspect of their sense of selfidentity. In this context, the impact of changing weather patterns and dry conditions on the land generate emotional reactions from farmers and affect their personal (farmer) identity.

However, there might be differences in how individual farmers are affected by climate variability. Those differences can be due to the pre-existing viability of the business, income security, financial resources, the management of risk and decision making, farmers' identity, options to diversify incomes beyond farm, and the conditions of the natural assets (Greenhill, King, Lane, & MacDougall, 2009; Hogan, Bode, & Berry, 2011). Another factor that can play an important role in mitigating or aggravating the impacts of climate change or drought on farmers' mental health is the farmer's pre-existing physical and mental health issues. Indeed, Greenhill et al. (2009) explain that mental health issues can be worsened by drought, while Hart, Berry, and Tonna (2011) argue that individuals with mental health issues often have little personal resources and are therefore less likely to be able to cope with the impacts of climate and engaging in mitigation and adaptation activities.

Physical health has also been identified as important in determining farmers' ability to cope with climate change impacts. Indeed, Hogan et al. (2011) showed that pre-existing poor physical health acts as a barrier to continue farming and adapt to climate change.

Age

A study by Gunn et al. (2012), found that younger (25 to 54) and older farmers (above 65) experience higher degrees of psychological distress than farmers between 55 and 64 (Gunn et al, 2012). Austin et al. (2018) also found that age (along with other factors) plays a role. In their study, they identify that farmers under 35, who live and work on farm, experience financial hardship and, are living in outer regional, remote, or very remote NSW, are more likely to experience stress related to the drought.

While reasons for younger farmers' distress do not seem to have been widely considered, the distress of older farmers is often explain by a sense of loss and failure, the feeling of being trapped on the property as succession planning becomes impossible and the difficulty of seeing the new generation of farmers struggling to remain on the land (Gunn et al., 2012; Hart et al., 2011).

Gender

There are considerable gender differences related to health. This is particularly true in rural areas, where, in general, rural men are found to be less healthy than rural women (Alston & Kent, 2008). As such, the impacts of climate change on health are also potentially gendered. While some studies suspected that drought would lead to higher level of distress in women than men, several studies showed that women were no more distressed than men (in Gunn et al., 2012) or even that men were often more impacted by drought than women (Greenhill et al., 2009). When looking at women in isolation from men, a study by Powers, Loxton, Baker, Rich, and Dobson (2012) found that women's health and wellbeing was not affected by adverse climate events such as drought, fire and floods. Another study by I. Hanigan (2018) nuances this observation by explaining that they found higher level of distress in younger and mid-aged rural women, but not so much in older rural women.

Several reasons can explain the differentiated impact of climate change on mental health between farm men and women. They have to do with gender roles and the use of different coping mechanisms. Indeed, in times of drought, men tend to remain on the farm to take care of the animals and become more isolated, while women seek work off-farm in order to support the family (M. Alston & Kent, 2008; Greenhill et al., 2009). As the income generated by the farm diminishes, the income brought from off-farm by the women becomes essential. This change in gender roles and the inability of farm men to generate an income from the farm have been shown to threaten farm men's masculinity and sense of identity as a farmer (Margaret Alston, 2012; M. Alston & Kent, 2008; H. Berry, Hogan, Ng, & Parkinson, 2011). Indeed, the form of hegemonic masculinity described by M. Alston and Kent (2008) as pervasive in rural areas, is based on the ideal of the male breadwinner and family provider. Seeing their identity and masculinity challenged can lead to the development of mental health issues among men.

This form of hegemonic masculinity glorifies stoicism and individualism in the face of adversity (Margaret Alston, 2012; M. Alston & Kent, 2008). As a result, farm men often consider that they are responsible for the situation they are in, rather than the economic circumstances and the changing climate (Margaret Alston, 2012). Their attachment to stoicism also prevents them from acknowledging mental health issues (which are often referred to as 'stress') and to seek help – financial or psychological (M. Alston & Kent, 2008; Perceval et al., 2019; Sartore et al., 2007). As such, it seems that droughts are more likely to impact men's mental health, rather than women's mental health.

Studies focusing on women provide a nuanced picture of the impacts of droughts on their mental health. Some studies, such as Powers et al. (2012), show that women do not seem to have suffered health impacts due to climate events. However, others (Hart et al., 2011) found that women face specific challenges due to the fact that they often assume the role of caregiver and supporter in times of drought. In addition, as mentioned by M. Alston and Kent (2008), they often take more on-farm work (e.g. feeding livestock, checking water), assume the role of farm financial managers, while also taking care of the household. As such, they are likely to work longer hours, and to buffer the emotional stresses of their husbands and children (Greenhill et al., 2009). They are therefore also likely to face mental health issues related to their role as supporter and caregiver. While women face mental health issues of their own, they are also more likely than men to have social support and resilience (Gunn et al., 2012). This might in turn enhance their ability to cope with their difficulties.

Strategies to tackle mental health issues in farming communities

Several ways forward have been envisioned in the literature, which could be divided into four categories: 1) supporting farmers' individual and collective adaptation; 2) providing better and adequate mental health support and services, 3) reframing the discourse on masculinity in rural areas and 4) supporting exit of farming.

Regarding support for farmers' individual and collective adaptation, several studies (Caldwell & Boyd, 2009; Congues, 2014; N. R. Ellis & Albrecht, 2017; Wheeler et al., 2018) have highlighted their importance and provided some recommendations. Wheeler et al. (2018) who focus on irrigators insisted on the need to encourage farmer adaptation through, for example, supporting water entitlement buy-back and eliminating on-farm irrigation infrastructure subsidies. Without a specific sector focus, N. R. Ellis and Albrecht (2017) explain that considering the strong connections between farmers and their land and the ecosystem that supports it, investing in NRM could increase agricultural sustainability as well as farmers' mental health. However, they acknowledge that more research is needed on the type of NRM delivery that would have the best health benefits and the members of the farming community that would benefit from these types of activities. Caldwell and Boyd (2009) and Congues (2014) focus on collective adaptation strategies and explain that providing financial support to community initiatives and events could be a way to improve the ability of the community to cope with climate change impacts. Somewhat contradicting the previous suggestion, Caldwell and Boyd (2009) highlight the importance of enhancing farmers' individual coping strategies. The reason for that being that while community support and social capital can mitigate the effects of drought on farmers' mental health (Caldwell & Boyd, 2009; Stain et al., 2011; Stain et al., 2008), those collective mechanisms are showing signs of weakening (Caldwell & Boyd, 2009). This weakening is likely to be enhanced by climate variability. Indeed, Hart et al. (2011) show that, with time, adverse weather events negatively affect the economic situation and social fabric of rural areas, leading to a weakened social capital. This leads to an increase in mental health issues, which in turn leads to an inability to cope and adapt to climate change, as individuals facing mental health issues often have fewer personal resources and abilities to cope and adapt. As a result, putting emphasis on farmers' individual coping strategies is also of importance.

Regarding the provision of better and adequate support and services, several studies argue that GPs could play a role, and that improving farmers' access to GPs as well as mental health professionals could be of importance (Brew, Inder, Allen, Thomas, & Kelly, 2016; Hogan et al., 2011; Sartore et al., 2007; Shorthouse & Stone, 2018). They also mention the importance of providing targeted health-related support for farmers (Hogan et al., 2011). N. R. Ellis and Albrecht (2017) provided insights on the nature of the mental health intervention that should be carried out in rural areas, and insisted on the importance of taking a place-based approach that considers farmers' sense of place and how it relates to their identity. Regarding the question of rural masculinity, M. Alston and Kent (2008) stress the need to shed light on the damage of hegemonic rural masculinity and to encourage the development of a different discourse on masculinity.

Finally, regarding exiting farming, Wheeler et al. (2018) observe that one way forward would be to remove existing farm exit barriers.

Physical health: the 'poor cousin' of the research on the impacts of climate change on farming communities' work health and safety

In our review, we only identified two publications that focused on how climate change might impact the physical health of farmers. The first study (Brumby, Chandrasekara, McCoombe, Kremer, & Lewandowski, 2011) offered to look at the potential connection between prolonged stress in farmers, in part due to climate variability, and the increase in systemic cortisol, which promotes abdominal adiposity (i.e., abdominal overweight or obesity) and weight gain. This study posits that some aspects of physical health are mediated by mental health, i.e., stress levels. However, the paper does not provide any results from the research, so it is not possible to know whether this hypothesis proved to be correct or not.

Another study (Nerbass et al., 2017) reviewed the literature on the connection between heat stress and kidney disease for indoor and outdoor workers more generally. This review highlights that regular heat stress and dehydration can cause subclinical ischemic kidney injuries, which, in the long term, can lead to permanent kidney damage or chronic kidney disease. As global temperatures rise and access to clean drinking water decreases, kidney diseases related to heat stress might become an increasing WHS issue.

This 'baseline' shows us that research has mostly been focusing on the impacts of climate change (and more specifically drought) on the mental health of farming communities, with a particular interest in how they vary according to farming status, gender and age. The focus of those studies is often on farming families and not so much on other members of farming communities, such as farm workers. We also saw that, while many strategies have been identified to tackle mental health issues in farming communities, the adoption of transformative livelihoods is not mentioned in the relevant literature. Finally, we also saw that physical health issues in farming communities were rarely a focus. In the first publication identified, physical health issues were only considered as mediated by mental health, while the second paper focused on health issues applying to workers in general, and not specifically farming communities. If more physical (and potentially safety) risks are to be identified, searches related to the impacts of climate change on WHS of outdoor workers more generally should be conducted.

The main learning from this stocktake of the literature on climate change and WHS risks is that mental health issues are already identified in farming communities, as a result of climate change, and are highly likely to become more prevalent as climate change progresses.

Adapting to and mitigating climate change through changes in farming systems and business models

In this section, we will provide an overview of the changes in farming systems and business models that have the potential to help farming communities adapt to climate change impacts. As presented in the Contextual Background section, farmers can: 1. Adjust their farming practices (persistence), 2. Change their farming systems (incremental adjustments) or 3. Transform their use of livelihood resources (transformational responses).

Adaptation: A strong focus on 'persistence'

A large part of the literature identified in this review focuses on identifying practices that can help farmers maintain their productivity and economic viability in different sectors, under a changing climate. The sector for which most of the research seems to have been done in the Australasian context is dairy farming, and more specifically how increasing inter- and intra-annual rainfall variability or water availability will impact pasture growth, which will, in turn, affect the productivity of dairy farms. Harrison, Cullen, and Armstrong (2017) identify three strategies (e.g. intensify, simplify or adapt), and a set of agricultural practices corresponding to each of those strategies (see Table 5 below), and apply them to three study cases in South Australia. They explain that no strategy was preferable across regions and systematically led to increase or decrease in pasture harvest.

Table 5: Adaptation strategies identified by Harrison et al. (2017) for the dairy sector in Australia.

Strategy	Agricultural practices
Intensify (definition)	-Increasing herd size/stocking rate -Increasing mature cow liveweight -Increasing the amount of purchased grain or hay/silage fed to animal
Simplify (definition)	-Reducing herd size/stocking rate and pasture inputs -Reducing the number of replacements required -Maintaining/reducing mature cow liveweight -Increasing the proportion of feed from grazed and conserved pasture while reducing the amount of supplementary feed
Adapt (definition)	Reorganisation of resources according to changes in pasture growth: -Changing (increase or decrease) the size of the milking herd -Changing the calving pattern (different time of year) -Increasing the irrigated area -Using partial mixed ration

Focusing more specifically on the water scarcity dimension of climate change for the irrigated dairy industry in southern Australia, Chapman, Dassanayake, Hill, Cullen, and Lane (2012) found that the use of summer-dormant perennial grass and double cropping on 20% of the farm area in conjunction with autumn calving could contribute to maintaining profitability of farms in a scenario of lower or fluctuating water allocations.

Four studies conducted in New Zealand (Kalaugher, Beukes, Bornman, Clark, & Campbell, 2017; Kalaugher, Beukes, Clark, & Bornman, 2012; Lee, Clark, & Roche, 2013; Lieffering, Newton, Vibart, & Li, 2016) also identified strategies to adapt to the effects of climate change, but rather than focusing on the 'intensity' of the practices, they put them on a spectrum from tactical to transformational: tactical, strategic and transformational adaptations. Tactical adaptations are adaptations that require minimal investment and involve the adoption of well-known practices, while strategic adaptations necessitate the implementation of structural changes in regards to farm management or land use. Transformational adaptations are changes that lead to the development of a new farming system. Those three types of adaptations, which seem to mirror our three types of adaptation: persistence, incremental adjustments, or transformational responses, in fact fall under 'persistence' as they focus on modifying the existing systems at the margin, in order to maintain this system (see Table 6 below).

Table 6: Adaptation strategies in the New Zealand dairy sector.

Type of adaptation	Practices	References
Tactical adaptations	- Increase making of grass silage - Lengthen rotation length - Purchase/sell supplementary feed - Winter stock off-farm - Contract grazing - Changes to timing of operations	(Lee et al., 2013) (Lieffering et al., 2016) (Kalaugher et al., 2012) (Kalaugher et al., 2017)
Strategic adaptations	- Irrigation[6] - Change in pasture species (more water efficient and drought tolerant species)[7] - Use of a higher diversity of pastures (four or more species) with differing threshold in terms of C0^2 water and temperature - Increase in pasture renewal as climate change leads to a decline in the production and persistence of pasture - Increase in the use of crops on farms, either before pasture renewal to break the cycles of weeds and pests or to increase DM production - Use endophyte (fungus toxic to various insects) affected grasses	

[6] Kalaugher et al (2017) observe that climate change might lead to a decrease in water availability. As such, irrigation might not be an adaptation strategy, but rather a source of vulnerability in the context of climate change

[7] Kalaugher et al (2017) note that changes in pasture species comes with its challenges. For example, in the case of tall fescue, which is a species change recommended for New Zealand, they explain that tall fescue: 1) loses its feed quality faster than ryegrass if not managed carefully, 2) establishes slower than ryegrass. Therefore, considering those trade-offs is of importance to determine whether changes in pastures species will maintain or increase productivity.

	- Changes in stock number (e.g. use of conservative stocking rates[8]) - Move stock/feed between regions - Increase size of farming enterprise	
Transformational adaptations	-Develop more stress-tolerant plants -Breed plants with an improve stress response	

Similar research has been carried out for cropping and horticulture. Regarding cropping systems, several studies were identified, which focus on how different cropping systems can adapt to climate change in Australia (Williams et al., 2018), the USA (Prato & Qiu, 2014), Canada (McMartin & Hernani Merino, 2014) and Europe (de Frutos Cachorro, Gobin, & Buysse, 2018; Himanen, Mäkinen, Rimhanen, & Savikko, 2016; Nendel, Kersebaum, Mirschel, & Wenkel, 2014). The adaptation strategies identified in these four publications are presented in Table 7 below. Three qualitative studies focus on how a specific practices, such as crop diversification (Bradshaw, Dolan, & Smit, 2004), intercropping (Himanen et al., 2016), zero till cropping and cropping choices/rotations (McMartin & Hernani Merino, 2014) already contribute or could contribute to farmers' adaptation to climate change, and the barriers and enablers to their adoption. Again, those studies refer to 'persistence' as they focus on modifying practices within the existing farming system to maintain the profitability of the farm under a changing climate.

Table 7: Adaptation strategies for different cropping systems

Type of cropping systems	Adaptation practices	Country	References
Irrigated cotton	-Less intensive system (2m row spacing) and limiting in-crop irrigations to two instead of four currently -Dryland cotton in the rotation	Australia	(Williams et al., 2018)
Hay, wheat, barley, oats, and lentil production	-Flexible scheduling for crops (ineffective) -Adding irrigation to the farming operation (ineffective) -Other strategies to explore: later maturing cultivars, use of more heat tolerant crops and changes in nutrient and pesticide management.	USA	(Prato & Qiu, 2014)

[8] While a reduction in stocking rate might appear uneconomic as it might lead to lower production and profit (Kalaugher et al, 2017), it might be necessary as more intensive systems might be less successful at coping with extreme weather events (Lee et al, 2013)

Summer and winter crops	-Reducing share of summer crops and barley and increasing the share of less vulnerable crops, such as winter Wheat	Belgium	(de Frutos Cachorro et al., 2018)
Summer and winter crops	-Adapting the crop rotation design to the climate (spring barley succeeding a winter barley may be suitable in the future) -Irrigation on sandy soils -Adjustment of nitrogen management	Germany	(Nendel et al., 2014)

Mixed farming systems have also been scrutinised. Two Australian studies (John, Pannell, & Kingwell, 2005; Thamo et al., 2017) identify a series of adaptation strategies, which will allow the persistence and profitability of mixed-crop systems in the Australian landscape under a changing climate. Those adaptations are, among others, reduction in animal numbers and fertiliser rates, purchase of supplementary feed, and changes in land use, such as the allocation of crop and pasture areas, and rotational sequences.

Finally, two studies have been identified that focus on the horticultural sector, respectively on how citrus farms in the Murray and Darling rivers in South Australia, Victoria and New South Wales can adapt to reduced yield due to reduced water availability (Skewes, Dyson, & McCarthy, 2016) and how vineyards in Italy can adapt to yield reduction due to drought, frost, hail and heat waves (Sacchelli et al., 2017). Again, the focus here is on 'persistence', with the exception of the transition to organic farming, which can be considered as an incremental adjustment (see Table 8 below). This focus on 'persistence' is highlighted by Nicholas and Durham (2012) in a study on vineyards in North Carolina, where they identify that most of the adaptation strategies used by farmers are responsive or anticipatory, but always focus on short-term threats. This focus on short-term threats can potentially contribute to explaining why we do not identify more incremental adjustments and transformational responses.

Table 8: Adaptation strategies in different horticultural systems

Type of horticultural systems	Adaptation practices	References

Citrus farms	-Match water application with water demand[9] -Select cultivars and rootstocks with a higher resistance to drought	(Skewes et al., 2016)
Vineyards	-Use fans to counter the effect of frost -Use next to counter the effect of hail -Emergency irrigation in case of drought (irrigation in vineyards is usually forbidden) -Use of different cultivars[10] -Transition to organic farming	(Sacchelli et al., 2017)

Another type of adaptation that is more rarely mentioned is the use of technologies and smart farming to better adapt to climate change. For example, Adamides et al. (2020) implemented an Internet of Things (IoT) 'Deploy-and-Forget platform' in a potato farm in Cyprus. This platform collected atmospheric, soil and plant data through sensors put in the field. Those data were then processed in a cloud computing repository and analysed by experts, in order to provide farmers with advice tailored to their farming operation regarding irrigation, pest management and fertilisation. The experiment showed that the system could lead to a reduction of irrigation needs by 22%, as well as an optimisation of pesticide use. Without referring to IoT, Hochman et al. (2013) also argue that technology could contribute to climate change adaptation by providing information that allows for better planning, notably through reliable multi-week and seasonal climate forecasts and soil water measurements. The wider adoption of technological tools to support decision making is again conducive to 'persistence' as it is a way to enhance the profitability of the existing farming system by better understanding the parameters within which it operates.

Towards incremental adjustments for climate change adaptation

While this has not been the focus of most of the literature reviewed, a few studies mentioned additional changes in practices that could be considered as incremental changes. Two studies (Sacchelli et al., 2017; Scialabba & Müller-Lindenlauf, 2010) mentioned the possibility of implementing incremental adjustments, in the form of the adoption of an organic farming system,

[9] This can be done by increasing the supply through increasing irrigation (which was possible in this specific case as a water trading systems exists in the Murray Darling Basin) or by providing more water to healthy and high value trees and abandoning trees with lower value or poor health. This can also be done by decreasing the demand, through hedging (trimming outer canopy) and topping trees (reducing tree height) or doing a partial root drying.

[10] It is considered as an expensive option that should only be used when climate change impacts are already occurring, and the price of the wine is relatively high (at leads 20 euro per liter).

to adapt to climate change. Scialabba and Müller-Lindenlauf (2010) notably argue that organic farming can contribute to farmers' adaptation to climate change by enabling farm diversification, enhanced soil fertility and higher selling prices for products. Incremental adjustments beyond conversion to organic farming have been identified. Leclère, Jayet, and de Noblet-Ducoudré (2013) in an attempt to model farm-level autonomous adaptation to climate change at the scale of Europe, identified a possible shift from pasture to crops, with a loss of 20% of pasture areas in Europe. Paul, Weber, and Knoke (2017) show that agroforestry can be an economically viable strategy for farmers, and is preferable to a farm mosaic approach[11] in terms of climate change adaptation. Finally, Christmann and Aw-Hassan (2012) explain how a farming approach, called farming with alternative pollinators, include a range of practices which encourage the presence of wild pollinators, which are considered more reliable than honeybees in the context of a changing climate, while increasing farmers' income.

Little attention paid to business models

When it comes to the question of how business models can help farmers adapt to climate change, only one study was identified (Zhang, Mu, & McCarl, 2018). This study identified that land leasing patterns in the U.S Pacific Northwest will decline between now and 2050 by 23% under a medium greenhouse gas (GHG) emission scenario and by 29% under a high GHG emission scenario. According to the authors, this shows that, under a changing climate, farms are more likely to become larger and owner operated. Rather than providing insights on business models that could help farmers adapt to climate change, this study describes how climate change will impact business models, by limiting land leasing.

Mitigation: The focus remains on 'persistence'

Another part of the literature focuses on how farming operations might make systemic changes to contribute to climate change mitigation (Henry, Charmley, Eckard, Gaughan, & Hegarty, 2012; Hochman et al., 2013; Huang et al., 2020; Marino et al., 2016; Müller & Aubert, 2014). Several strategies to reduce emissions of methane, nitrous oxide and carbon dioxide are identified, particularly in the livestock sector and to a lesser extent in the cropping sector (see Table 9 below). While several of the practices described in Table 9 below are commonly used in organic farming systems (i.e. use of organic fertilisers and crop rotations), others might be more readily used in conventional farming systems (i.e. feeding supplements to increase dietary concentration of lipids) (Müller & Aubert, 2014). As such, rather than suggesting a shift in farming systems, which could be described as an incremental adjustment, the focus seems to be again on 'persistence', where certain practices are adopted to mitigate climate change effects. However, the adoption

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[11] Trees and farmlands are next to each other rather than interspersed

of those practices could be considered as incremental adjustments if a market came to be established that rewarded farmers financially to implement those practices that contribute to climate change mitigation. In that case, rather than a simple change in practices, it would be a change in the farming system and the business model, as the focus would shift from selling agricultural products to selling capture of GHG.

Table 9: Mitigation strategies identified in livestock and cropping systems

Sector	Reducing methane production	Reducing nitrous oxide production	Reducing carbon dioxide production	References
Livestock	-Feeding supplements that increase dietary concentration of lipids by 6% -Change the microbial population of the rumen (use of microbes or vaccination) -Selective breeding -Capturing methane to use it as biogas - Intensive production (livestock is fed more concentrate than forage, which diminishes methane production) -Pit storage of liquid swine manure – composting of solid part and sequential aeration of liquid part -Reducing number of animals	-Nitrification inhibitors -Soil management strategies (e.g. reducing soil compaction, minimising soil disturbance etc.) -Use of pasture species and supplementary feed to manage energy-to-protein ratios in stock -Organic fertilisers	-Increase energy efficiency of machinery -Use of renewable energies -Use of (organic) fertilisers -Optimised crop rotations	(Henry et al., 2012) (Hochman et al., 2013) (Huang et al., 2020) (Marino et al., 2016) (Müller & Aubert, 2014) (Scialabba & Müller-Lindenlauf, 2010) (Zhao et al., 2013)
Cropping	N/A	-Use variable rate fertiliser application -Organic fertiliser	-Conservation tillage/ no-tillage with cover crops -Increase energy efficiency of machinery -Use of renewable energies -Use of organic fertilisers -Use of legumes -Optimised crop rotations	

			–Reduction of residue removal	

Towards incremental adjustments for climate change mitigation

While the focus of the literature is on how existing farming systems can contribute to climate change mitigation, several studies also mention how the adoption of specific farming systems (i.e. agroecology, regenerative farming and organic farming) or a shift in land use could contribute to the mitigation of climate change (Bonfante et al., 2017; Colley, Olsen, Birkved, & Hauschild, 2020; Diacono, Persiani, Fiore, Montemurro, & Canali, 2017; Gattinger et al., 2013). Agroecology, in the form of the combination of several practices[12], is presented by Diacono et al. (2017) as a possible mitigation strategy through the reduction of high energy inputs, such as fertiliser, fuel and water. Colley et al. (2020) look at how regenerative agriculture can offset a large part of the climate change impacts of a farm through carbon biosquestration in soils and in biomass and to use this biomass to offset the use of fossil fuel. Regarding organic farming, there is some debate around whether or not it contributes to climate change mitigation. While some argue that organic farming contributes to climate change mitigation by sequestering carbon in the soil (Gattinger et al., 2013), others highlight that organic farming has higher GHG emissions per unit of product due to the lower yield (Clark, 2020) and that to maintain the same level of production as conventional farming, more land would need to be converted into farmland, leading to carbon emissions (Leifeld et al., 2013). Finally, Bonfante et al. (2017) look at land use change, more specifically the potential of growing Giant Reed (*Arundo donax*) as a bioenergy crop on marginal land. The study shows that growing this biocrop on marginal land can support the resilience of farming communities by providing additional income and by contributing to climate change mitigation by reducing carbon emissions.

Adaptation and mitigation: tradeoffs and synergies

Finally, certain studies illustrate the potential tradeoffs (Ghahramani & Bowran, 2018; Ghahramani & Moore, 2015; Godde et al., 2019) between adaptation and mitigation strategies. Ghahramani and Bowran (2018) analysed how moving towards larger livestock enterprises, by increasing stocking rates and pasture areas, could be seen as a profitable and low-risk approach during extremely low rainfall years. However, this would lead to an increase in greenhouse gas emissions by livestock and soil degradation. Similarly, Ghahramani and Moore (2015), looking at grasslands and

[12] Soil surface shaping, cash crop rotation, agro-ecological service crops, living much and complementary crops, tailored organic fertilization and alternative tillage strategies

livestock production in Australia, argue that a combination of adaptation practices could be adopted relating to grassland management (e.g., increase applications of phosphorus, confinement feeding, sowing lucerne, removal of annual legumes from pastures to slow loss of ground cover during dry summers) and livestock genetics (e.g., for sheep: larger animals, greater conception rate, increasing potential fleece weight, increasing ram size). The study identified an 'optimal systemic adaptation', which is the optimal combination of all adaptations for the profitability of grazing systems, which would offset or even increase profitability of grazing systems. The study goes on to identify that this optimal systemic adaptation would provide several positive environmental outcomes on farm, such as soil conservation, higher rainfall capture efficiency and reduced salinization risk. However, it also shows that the optimal combination will also lead to a higher emission of methane, which contributes to climate change. A third study (Godde et al., 2019) comes to a similar conclusion: intensification strategies, such as feed supplements and improved pastures, might contribute to climate change adaptation by increasing the productivity of the farm, but also lead to an increase in GHG emissions.

In this section, we saw that changes in practices were identified for both adaptation and mitigation to climate change, and the tradeoffs between the two. The main learning is that the practices that are presented as enabling the adaptation or mitigation of climate change on farm are mostly meant to allow existing systems to persist through time. Incremental adjustments are also mentioned, such as shift in farming systems and land-use with very little focus on business models. Finally, no studies looking at how transformational responses might enable farming operations to adapt to or mitigate the effects of climate change have been identified.

Changes in farm systems and business models and work health and safety risks

When it comes to the question of understanding how changes in farms systems or business models might affect the WHS risk profile of farming communities, the focus has mostly been on comparing conventional and organic farming systems.

Several studies focus on mental health. While it is acknowledged that organic farmers are subjected to stressors that are of a similar nature to those faced by conventional farmers, such as workload, work-life balance, strain on relationships, isolation, lack of control over weather conditions, economic insecurity (Brigance, Soto Mas, Sanchez, & Handal, 2018; Soto Mas, Handal, Rohrer, & Tomalá Viteri, 2018), it is also observed that, overall, they seem to have a better mental health than conventional farmers. Several studies (Daghagh Yazd et al., 2019a; Khan, Baidya, Aryal, Farmer, & Valliant, 2018) found that being an organic farmer was associated with lower overall depression problems (Khan et al., 2018) and lower psychological distress (Daghagh Yazd et al., 2019a). However, it is worth mentioning that while the studies showed a positive association between farming system and mental health there was no or a weak statistical significance (Daghagh Yazd et al., 2019a). Regarding the factors that could explain improved mental health from organic farming, Brigance et al. (2018) identify potential 'protective' factors, such as higher degree of community participation, through farmers' markets or educational workshops and the holistic approach of organic farmers to farming, which is based on the principles of living in harmony with nature. Another factor that is most likely of importance is the increase in economic viability of operations in organic farming. A financial study of organic farmers in the Czech republic demonstrated that when comparing financial outputs per hectare, organic farming delivered "higher average profit rates" (Brožová, 2011, p. 91)[13]. As financial stress has been found to be a driver of poor mental health (Daghagh Yazd et al., 2019a), it can be hypothesised that the improved profitability offered by organic farming could lead to better mental health outcomes. However, Brigance et al. (2018) also warn us that the positive aspects of organic farming on mental health can also have negative impacts. For example, the increased community engagement through various farming events can also add additional stress to farmers.

Regarding risks related to neurological and physical health in organic farming, initial research shows that organic farming might reduce certain risks and enhance others. While the link to risk reduction from organic farming is not always demonstrated, authors often seem to associate the reduction of physical health risks with the use of organic materials instead of pesticides. For example, Khan et al. (2018) found that conventional farmers are more likely to demonstrate neurological symptoms, particularly sensory, behavioural symptoms, and less so cognitive and motor symptoms, than organic farmers. While the correlation between neurological symptoms and the use of pesticides is not demonstrated in this study, Khan et al. (2018) argue that the long-term implications of pesticide usage should be questioned. Another study conducted in Portugal explored genetic and immunological changes in workers of both traditional systems using pesticides and organic systems using organic materials. It found that workers in an organic system experience "similar levels of genetic damage than unexposed controls demonstrated" (Costa et al., 2014, p. 14). Although there may be lifestyle factors (e.g. smoking) and other co-morbidity factors that make it difficult to confirm these findings, Costa et al. (2014) conclude that "farm workers may be influenced by the type of agriculture they practice" (Costa et al., 2014p. 14) . While organic farming seems to diminish some physical health risks due to the use of organic materials rather than pesticides, a qualitative study based on interviews with farmers and farm workers in New Mexico, USA (Soto Mas et al., 2018) also found that organic farming, particularly the increase in manual work and the use of organic inputs, could lead to additional physical health risks. Increased physical risks, such as carpel tunnel syndrome and spine issues are related to increased manual work involving hand weeding, bending and squatting (Soto Mas et al., 2018). However, as a qualitative study, there was no quantitative suggestion that these risks were higher than those in a conventional system. Organic inputs (e.g., bone or meal) were also seen to pose a

[13] It is important to mention that this study has been done in the European context where farmers benefit from subsidies. Findings might be different in an Australian context where no subsidies exist.

risk to physical health. Due to the size of the particulates, it was noted that they may be dangerous to inhale. However, within this study no personal protection equipment was mentioned (Soto Mas et al., 2018). When it came to harvest, the pressure to perform remained and workers sometimes worked through electrical storms with one participant noting "*even though there's lighting strikes hitting the ground, we still need this harvested, and so you can't leave the field. You've got to take your chances of getting struck by lightning*" (Soto Mas et al., 2018, p. 97). Producers were also conscious of the risk of heat to workers, particularly when they are working in greenhouses (Soto Mas et al., 2018).

The limited literature on the connections between changes in farming systems and business models and WHS risks mostly focuses on how the adoption of organic farming systems might modify mental and physical health risks for farmers and farm workers. While it has been shown that, overall, organic farming may improve farmers' mental health in comparison to conventional farming, as well as some physical health risks related to the non-use of pesticides, other physical health risks may be enhanced due mostly to an increase in manual work.

Summary and Conclusion

This literature review forms part of larger project that aims to identify:

1. the current impact of disruptors, increased climate variability in particular, on the WHS of farming communities
2. the changes farmers are already implementing or likely to implement in the future in response to climate variability, and how that might lead to a change in the WHS risks they will be exposed to.
3. how to best communicate with farming communities about these new sets of risks and influence the adoption of practices that minimise WHS risks.

This report addresses the first two aims by providing the contextual background for the research, offering an overview of the current literature on the connections between changes triggered by increased climate variability in farming and WHS risks as identified by a thematic and bibliometric analysis of the literature. The framing of this review around persistence, incremental adjustments and transformational responses (Figure 8) will be used as the structure for an online survey that will answer our second objective (identify the changes farmers are already implementing or likely to implement in the future in response to climate variability, and how that might lead to a change in the WHS risks they will be exposed to).

This literature review identified several research gaps:

Firstly, the literature on the impacts of climate variability on WHS, which we consider as the 'baseline' against which we can assess changes in risk profiles, focuses mainly on the mental health impacts of drought, and does not consider physical WHS impacts.

Secondly, and most importantly, the set of changes in farming systems and business models focus mostly on the 'persistence' of existing systems, through the implementation of changes in practices 'at the margin'. Bene et al (2018) described a spectrum of adaptation pathways to vulnerability reduction for farmers remaining on the land as spanning persistence, through incremental adjustments to transformation. Marginal changes (or 'coping' responses) contribute largely to support of current practices rather than leading to the fundamental system changes. In contrast, only a few existing (organic) and potential (payment for GHG capture) incremental adjustments were identified. While transformational responses through fundamental changes to livelihoods and novel uses of agricultural land are beginning to emerge in the scholarly literature (e.g. Stringer et al. 2020), some of the 'novel uses' of agricultural lands depicted in the contextual background section are already being implemented in the agricultural landscape, such as those related to conservation (Sweeney et al., 2019), recreation (Brown & Reeder., 2007) and to a lesser degree commercial use (Van der Vaart, 2005). Moreover, the potential effects of transformational changes to land use on agricultural industries and rural communities remain speculative but could potentially alter the value of agricultural production and land value (e.g. Tubb and Seba 2019), the style and function of buildings (Van der Vaart 2005), the viability of family-farm businesses (Salvoni et al 2020) and the loss of ecosystem services (Francis et al., 2012). The broad range of impacts suggests that farmers and rural communities may need to negotiate significant socio-cultural and biophysical tradeoffs. Discussions of the WHS impacts of novel uses of land have not yet appeared in the literature and have not been linked to climate change adaptation and mitigation. This may be because their link to climate change adaptation might be indirect and involve complex, context-specific changes in exposure and sensitivity to climate drivers.

Thirdly, the link between changes in farming systems, business models and WHS risks has been the subject of only limited research interest. The main focus has been on how a specific type of incremental adjustment, i.e. organic farming, is changing the risk profile of farmers and farm workers. WHS aspects of adaptations related to 'persistence' of existing farming systems may not lead to major changes in risk profiles, as the nature of the practice may not change substantially (e.g. substituting one pasture species for another). While incremental adjustments have been the subject of limited interest around organic farming, many other types of incremental adjustments have not been tackled, such as the shift from cropping to livestock systems. Finally, changes in risk profiles due to adoption of transformational responses (novel uses of agricultural lands) have not been explored.

Currently, institutional responses to climate variability in agriculture focus on operationalising resilience (e.g. disaster recovery, (Keating et al., 2014)) rather than promoting risky transformations (such as adoption non-agricultural enterprises). Farming entrepreneurs are likely the principal actors in the transformation. This constitutes, according to us, the main research gap. While the WHS risks of the types of activities that constitute 'novel uses of agricultural lands' might be already known in other industry sectors; for example, in warehousing (Waters et al., 1998); hospitality (Sharma, 2019), and solar energy systems (Aman et al., 2015), for farmers, these represent emerging risks. The way farming communities interact with the establishment of novel activities in farming environments, may create different risks and/or require a different way to communicate about those risks. In light of the already high rate of WHS incidents among farming communities, and their distinct physical and cultural environment, the way they manage WHS risks becomes an important issue in the development of sustainable rural livelihoods in NSW.

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Appendix A - Literature Review Search 1

Database	Search number	Theme	Search terms	Number of results (selected results in green)	Research domain	Source type (e.g., article, book, dissertation etc.)
Scopus	Search 1	Nexus of climate change & farming systems	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR Adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation*	(title, keywords, abstracts):7109 results/ (title): 165 results	Environmental science (101), Agricultural and biological sciences (73), Social sciences (53), Earth and planetary sciences (19), Economics, econometrics and finance (15), Energy (11), Engineering (9), Computer science (5), Business management and accounting (4), multidisciplinary (4)	Article (135), Book chapter (16), Conference paper (10), Review (4)
Scopus	Search 2	Nexus of climate change & business models	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND OR "farming management model" OR "farming practice model" OR "business management model" OR "farm ownership model" OR "farm leasing model" OR "share farming" OR "contract farming"*	(title, keywords, abstracts): 30 / (title): 2 results	Social sciences (13), agricultural and biological sciences (11), environmental science (11), earth and planetary sciences (5), engineering (5), economics, econometrics and finance (3), energy (3), arts and humanities	Article (22), Book chapter (4), Conference paper (3), Book (1)

					(2), business management and accounting (2), veterinary (2)	
Scopus	Search 3	*Nexus of climate change & work health and safety*	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	(title, keywords, abstracts): 169 / (title): 34 results	Agricultural and Biological Sciences (92), Veterinary (57), Environmental Science (24), Medicine (20), Biochemistry, Genetics and Molecular Biology (18), Engineering (15), Social Sciences (15), Immunology and Microbiology (12), Energy (5), Multidisciplinary (5)	Article (119), Review (22), Conference Paper (12), Book Chapter (8), Book (3), Editorial (2), Short Survey (2), Erratum (1)
Scopus	Search 4	*Nexus of farming systems and business models & work health and safety*	*Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR Adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	(title, keywords, abstracts): 7955/ (title): 41	Agricultural and Biological Sciences (27), Veterinary (11), Environmental Science (7), Biochemistry, genetics and molecular biology (6), engineering (6), economics, econometrics and finance (3), medicine (3), social sciences (3), Arts and humanities (1),	Article (30), Conference paper (3), Review (3),

					Computer science (1)	
Scopus	Search 5	*The three together*	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR Adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation OR "farming management model" OR "farming practice model" OR "business management model" OR "farm ownership model" OR "farm leasing model" OR "share farming" OR "contract farming" AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	(title, keywords, abstract): 1552// Second search (title): 0	Agricultural and biological sciences (822), Environmental sciences (503), Social sciences (226), Engineering (224), Earth and Planetary sciences (154), Biochemistry, genetics and molecular biology (138), Medicine (116), Veterinary (103), Computer science (76). Energy (65)	Articles (924), Review (225), Book chapter (187), Conference paper (166), Conference review (20), Book (18), Editorial (4), Short survey (4), Note (3), Data paper (1)
PubMed	Search 6	Nexus of climate change & farming systems	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land*	(title and abstract): 504 results // (title): 11 results		

			degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR Adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation			
PubMed	Search 7	Nexus of climate change & business models	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND OR "farming management model" OR "farming practice model" OR "business management model" OR "farm ownership model" OR "farm leasing model" OR "share farming" OR "contract farming"*	(title and abstract): 1 result		
PubMed	Search 8	*Nexus of climate change & work health and safety*	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	title and abstract: 1019 results/ title: 4 results		

PubMed	Search 9	*Nexus of farming systems and business models & work health and safety*	*Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	title and abstract: 978 results / title: 541 results		
PubMed	Search 10	*The three together*	*"climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events" OR disasters OR drought OR "water availability" OR heat OR "on-farm heat" OR heatwaves OR bushfire OR flood OR storms OR "precipitation patterns" OR desertification OR "land degradation" OR biosecurity OR "biodiversity migration" OR "livestock and crop diseases" OR weeds OR "feral animals" AND Farm OR Farming AND "organic agriculture" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR agroforestry OR "sustainable farming practices" OR "farming diversification" OR "diversified production" OR pluriactivity OR servitisation OR "farming cooperative groups" OR Adaptation OR "land use change" OR resilience OR "farm management" OR technology OR automation OR "farming management model" OR "farming practice model" OR "business management model" OR "farm ownership model" OR "farm leasing model" OR "share farming" OR "contract farming" AND "health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety"*	title and abstract: 130 results // title: 0		

Appendix B - Literature Review Search 2

Database	Search number	Theme	Search terms	Result #s	Research domain	Source type (e.g., article, book, dissertation etc.)
Scopus	Search 11	Nexus of climate change and sustainable practices	TITLE ("climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events") AND TITLE ("organic agriculture" OR "organic farming" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR "sustainable farming")	26	Agricultural and Biological Sciences (14) Environmental Science (10), Social sciences (6), Economics, Econometrics and Finance (3), Engineering (3) Earth and Planetary Sciences (2), Energy (2), Multidisciplinary (2), Business, Management and Accounting (1), Medicine (1)	Article (11), Book chapter (5), Review (5), Conference Paper (3), Letter (2)
Scopus	Search 12	Nexus of climate change, sustainable practices, and business models	TITLE ("climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events") AND TITLE(farm*) AND TITLE("health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety")	10	Medicine (6), Agricultural and Biological Sciences (4), Environmental Science (4), Earth and Planetary Sciences (2), Engineering (2), Immunology and Microbiology (1), Social Sciences (1), Veterinary (1),	Article (6), Review (2), Book Chapter (1), Editorial (1)
Scopus	Search 13	*Nexus of climate change and work health and safety*	TITLE (*"organic agriculture"* OR *"organic farming"* OR *"regenerative agriculture"* OR *"regenerative farming"* OR *"agro-ecology"* OR *"sustainable farming"*) AND TITLE (*farm**) AND TITLE (*"health"* OR *"mental health"* OR *suicide* OR *depression* OR *anxiety* OR	52	Agricultural and Biological Sciences (31) Environmental Science (12), Veterinary (12) Social sciences (4), Business, Management and Accounting (3) Energy (3) Biochemistry, Genetics and Molecular Biology	Article (33), Conference Paper (7), Review (6), Book chapter (4), Erratum (1), Note (1)

			disease OR *safety* OR *accidents* OR *incident* OR *injuries* OR *death* OR *fatality* OR *"chemical exposure"* OR *"pesticide exposure"* OR *"work health and safety"* OR *"WHS"* OR *"occupational health and safety"*)		(2) Immunology and Microbiology (2), Medicine (1), Pharmacology, Toxicology and Pharmaceutics (1)	
Scopus	Search 14	*Nexus of sustainable practices and work health and safety*	TITLE ("climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events") AND TITLE (farm* OR agriculture) AND TITLE ("management" OR "business management" OR "ownership" OR "lease" OR "leasing" OR "share farming" OR "share farm" OR "contract farm" OR "contract farming" OR pluriactivity OR diversification OR "diversified production" OR pluriactivity OR servitisation OR cooperative OR technology OR automation)	82	Environmental Science (49), Agricultural and Biological Sciences (42), Social Sciences (26), Earth and Planetary Sciences (13), Engineering (11), Economics, Econometrics and Finance (9), Energy (6), Chemical Engineering (2), Chemistry (2), biochemistry, Genetics and Molecular Biology (1), Health Professions (1), Multidisciplinary (1), Nursing (1)	Article (59), Book Chapter (13), Conference Paper (4), Book (2), Editorial (1), Erratum (1), Letter (1), Review (1)

Scopus	Search 15	*The three together:*	TITLE-ABS-KEY ("climate change" OR "global warming" OR "climatic variability" OR "extreme climatic events" OR "extreme weather events") AND TITLE-ABS-KEY ("organic agriculture" OR "organic farming" OR "regenerative agriculture" OR "regenerative farming" OR "agro-ecology" OR "sustainable farming" "management" OR "business management" OR "ownership" OR "lease" OR "leasing" OR "share farming" OR "share farm" OR "contract farm" OR "contract farming" OR "reactivity" OR diversification OR "diversified production" OR servitisation OR cooperative OR technology OR automation) AND TITLE-ABS-KEY ("health" OR "mental health" OR suicide OR depression OR anxiety OR disease OR safety OR accidents OR incident OR injuries OR death OR fatality OR "chemical exposure" OR "pesticide exposure" OR "work health and safety" OR "WHS" OR "occupational health and safety") AND TITLE-ABS-KEY (farm*)	19	Agricultural and Biological Sciences (10), Environmental Science (9), Engineering (3), Social Sciences (3), Medicine (2), Computer Science (1), Earth and Planetary Sciences (1)	Article (10), Book Chapter (3), Conference Paper (3), Review (2), Short Survey (1)

Appendix C – Bibliometric Review 1 (Landscape)

Quantitative bibliometric results

Trend report Scopus SciVal

To understand the trends of research within each of the distinct research spaces, we used the Scopus Sci Val "Trends" function to run a trend analysis within four topic domains which are themselves made up of a variable number of sub-topics:

- Accident Prevention; Hazards; Accidents – 40 topics
- Climate Models; Model; Rainfall – 210 topics
- Disasters; Floods; Risks – 121 topics
- Farmers; Smallholder; Farm – 118 topics

Sub-topics were then selected for further interrogation under several themes:

- Climate Change Adaptation; Urban Climate; Adaptive Capacity (part of Disasters; Floods; Risk topic cluster)
- Climate Change Impact; Irrigated Agriculture; Forestry (part of Water; Water Resources; Water Management topic cluster)
- Mixed Farming; Livestock; Stocking Rate (part of Farmers; Smallholder; Farms topic cluster)

Table C1 outlines the total sources and citations from the 7 key topic and sub-topic areas.

Table C1: Scopus SciVal sources and citation by research topic 2017-2019

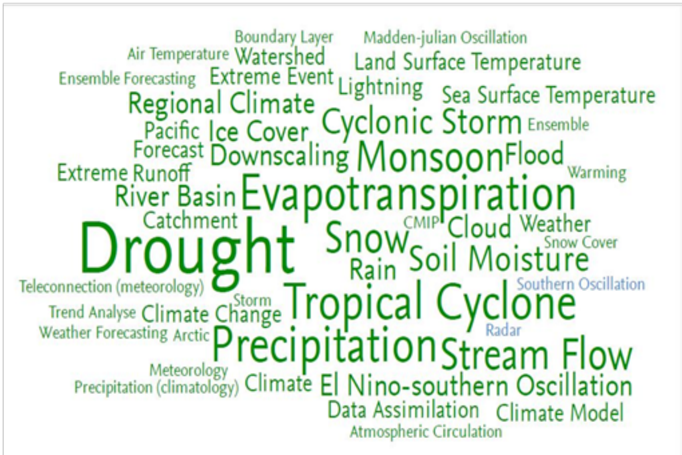
Topic Entity	Total Sources	Total Citations
Accident Prevention; Hazards; Accidents (TC.692)	4,076	9,562
Climate Models; Model; Rainfall (TC.5)	47,506	285,434
Disasters; Floods; Risks (TC.438)	13,388	55,489
Farmers; Smallholder; Farms (TC.621)	3,772	13,983
Climate Change Adaptation; Urban Climate; Adaptive Capacity (T.1567)	3,234	15,369
Climate Change Impact; Irrigated Agriculture; Forestry (T.69789)	19	122
Mixed Farming; Livestock; Stocking Rate (T.21529)	129	447

The key phrase analysis demonstrated that these domains had some similarity while maintaining distinct areas of work (see figure C1 below). The key phrase analysis counted the number of times that each term was used, the higher the relevance to that topic, the larger the size of the letters. Declining key phrases in blue, static key phrases in black, growing key phrases in green. In regards to the prevalence of topics within each of the Word clouds: (a) mainly biological and chemical hazards (b) resilience and vulnerability, disaster risk reduction (c) global precipitation models, catchment management and hydrology (d) developing world agriculture (e) decision support, integrated assessment (f) natural hazards, livelihood, resilience and vulnerability (g) farming systems and farmers.

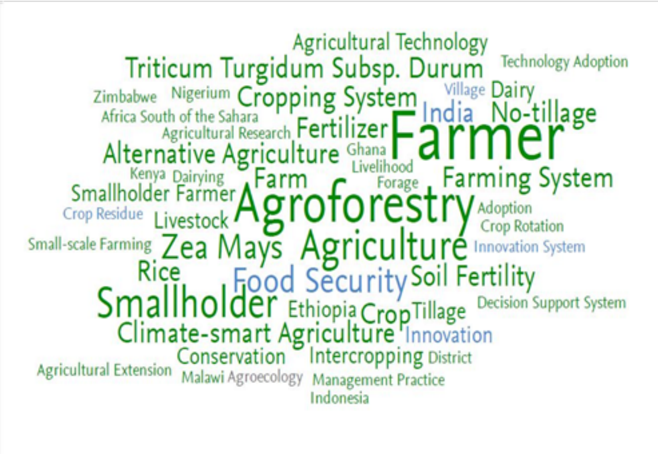
The trend analysis did not provide the detailed bibliometric results across the nexus areas as required, nor did it reflect the papers identified through the keywords; further the trend analysis included only documents from 2017-2019. Table 3 details the total output, citation count, highest ranked countries, Australia's ranking, and the highest ranked journals for each topic. Despite this fulsome analysis (full reports available in Appendix D), the trend analysis did not provide the granular level of detail required for a traditional bibliometric analysis.

a) Accident Prevention; Hazards; Accidents

b) Disasters; Floods; Risks



c) Climate Models; Model; Rainfall



d) Farmers; Smallholder; Farms

e) Climate Change Impact; Irrigated Agriculture; Forestry

f) Climate Change Adaptation; Urban Climate; Adaptive Capacity

g) Mixed Farming; Livestock; Stocking Rate

A A A relevance of keyphrase | declining A A A growing (2017-2019)

Figure C1: Word clouds formed from Scopus SciVal key phrase analysis of topics and subtopics from 2017-2019. Declining key phrases in blue, static key phrases in black, growing key phrases in green.

Table C2: Summary table of SciVal trend analysis for selected combinations of key words.

Topic entity	Accident Prevention, Hazards, Accidents	Climate Models; Model; Rainfall	Disasters; Floods; Risks	Farmers; Smallholder; Farms	Climate Change Adaptation; Urban Climate; Adaptive Capacity	Climate Change Impact; Irrigated Agriculture; Forestry	Mixed Farming; Livestock; Stocking Rate
Total output	4,076	47,506	13,388	3,772	3,234	19	129
Citation count	9,562	285,434	55,489	13,983	15,369	122	447
Highest ranked countries	China, Italy, Russian Federation, France, Canada	USA, China, United Kingdom, Germany, India	USA, United Kingdom, China, Australia, The Netherlands	India, USA, France, Germany, China	USA, United Kingdom, Australia, Germany, Canada	United Kingdom, Sweden, Portugal, China, Czech Republic	France, Brazil, USA, Belgium, The Netherlands
Australia's ranking	15th	7th	4th	9th	3rd	nil	9th
Highest ranked journals	Chemical Engineering Transactions; Journal of Loss Prevention in the Process Industries; Institution of Chemical Engineers Symposium Series	Climate Dynamics; Journal of Geophysical Research; Journal of Climate; International Journal of Climatology; Geophysical Research Letters	International Journal of Disaster Risk Reduction; Sustainability; IOP Conference Series: Earth and Environmental Science; Natural Hazards; Ecology and Society; Environmental Science and Policy	IOP conference Series: Earth and Environmental Science; Agricultural Systems; Sustainability; Agroforestry Systems; and Land Use Policy	Sustainability; the International Journal of Disaster Risk Reduction; Climate and Development; Climate Change Management; Environmental Science and Policy; Regional Environmental Change	Regional Environmental Change; Proceedings of the Institution of Civil Engineers: Engineering Sustainability; Agricultural Water Management; and the IOP Conference Series: Earth and Environmental Science	Fourrages; Agronomy for Sustainable Development; Agricultural Systems; and Animal

Bibliometric analysis in Scopus and PubMed

In addition to trend analysis, additional bibliometric analyses were undertaken using both Scopus and PubMed as source databases using climate change, sustainable piracies, business models, and work health and safety (as well as the appropriate variations, see Appendix A) to develop five searches (the 4 nexus searches and one search with all nexus information combined). These five searches undertaken in each database, resulted in a total of 1552 publications from Scopus and 130 from PubMed (see table C3).

Table C3: Database search output details for Scopus and PubMed

Nexus	# Scopus results	# PubMed results	Total number of publications
Nexus of climate change and sustainable practices	165	504	669
Nexus of climate change, sustainable practices, and business models	30	1	31
Nexus of climate change and work health and safety	169	1019	1188
Nexus of sustainable practices and work health and safety	41	541	582
Combined NEXUS	1552	130	1682

The articles were then analysed by looking at the title, year and abstract to ascertain if the document was relevant for this research. For example, a study exploring the farm management to remove herpesvirus (OsHV-1) disease from an oyster farm in Tasmania may have health and safety impacts for the oysters, but not for humans. Papers that held a focus on the health of animals, plants or environments were discarded. This resulted in a total of 2196 papers from the PubMed database and 933 papers in from the Scopus database for further bibliometric review. Additional analysis of the PubMed database was not undertaken as the format from this database was not compatible with the bibliometric analysis software VOSviewer. The following focuses on the outputs from the Scopus database N=933. Interrogation of journal titles yielded a total of 506 different journals and conference proceedings within this selection of articles. Of these, the top 10 journals that published more than 10 papers included Agricultural Systems, MDPI Sustainability, the International Journal of Climate Change Strategies and Management, Acta Horticulture, Climatic Change, Land Use Policy, Renewable Agriculture and Food Systems, Journal of Dairy Science, Science of the Total Environment, and Climate and Development (see figure x). The scope of this selection of journals encompasses topics of relevance to our search.

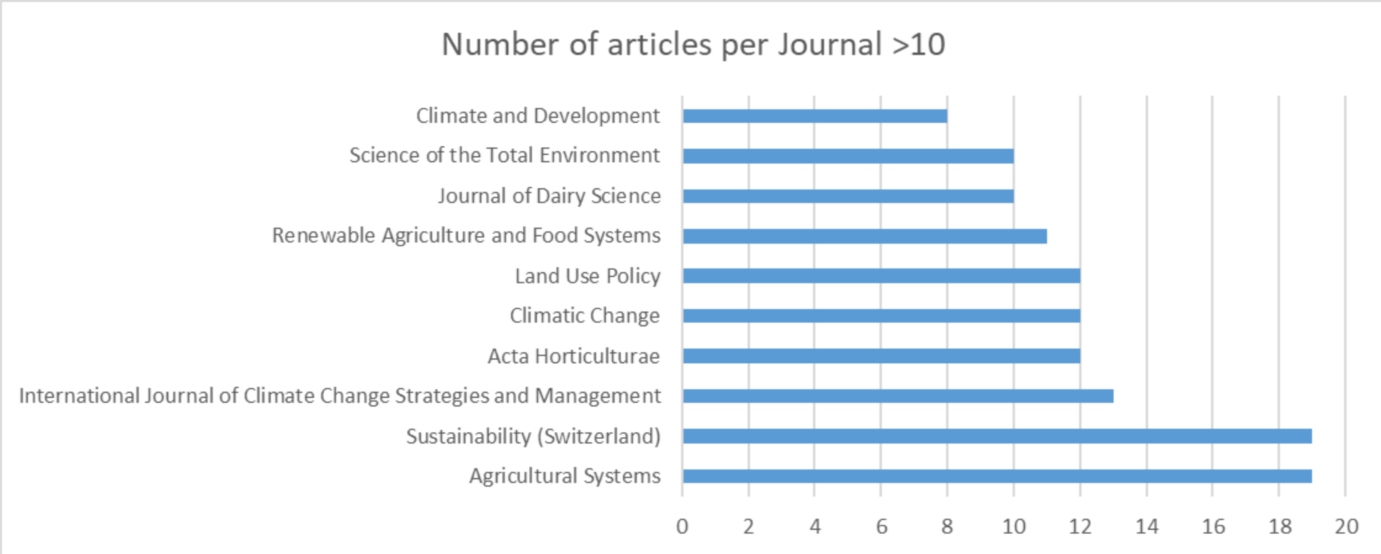


Figure C2: Scopus N=933 Top 10 published journals

In addition to understanding where the articles were published, the database was examined to identify the key journals and articles with the highest level of citation. Table 5 lists the six most highly cited papers, while Appendix C lists those with citations >100.

Table C4: Scopus N=933 Highest cited papers Top 6

No	Nexus theme	Authors	Year	Title	Source title	Cited by	Author keywords	Document type
1	T 5	Morton J.F.	2007	The impact of climate change on smallholder and subsistence agriculture	Proceedings of the National Academy of Sciences of the United States of America	612	Developing countries; Livelihoods; Subsistence farmers; Vulnerability	Review
2	T 5	Derpsch R., et al	2010	Current status of adoption of no-till farming in the world and some of its main benefits	International Journal of Agricultural and Biological Engineering	383	Climate change; Conservation agriculture; Ecosystem services; Soil health; World-wide no-till adoption; Zero tillage adoption	Article
3	T 5	Mertz O., et al	2009	Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel	Environmental Management	380	Drivers of change; Dryland farming; Land use change; Livelihood strategies; Senegal; West Africa	Article
4	T 5	Kremen C., Miles A.	2012	Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs	Ecology and Society	355	Agricultural food production; Agricultural intensification; Agrobiodiversity; Agroecology; Biodiversity; Conventional agriculture; Conventional farming systems; Diversified farming systems; Ecosystem services; Land-sharing; Land sparing; Organic agriculture	Review
5	T 5	Knapp J.R., et al	2014	Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions	Journal of Dairy Science	315	Enteric methane; Feed efficiency; Lifetime productivity; Methanogen; Mitigation	Review
6	T 1		2010	Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses	European Journal of Agronomy	257	Adaptation; Agricultural vulnerability; Climate change; Crop yield; Farm management; Farmers' income	Article

To understand how authors framed their work within these nexus spaces, we used VOSviewer software to create a map of the co-occurrence of author-specified keywords, co-authorship, and the countries of authorship.

Figure C3 showed the authorship network of 933 papers wherein they had published a minimum of 2 papers. The figure indicates that there are a number of cliques within this co-authorship network. To identify co-authorship cliques, an additional visualization was undertaken wherein the 266 authors (min 2 papers) were connected to other authors. This created a network of 49 authors (see figure C4).

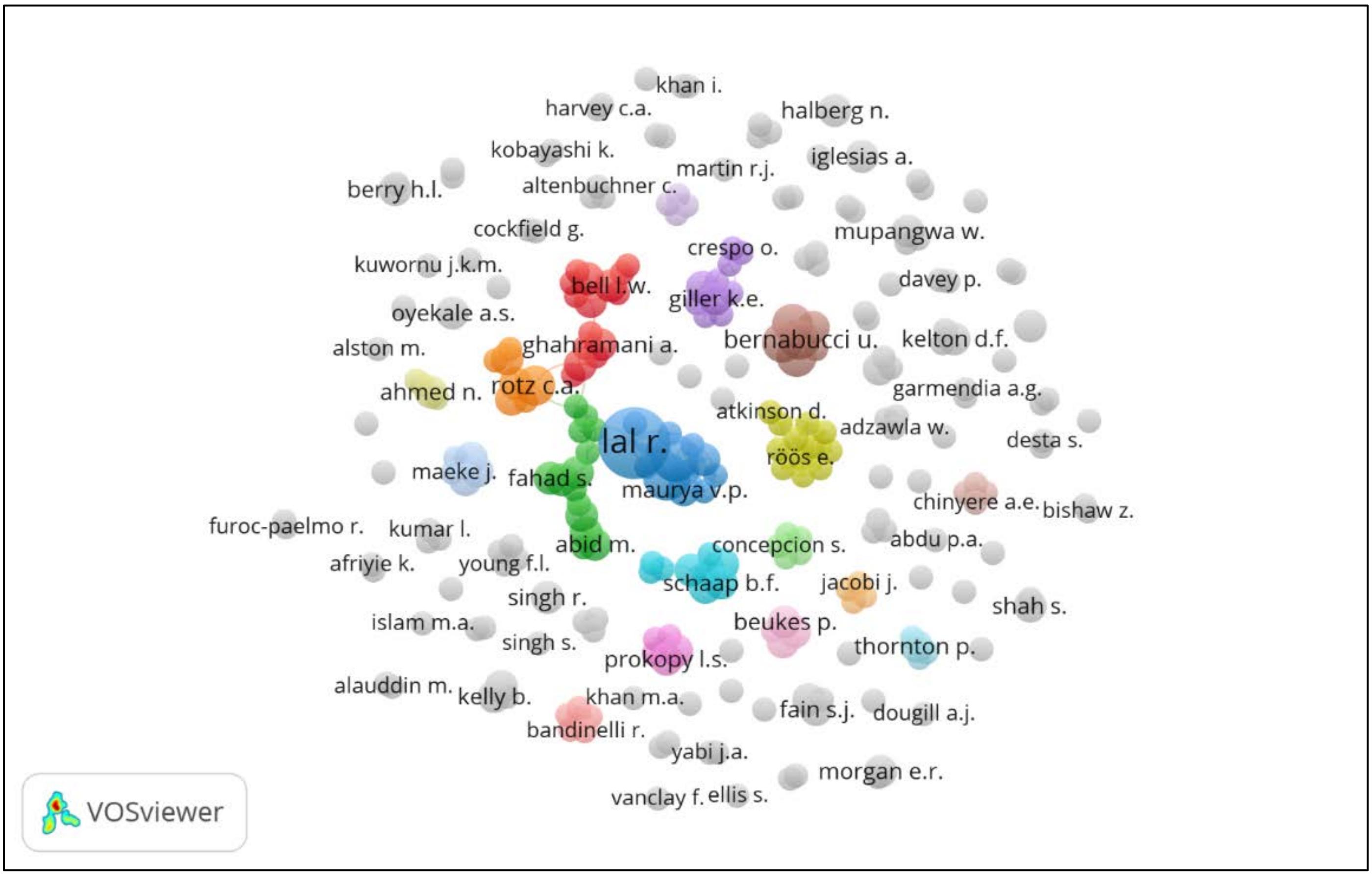
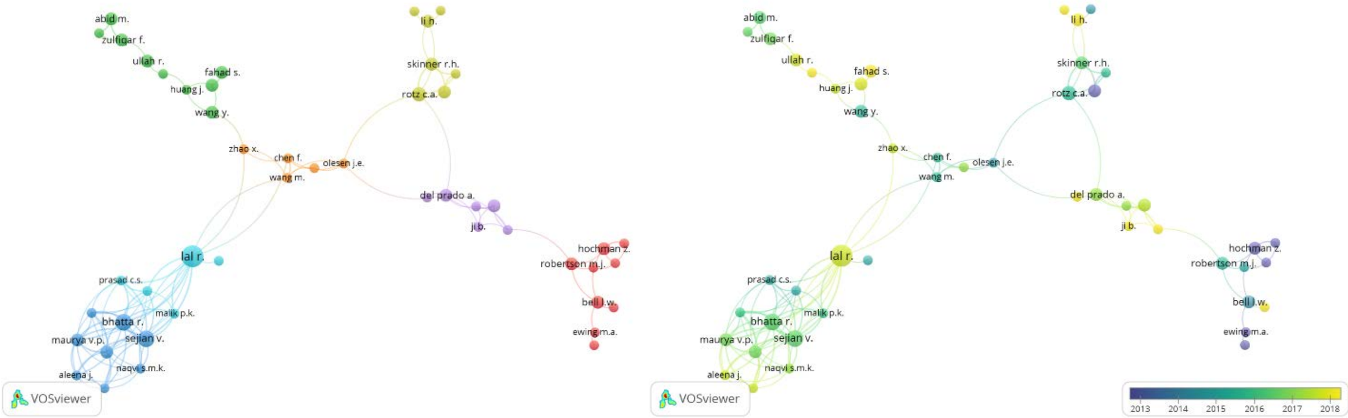


Figure C3: Author citation network. Total papers = 933; Total authors >2 papers = 266; Colour clustering = co-authorship cliques



b) Clusters of authorship citation n =49

a) Clusters of authorship citation n =49
Colour indicates authorship over time

Figure C4: Co-Authorship network (N=49)

To understand where the authors working in this space resided, a geographical network of co-authorship was also developed (see figure C5). This network is made up of the same 49 nodes. The two large nodes in the centre are Australia and the United States with an additional large central purple node being the United Kingdom. The size of the node indicates link occurrence and the colour of the visualization indicates when the papers were published. This figure indicates that the majority of the research first came from Australia, the United State, the United Kingdom, Canada and Switzerland (purple nodes) , while since 2017, Iran, Costa Rica, Fiji, the Philippines, Costa Rica, Indonesia, Poland and others (yellow nodes) have started publishing in this space.

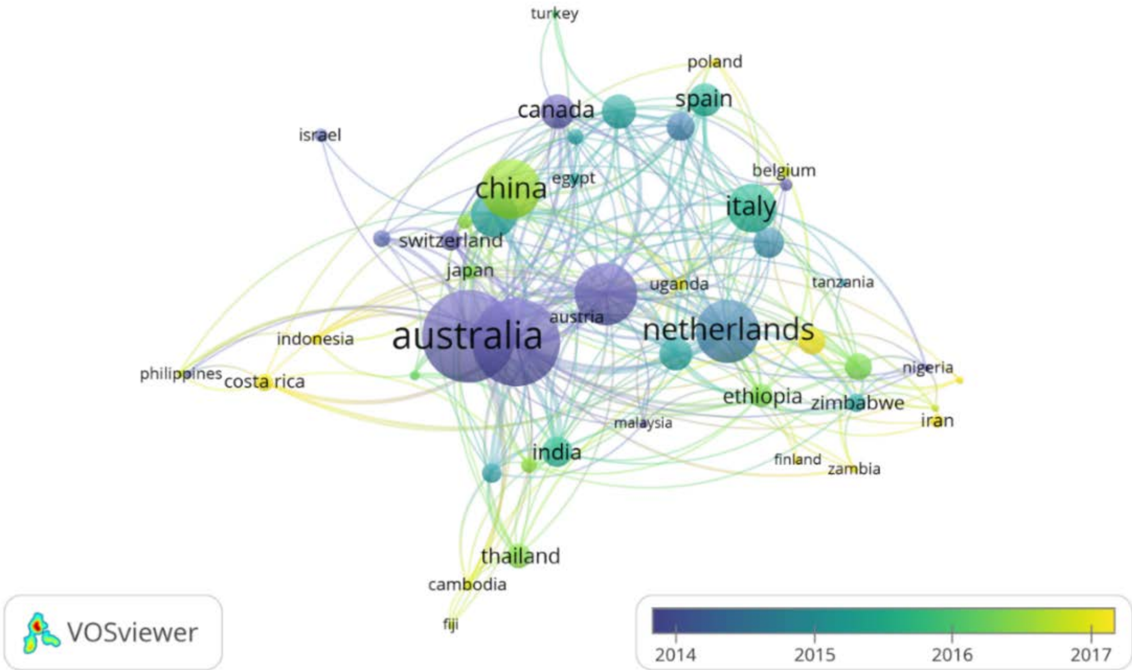


Figure C5: Co-Authorship network by Country (N=49).

To understand how keywords were utilised by authors, a keyword analysis was undertaken on this database. Figure C8 visualizes the author keyword networks appearing in the network when the word occurred more than five times. The clustering of co-keywords is ordered by colour. Climate change, adaptation, drought, agriculture, and organic agriculture were among the highest nominated keywords.

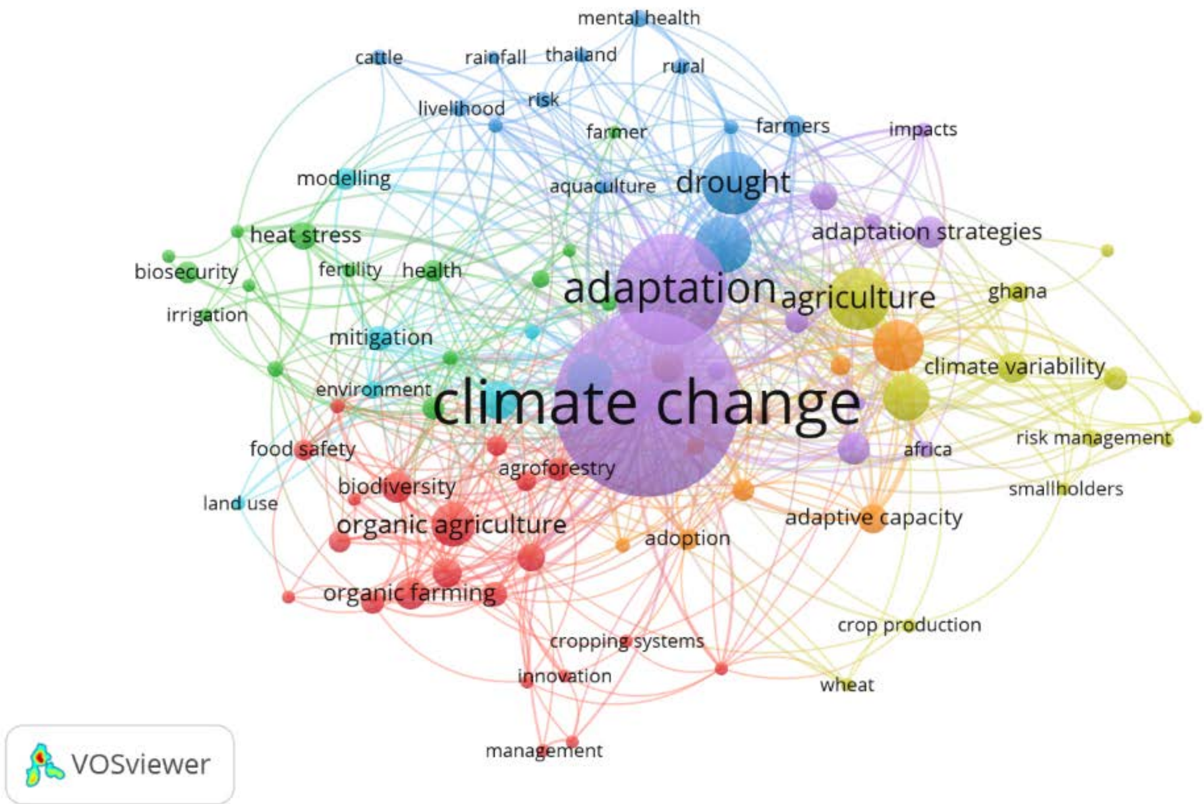


Figure C8: Author Keyword network occurrence >5 (N=88).

Appendix D - Bibliometric Review 1 - Sci Val Trend Analysis full reports

Accident Prevention; Hazards; Accidents

The total scholarly output for this topic was 4,076 with these items having a further citation count of 9,562. The majority of the outputs were from China and Italy, followed by the Russian Federation, France and Canada (Figure i) while the majority of articles were published in the journals of Chemical Engineering Transactions, the Journal of Loss Prevention in the Process Industries and the Institution of Chemical Engineers Symposium Series (Table i).

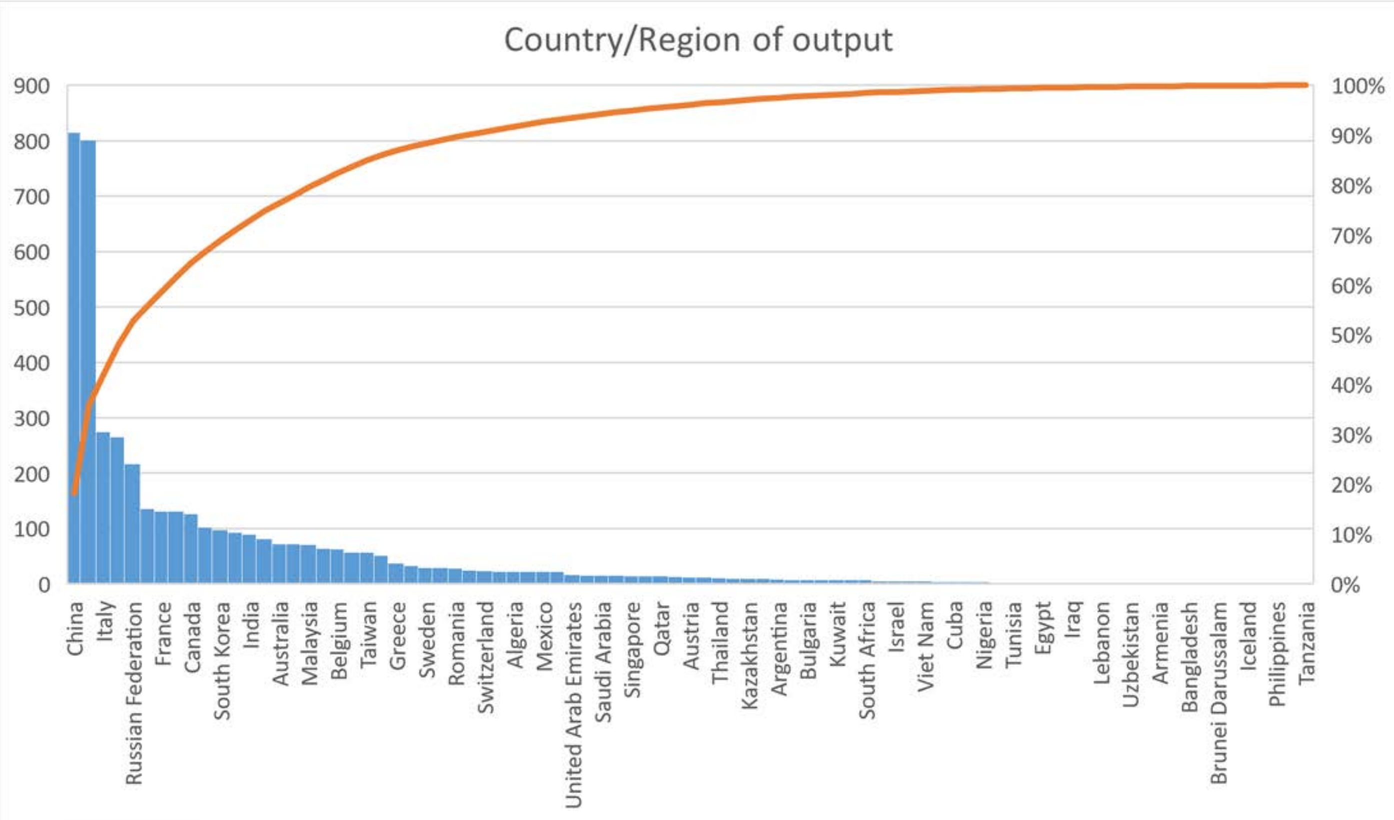


Figure i: Topic: Accident Prevention; Hazards; Accidents - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total.

Table i: Topic: Accident Prevention; Hazards; Accidents - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Number of Scholarly Outputs	Citation Count (excl. self-citations)
Chemical Engineering Transactions	198	159
Journal of Loss Prevention in the Process Industries	181	1270
Institution of Chemical Engineers Symposium Series	132	11
Process Safety and Environmental Protection	109	808
International Journal of Hydrogen Energy	95	616
Process Safety Progress	90	177
Safety Science	65	666
MATEC Web of Conferences	56	151
Global Congress on Process Safety 2017 - Topical Conference at the 2017 AIChE Spring Meeting and 13th Global Congress on Process Safety	55	30
IOP Conference Series: Materials Science and Engineering	54	44

Climate Models; Model; Rainfall

The total scholarly output for this topic was 47,506 with these items having a further citation count of 285,434. The majority of the outputs were from the United State and China followed by the United Kingdom, Germany, India, France, and Australia (Figure ii). Popular journals were Climate Dynamics, the Journal of Geophysical Research, Journal of Climate, International Journal of Climatology and Geophysical Research Letters (Table ii).

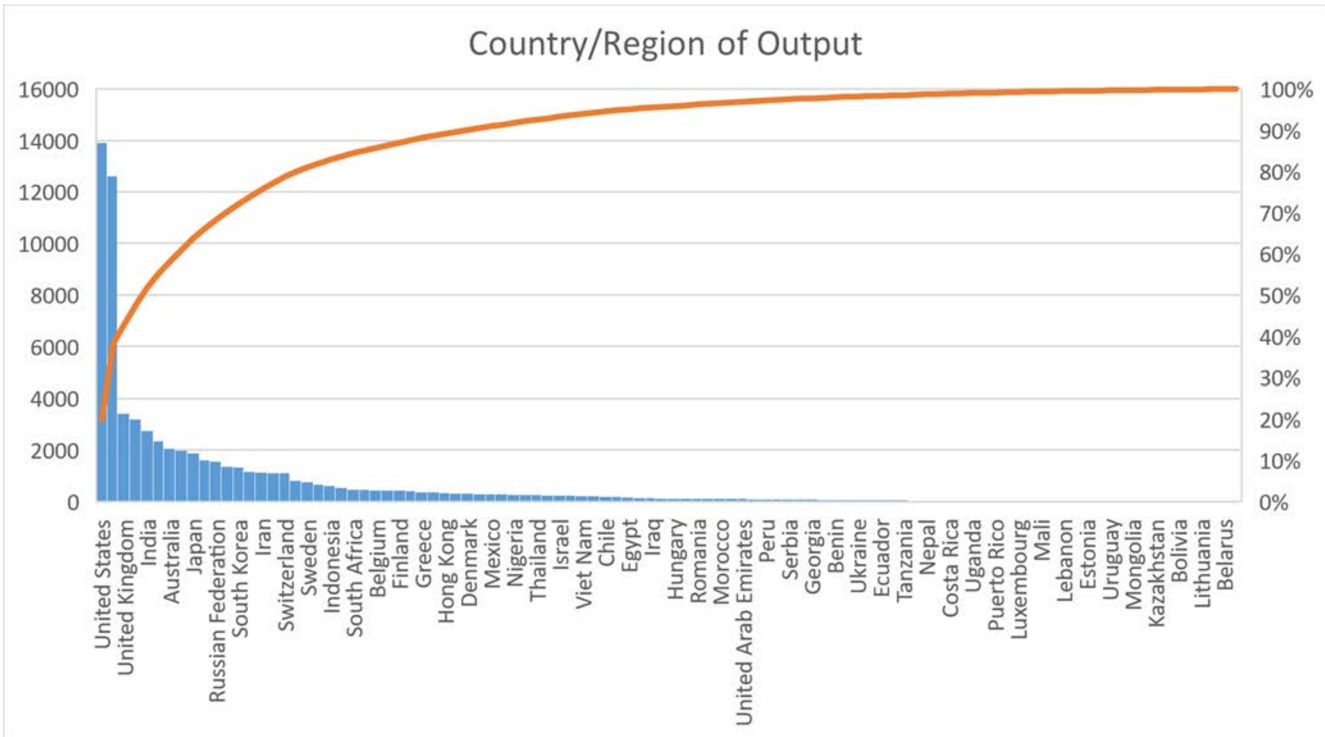


Figure ii: Topic: Climate Models; Model; Rainfall - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total

Table ii: Topic: Climate Models; Model; Rainfall Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
Climate Dynamics	1521	12698
Journal of Geophysical Research	1471	10843
Journal of Climate	1341	15671
International Journal of Climatology	1130	8747
Geophysical Research Letters	1122	10643
Water (Switzerland)	983	6160
Theoretical and Applied Climatology	900	5450
Remote Sensing	896	5958
International Geoscience and Remote Sensing Symposium (IGARSS)	895	607
Journal of Hydrology	792	9897
Monthly Weather Review	661	4479
ATMOSPHERE	622	2263
Quarterly Journal of the Royal Meteorological Society	613	4550

Disasters; Floods; Risks

The total scholarly output for this topic was 13,388 with these items having a further citation count of 55,489. The majority of the outputs were from the United State, the United Kingdom, China and Australia, followed by the Netherlands, Germany and Canada with Japan, Indonesia and Italy having similar outputs (~500) United Kingdom, Germany, India, France and Australia (Figure iii). Popular journals for this topic include the International Journal of Disaster Risk Reduction, Sustainability, and the IOP Conference Series: Earth and Environmental Science and Natural Hazards. Social science journals Ecology and Society and Environmental Science and Policy also feature (Table iii).

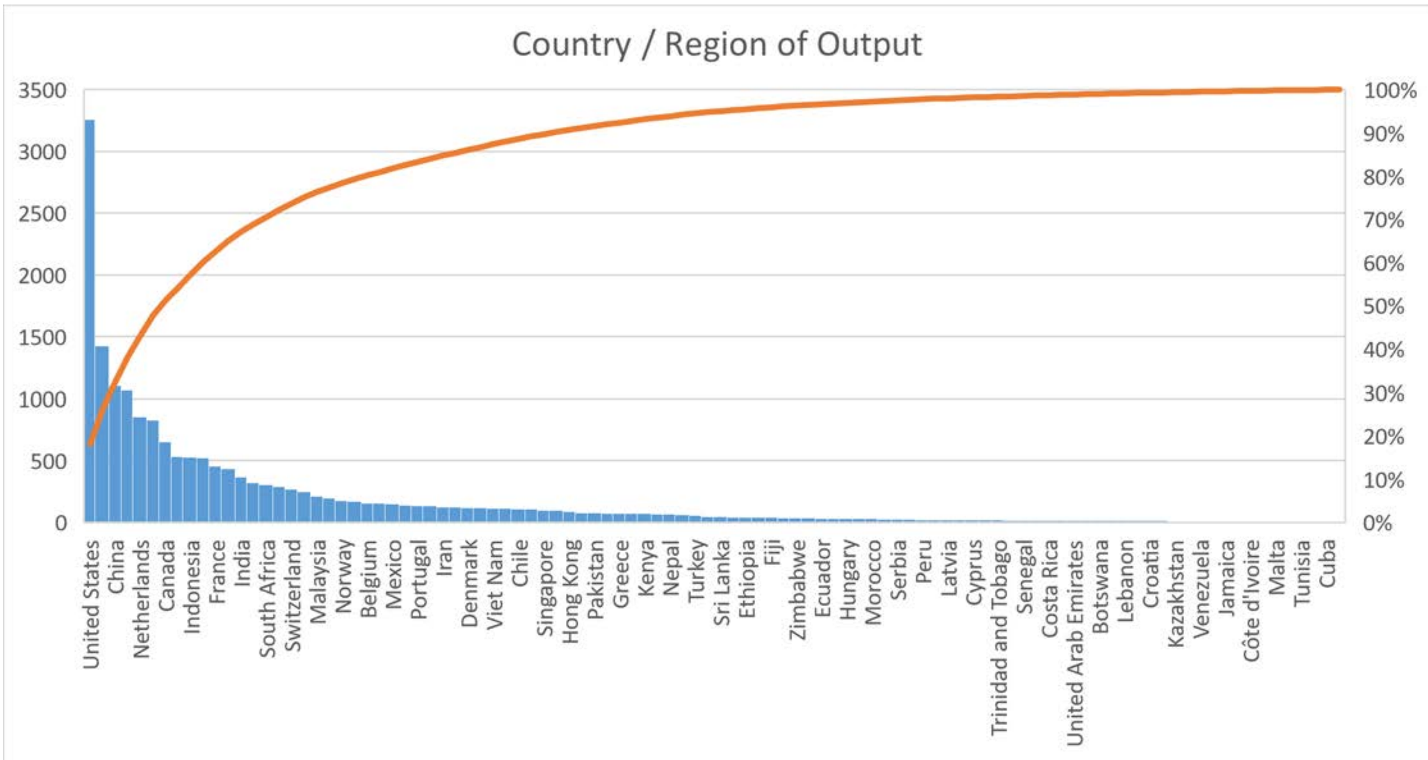


Figure iii: Topic: Disasters; Floods; Risks - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total

Table iii: Topic: Disasters; Floods; Risks - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
International Journal of Disaster Risk Reduction	361	2678
Sustainability	336	1698
IOP Conference Series: Earth and Environmental Science	288	164
Natural Hazards	190	1207
Ecology and Society	155	1308
Environmental Science and Policy	148	1293
Water (Switzerland)	137	757
Regional Environmental Change	123	1050
Climate Change Management	109	160
Journal of Flood Risk Management	104	722

Farmers; Smallholder; Farm

The total scholarly output for this topic was 43,772 with these items having a further citation count of 13,983. The majority of the outputs were from the India and the United State followed by France, Germany, China, and the United Kingdom (Figure iv). Popular journals included the IPO conference Series: Earth and Environmental Science, Agricultural Systems, Sustainability, Agroforestry Systems and Land Use Policy (Table iv).

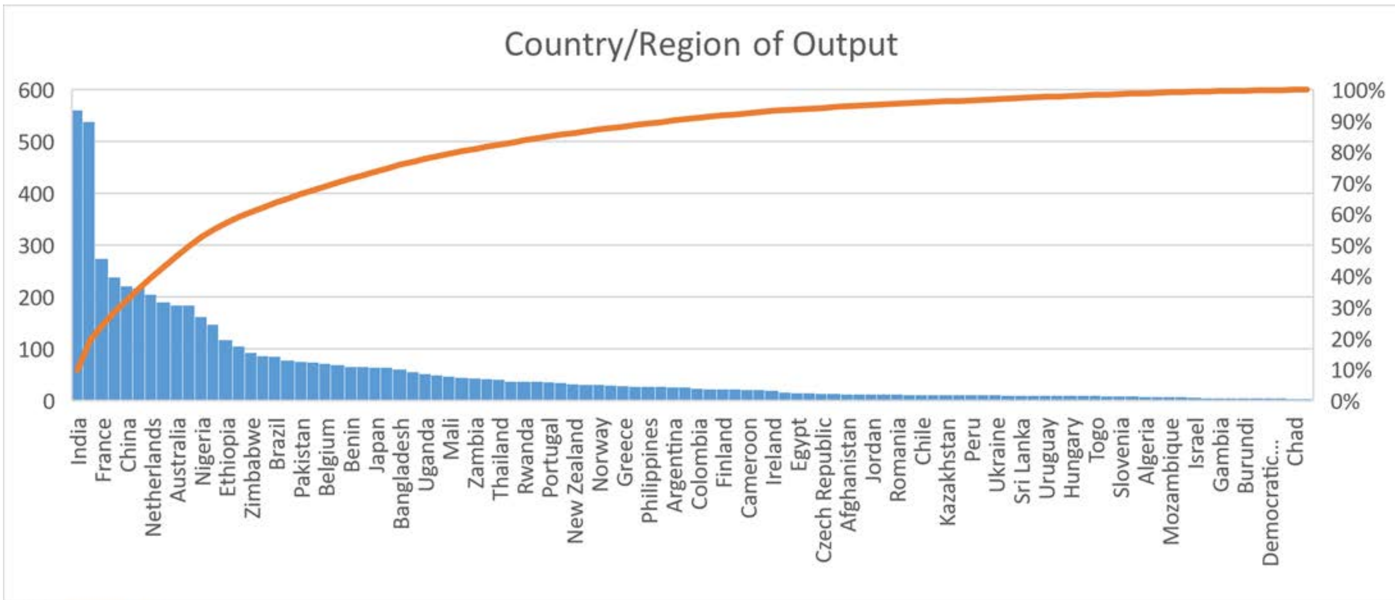


Figure iv: Topic: Farmers; Smallholder; Farm - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the to

Table iv: Topic: Farmers; Smallholder; Farm - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
IOP Conference Series: Earth and Environmental Science	89	56
Agricultural Systems	75	767
Sustainability	62	262
Agroforestry Systems	53	276
Land Use Policy	48	508
Indian Journal of Agricultural Sciences	43	22
Environmental Modelling and Software	39	280
Journal of Agricultural Education and Extension	39	140
Experimental Agriculture	38	191
Field Crops Research	37	295
International Journal of Agricultural Sustainability	36	209
Food Security	32	233
Agronomy for Sustainable Development	31	250
Agriculture, Ecosystems and Environment	29	423

Climate Change Adaptation; Urban Climate; Adaptive Capacity

The total scholarly output for this sub-topic was 3,234 with these items having a further citation count of 15,369. The majority of the outputs were from the United State, the United Kingdom and Australia, followed by Germany, Canada, and the Netherlands (Figure v). Popular journals for this sub-topic includes Sustainability, the International Journal of Disaster Risk Reduction, Climate and Development, Climate Change Management, Environmental Science and Policy and Regional Environmental Change (Table v).

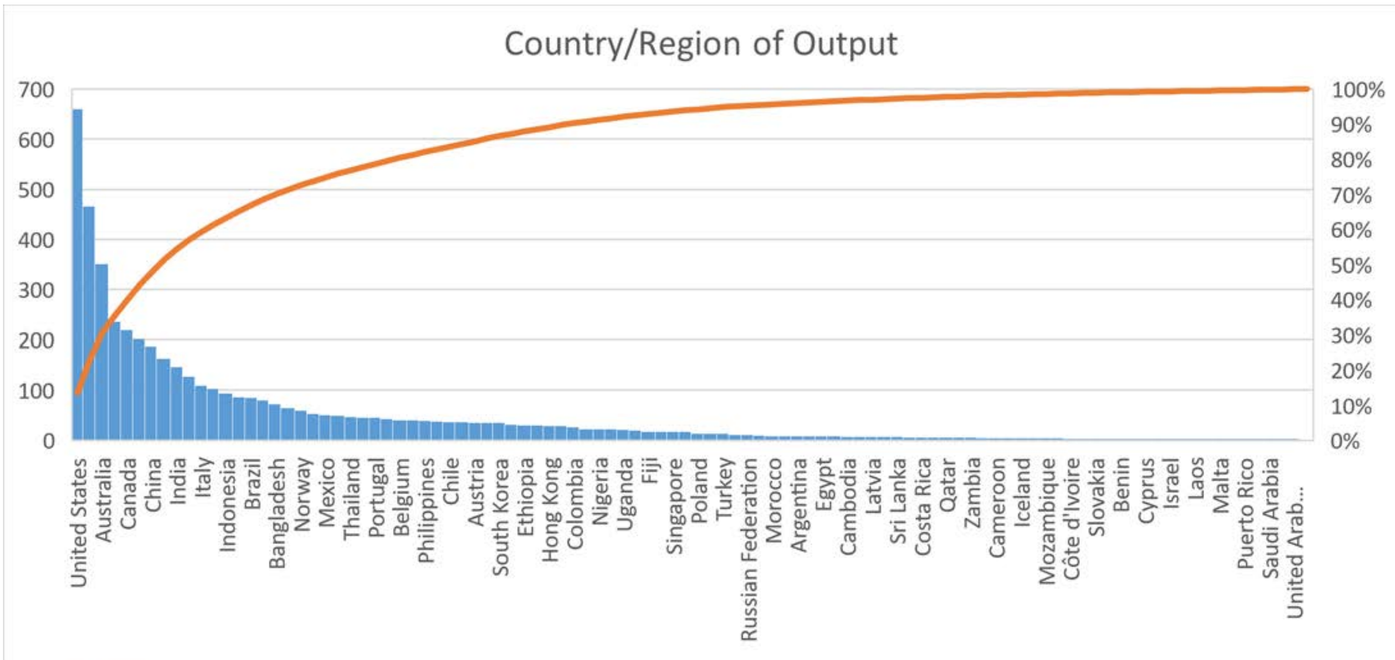


Figure v: Topic: Climate Change Adaptation; Urban Climate; Adaptive Capacity - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total

Table v: Topic: Climate Change Adaptation; Urban Climate; Adaptive Capacity - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
Sustainability	137	682
International Journal of Disaster Risk Reduction	92	661
Climate and Development	79	419
Climate Change Management	78	89
Environmental Science and Policy	68	604
Regional Environmental Change	61	516
IOP Conference Series: Earth and Environmental Science	54	23
Climatic Change	49	312
Natural Hazards	35	204
Urban Book Series	33	55
Global Environmental Change	30	356
International Journal of Climate Change Strategies and Management	30	118
Journal of Environmental Management	25	220
Journal of Environmental Planning and Management	25	218
Land Use Policy	25	163
Wiley Interdisciplinary Reviews: Climate Change	25	355

Climate Change Impact; Irrigated Agriculture; Forestry

The total scholarly output for this sub-topic was 19 with these items having a further citation count of 122. The majority of the outputs were from the United Kingdom with no publications coming from Australia (Figure vi). Popular journals and conferences for this sub-topic include Regional Environmental Change, Proceedings of the Institution of Civil Engineers: Engineering Sustainability, Agricultural Water Management and the IOP Conference Series: Earth and Environmental Science (Table vi).

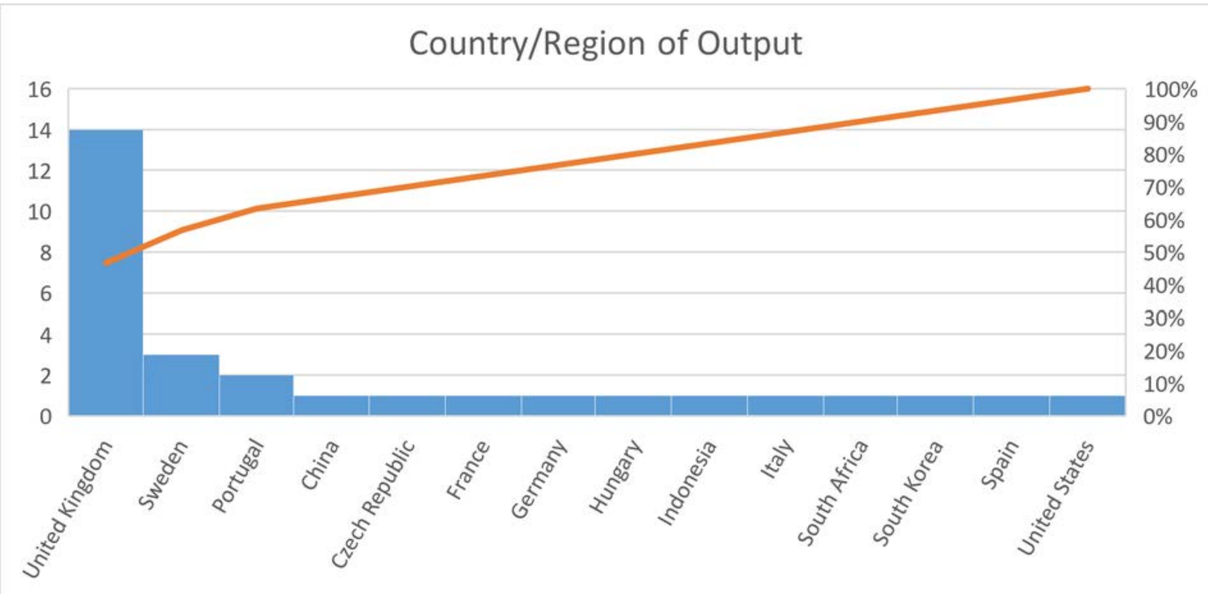


Figure vi: Topic: Climate Change Impact; Irrigated Agriculture; Forestry - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total

Table vi: Topic: Climate Change Impact; Irrigated Agriculture; Forestry - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
Regional Environmental Change	4	43
Proceedings of the Institution of Civil Engineers: Engineering Sustainability	3	10
Agricultural Water Management	2	10
IOP Conference Series: Earth and Environmental Science	2	0
Agricultural Systems	1	36
Climatic Change	1	5
Computers and Electronics in Agriculture	1	3
Ekoloji	1	1
Food Security	1	2
Journal of Environmental Management	1	12
Water Management	1	0

Mixed Farming; Livestock; Stocking Rate

The total scholarly output for this sub-topic was 129 with these items having a further citation count of 447. The majority of the outputs were from France, followed by Brazil and the United States (Figure vii). Popular journals for this sub-topic include Fourrages, Agronomy for Sustainable Development, Agricultural Systems and Animal (Table vii).

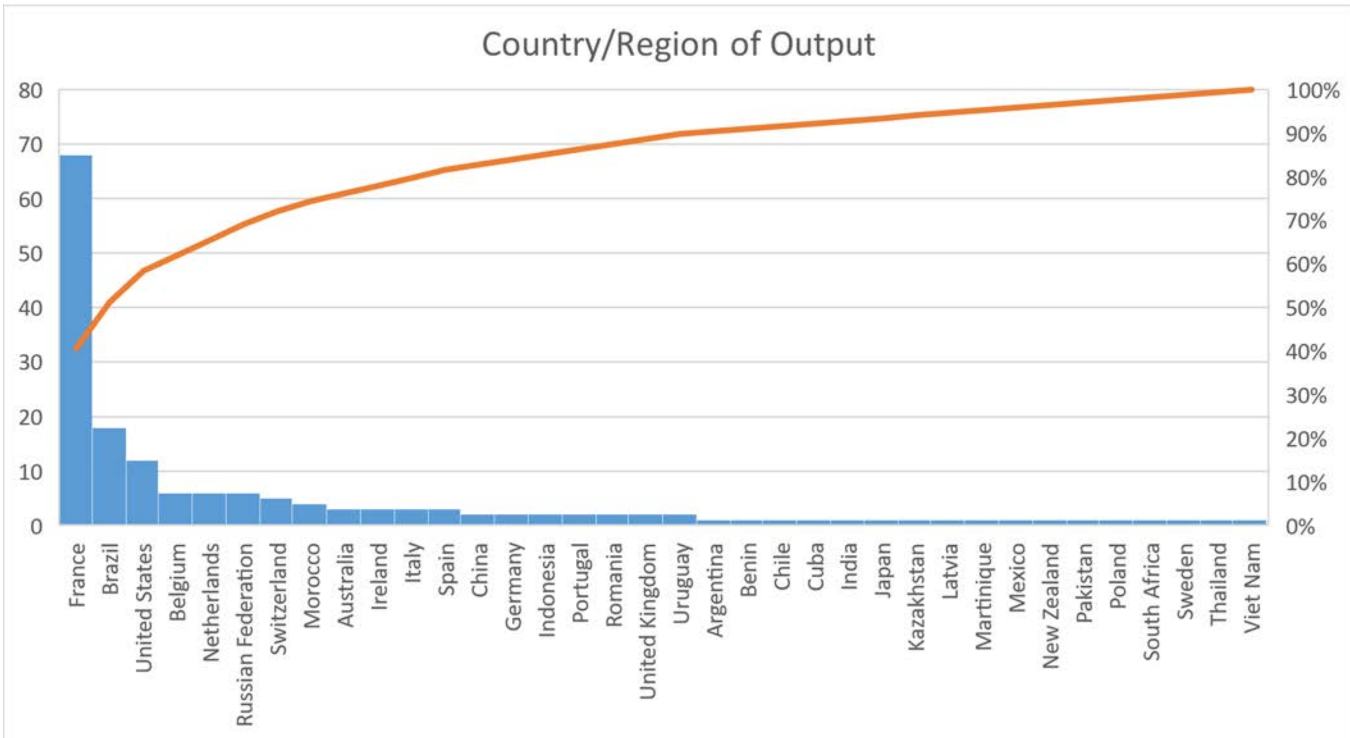


Figure vii: Topic: Mixed Farming; Livestock; Stocking Rate - Pareto chart plotting the distribution of country/region of output and numbers of articles per country. This data in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total

Table vii: Topic: Mixed Farming; Livestock; Stocking Rate - Total numbers of scholarly outputs and citations per journal / Scopus source type

Scopus Source	Scholarly Output	Citation Count (excl. self-citations)
Fourrages	17	9
Agronomy for Sustainable Development	11	45
Agricultural Systems	7	45
Animal	6	9
Cahiers Agricultures	5	12
Productions Animals	4	15
Agroecosystem Diversity: Reconciling Contemporary Agriculture and Environmental Quality	3	4
Agroecology and Sustainable Food Systems	2	2
Computers and Electronics in Agriculture	2	7
E3S Web of Conferences	2	0
Etudes Rurales	2	0
European Journal of Agronomy	2	25
International Journal of Agricultural Management	2	6
International Journal of Economic Perspectives	2	0
IOP Conference Series: Earth and Environmental Science	2	0
Journal of Animal Science	2	12
Land Use Policy	2	30

Appendix E - Bibliometric Review 1 (Journal Article Citations >100 per Nexus theme)

No	Nexus Theme	Authors	Year	Title	Source title	Cited by	Author Keywords	Document Type
1	T 5	Morton J.F.	2007	The impact of climate change on smallholder and subsistence agriculture	Proceedings of the National Academy of Sciences of the United States of America	612	Developing countries; Livelihoods; Subsistence farmers; Vulnerability	Review
2	T 5	Derpsch R., et al	2010	Current status of adoption of no-till farming in the world and some of its main benefits	International Journal of Agricultural and Biological Engineering	383	Climate change; Conservation agriculture; Ecosystem services; Soil health; World-wide no-till adoption; Zero tillage adoption	Article
3	T 5	Mertz O., et al	2009	Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel	Environmental Management	380	Drivers of change; Dryland farming; Land use change; Livelihood strategies; Senegal; West Africa	Article
4	T 5	Kremen C., Miles A.	2012	Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs	Ecology and Society	355	Agricultural food production; Agricultural intensification; Agrobiodiversity; Agroecology; Biodiversity; Conventional agriculture; Conventional farming systems; Diversified farming systems; Ecosystem services; Land-sharing; Land sparing; Organic agriculture	Review
5	T 5	Knapp J.R., et al	2014	Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions	Journal of Dairy Science	315	Enteric methane; Feed efficiency; Lifetime productivity; Methanogen; Mitigation	Review
6	T 1		2010	Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses	European Journal of Agronomy	257	Adaptation; Agricultural vulnerability; Climate change; Crop yield; Farm management; Farmers' income	Article
7	T 5	Lüscher A., et al	2014	Potential of legume-based grassland-livestock systems in Europe: A review	Grass and Forage Science	216	Animal health; Animal performance; Bloat; Climate change; Energy; Forage quality; Greenhouse gas emission; Helminths; Management; Nitrate leaching; Plant secondary metabolites; Tannins; Yield	Review

8	T 5	Keesstra S., et al	2018	The superior effect of nature based solutions in land management for enhancing ecosystem services	Science of the Total Environment	197	Ecosystem services; Nature based solutions; SDGs; System dynamics	Review
9	T 1	Bradshaw B., et al	2004	Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies	Climatic Change	181		Article
10	T 5	Lotter D.W.	2003	Organic agriculture	Journal of Sustainable Agriculture	174	Agricultural ecology; Agriculture; Agroecology; Crop systems; Integrated pest management; Organic agriculture; Organic farming; Organic food; Sustainable agriculture	Article
11	T 5	Campbell B.M., et al	2014	Sustainable intensification: What is its role in climate smart agriculture?	Current Opinion in Environmental Sustainability	162		Review
12	T 5	Brandle J.R., et al	2004	Windbreaks in North American agricultural systems	Agroforestry Systems	161	Crop production; Microclimate; Shelterbelt benefits; Shelterbelt structure; Wind protection	Conference Paper
13	T 5	Barkema H.W., et al	2015	Invited review: Changes in the dairy industry affecting dairy cattle health and welfare	Journal of Dairy Science	160	Antimicrobials; Automated calf feeder; Automated milking system; Biosecurity; Herd size	Article
14	T 5	Erenstein O.	2003	Smallholder conservation farming in the tropics and sub-tropics: A guide to the development and dissemination of mulching with crop residues and cover crops	Agriculture, Ecosystems and Environment	149	Conservation farming; Mulching; Small-scale farming; Technology development and dissemination; Tropics and sub-tropics	Review
15	T 5	Lotter D.W., et al	2003	The performance of organic and conventional cropping systems in an extreme climate year	American Journal of Alternative Agriculture	142	Crop water; Hydrology; Organic agriculture; Organic farming drought resistance	Article
16	T 5	McManus C., et al	2009	Heat tolerance in Brazilian sheep: Physiological and blood parameters	Tropical Animal Health and Production	133	Farm animal genetic resources; Haematological parameters; Ovis aries; Physiological parameters; Stress; Temperature	Article

17	T 5	Nichols P.G.H., et al	2007	New annual and short-lived perennial pasture legumes for Australian agriculture-15 years of revolution	Field Crops Research	128	Crop rotations; Cultivars; Nitrogen fixation; Pasture legumes; Plant breeding	Article
18	T 5	Dumont B., et al	2013	Prospects from agroecology and industrial ecology for animal production in the 21st century	Animal	123	Aquaculture; Environmental footprint; Farming systems; Inputs; Livestock	Article
19	T 5	Llewellyn R.S., et al	2012	Extensive use of no-tillage in grain growing regions of Australia	Field Crops Research	120	Adoption; Conservation agriculture; Farming systems; Innovation; No-tillage; Tillage	Article
20	T 5	Swallow B.M., et al	2009	Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa	Environmental Science and Policy	120	Conservation agriculture; Ecosystem services; Hydrologic modelling; Kenya; Lake Victoria; Land use change; Valuation; Wetlands	Article
21	T 3	Köberl M., et al	2011	Desert farming benefits from microbial potential in arid soils and promotes diversity and plant health	PLoS ONE	112		Article
22	T 5	Van Bueren E.T.L., et al	2002	Ecological concepts in organic farming and their consequences for an organic crop ideotype	Netherlands Journal of Agricultural Science	110	Biodiversity; Self-regulation; Varietal characteristics	Article
23	T 2	Li W., Huntsinger L.	2011	China's grassland contract policy and its impacts on herder ability to benefit in Inner Mongolia: Tragic feedbacks	Ecology and Society	109	Arid lands; Climate change; Community failure; Inner Mongolia; Pastoralism; Privatization; Property rights; Rangelands	Article
24	T 3	Alston M., Kent J.	2008	The big dry: The link between rural masculinities and poor health outcomes for farming men	Journal of Sociology	101	Drought; Masculinities; Mental health; Resilience; Rural	Article
25	T 5	Alston M., Kent J.	2008	The big dry: The link between rural masculinities and poor health outcomes for farming men	Journal of Sociology	101	Drought; Masculinities; Mental health; Resilience; Rural	Article

Appendix F – Bibliometric Review 2 (N=73, full citation list sorted by 'Cited by')

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
1	T 2	Bradshaw B., et al	Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies	2004	Climatic Change	181		Article
2	T 2	Scialabba N.E.-H., et al	Organic agriculture and climate change	2010	Renewable Agriculture and Food Systems	146	Adaptation; Carbon sequestration; Climate change; Diversification; Mitigation; Organic agriculture; Resilience	Review
3	T 1	Alston M.	Rural male suicide in Australia	2012	Social Science and Medicine	113	Australia; Climate; Farming; Gender relations; Masculinity; Men; Rural; Suicide	Article
4	T 1	Hanigan I.C., et al	Suicide and drought in New South Wales, Australia, 1970-2007	2012	Proceedings of the National Academy of Sciences of the United States of America	103	Depression; Rainfall; Self-harm; Weather	Article
5	T 1	Alston M., Kent J.	The big dry: The link between rural masculinities and poor health outcomes for farming men	2008	Journal of Sociology	101	Drought; Masculinities; Mental health; Resilience; Rural	Article
6	T 1	Berry H.L., et al	Climate change and farmers' mental health: Risks and responses	2011	Asia-Pacific Journal of Public Health	80	Adaptive strategies; Australia; Climate change; Farmers; Mental health; Rural	Review
7	T 2	Hochman Z., et al	Prospects for ecological intensification of Australian agriculture	2013	European Journal of Agronomy	76	Climate risk management; Crop-livestock integration; Deficit irrigation; Nutrient use efficiency; Precision agriculture; Water use efficiency	Article
8	T 2	Nicholas K.A., et al	Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in Northern California	2012	Global Environmental Change	76	Agriculture; Climate change; Climate change adaptation; Frost; Heat; Pests; Resilience; Vulnerability Scoping Diagram	Article
9	T 2	Zhao G., et al	Impact of agricultural management practices on soil organic carbon: Simulation of Australian wheat systems	2013	Global Change Biology	58	Agricultural management practice; APSIM; Australia; Carbon sequestration; Climate change; Crop model; Soil organic carbon; Wheat	Article

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
10	T 2	Leclère D., et al	Farm-level Autonomous Adaptation of European Agricultural Supply to Climate Change	2013	Ecological Economics	55	Agriculture; Autonomous adaptation; Climate change; Europe; Modeling; Residual impact; Water use efficiency	Article
11	T 2	Henry B., et al	Livestock production in a changing climate: Adaptation and mitigation research in Australia	2012	Crop and Pasture Science	50		Conference Paper
12	T 1	Stain H.J., Kelly B., Carr V.J., Lewin T.J., Fitzgerald M., Fragar L.	The psychological impact of chronic environmental adversity: Responding to prolonged drought	2011	Social Science and Medicine	44	Connectedness; Drought; Environmental adversity; Hopefulness; Mental health; Rural; Sense of place	Article
13	T 1	Ellis N.R., Albrecht G.A.	Climate change threats to family farmers' sense of place and mental wellbeing: A case study from the Western Australian Wheatbelt	2017	Social Science and Medicine	43	Agriculture; Climate change; Farmers; Place attachment; Place identity; Sense of place; Solastalgia; Western Australia	Article
14	T 1	Hart C.R., Berry H.L., Tonna A.M.	Improving the mental health of rural New South Wales communities facing drought and other adversities	2011	Australian Journal of Rural Health	40	Climate change; Health service; Psychiatric; Remote; Rural adversity	Article
15	T 2	Nendel C., Kersebaum K.C., Mirschel W., Wenkel K.O.	Testing farm management options as climate change adaptation strategies using the MONICA model	2014	European Journal of Agronomy	39	Adaptation strategies; Climate change; Crop management; Simulation model	Article
16	T 1	Stain H.J., Kelly B., Lewin T.J., Higginbotham N., Beard J.R., Hourihan F.	Social networks and mental health among a farming population	2008	Social Psychiatry and Psychiatric Epidemiology	39	Community; Connectedness; Rural mental health; Social connection	Article
17	T 2	John M., Pannell D., Kingwell R.	Climate change and the economics of farm management in the face of land degradation: Dryland salinity in Western Australia	2005	Canadian Journal of Agricultural Economics	38		Article
18	T 2	Marino R., Atzori A.S., D'Andrea M., Iovane G., Trabalza-Marinucci M., Rinaldi L.	Climate change: Production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming	2016	Small Ruminant Research	38	Animal health; Goat; Greenhouse gas emissions; Mitigation strategies; Sheep; Small ruminants production	Review
19	T 1	Sartore G.M., Kelly B., Stain H.J.	Drought and its effect on mental health--how GPs can help.	2007	Australian family physician	34		Review
20	T 2	Leifeld J., Angers D.A., Chenu C., Fuhrer J., Kätterer T., Powlson D.S.	Organic farming gives no climate change benefit through soil carbon sequestration	2013	Proceedings of the National Academy of Sciences of the United States of America	34		Letter

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
21	T 1	Caldwell K., Boyd C.P.	Coping and resilience in farming families affected by drought.	2009	Rural and remote health	33		Article
22	T 1	Greenhill J., King D., Lane A., MacDougall C.	Understanding resilience in South Australian farm families	2009	Rural Society	33	Drought; Farm family; Resilience; Rural mental health	Article
23	T 1	Guiney R.	Farming suicides during the Victorian drought: 2001-2007	2012	Australian Journal of Rural Health	31	Farmers; Mental health; Primary producers; Suicide risk; Suicide trends	Article
24	T 3	Costa C., García-Lestón J., Costa S., Coelho P., Silva S., Pingarilho M., Valdiglesias V., Mattei F., Dall'Armi V., Bonassi S., Laffon B., Snawder J., Teixeira J.P.	Is organic farming safer to farmers' health? A comparison between organic and traditional farming	2014	Toxicology Letters	31	Biomarkers; Genotoxicity; Immunotoxicity; Organic farming; Pesticides	Article
25	T 2	Thamo T., Addai D., Pannell D.J., Robertson M.J., Thomas D.T., Young J.M.	Climate change impacts and farm-level adaptation: Economic analysis of a mixed cropping–livestock system	2017	Agricultural Systems	27	Adaptation; Climate change impacts; Dryland farming; Mixed farming; Optimization; Profit	Article
26	T 1	Nerbass F.B., Pecoits-Filho R., Clark W.F., Sontrop J.M., McIntyre C.W., Moist L.	Occupational Heat Stress and Kidney Health: From Farms to Factories	2017	Kidney International Reports	26	acute kidney injury; chronic kidney disease; chronic kidney disease of unknown aetiology; climate change; heat exposure; Mesoamerican nephropathy; occupational heat stress	Review
27	T 2	Diacono M., Persiani A., Fiore A., Montemurro F., Canali S.	Agro-ecology for potential adaptation of horticultural systems to climate change: Agronomic and energetic performance evaluation	2017	Agronomy	25	Agro-ecological service crops; Crop rotations; Energy analysis; Energy productivity; Living mulch; Organic fertilization; Roller crimper	Article
28	T 2	Lee J.M., Clark A.J., Roche J.R.	Climate-change effects and adaptation options for temperate pasture-based dairy farming systems: A review	2013	Grass and Forage Science	25	Adaptation strategies; Botanical composition; Crops; Dry matter production	Article
29	T 1	Brew B., Inder K., Allen J., Thomas M., Kelly B.	The health and wellbeing of Australian farmers: A longitudinal cohort study	2016	BMC Public Health	24	Epidemiology; Farmers; Mental health; Rural; Wellbeing	Article
30	T 2	Paul C., Weber M., Knoke T.	Agroforestry versus farm mosaic systems – Comparing land-use efficiency, economic returns and risks under climate change effects	2017	Science of the Total Environment	22	Climate change; Ecosystem services; Land Equivalent Ratio; Land-use diversification; Portfolio theory; WaNuLCAS	Article

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
31	T 1	Austin E.K., Handley T., Kiem A.S., Rich J.L., Lewin T.J., Askland H.H., Askarimarnani S.S., Perkins D.A., Kelly B.J.	Drought-related stress among farmers: Findings from the Australian rural mental health study	2018	Medical Journal of Australia	21		Article
32	T 1	Brumby S., Chandrasekara A., McCoombe S., Kremer P., Lewandowski P.	Farming fit? Dispelling the Australian agrarian myth	2011	BMC Research Notes	20		Article
33	T 2	Christmann S., Aw-Hassan A.A.	Farming with alternative pollinators (FAP)-An overlooked win-win-strategy for climate change adaptation	2012	Agriculture, Ecosystems and Environment	19	Low cost measure; Nesting support; Optimizing crop pollination; Option value; Technology package; Three-season-forage-buffet	Article
34	T 1	Berry H.L., Hogan A., Ng S.P., Parkinson A.	Farmer health and adaptive capacity in the face of climate change and variability. part 1: Health as a contributor to adaptive capacity and as an outcome from pressures coping with climate related adversities	2011	International Journal of Environmental Research and Public Health	17	Adaptive capacity; Climate change; Farmer health	Article
35	T 1	Gunn K.M., Kettler L.J., Skaczkowski G.L.A., Turnbull D.A.	Farmers' stress and coping in a time of drought	2012	Rural and Remote Health	17	Agriculture; Australia; Coping; Drought; Farm; Mental health; Stress	Article
36	T1	Hogan A., Bode A., Berry H.	Farmer health and adaptive capacity in the face of climate change and variability. part 2: Contexts, personal attributes and behaviors	2011	International Journal of Environmental Research and Public Health	15	Adaptation; Climate change; Farmers; Health; Social profiles	Article
37	T 2	Himanen S.J., Mäkinen H., Rimhanen K., Savikko R.	Engaging farmers in climate change adaptation planning: Assessing intercropping as a means to support farm adaptive capacity	2016	Agriculture (Switzerland)	13	Adaptation planning; Adaptive capacity; Climate change; Ecological intensification; Intercropping; Legumes; Yield security	Article
38	T 2	Gattinger A., Muller A., Haeni M., Skinner C., Fließbach A., Buchmann N., Mäder P., Stolze M., Smith P., El-Hage Scialabba N., Niggli U.	Reply to Leifeld et al.: Enhanced topsoil carbon stocks under organic farming is not equated with climate change mitigation	2013	Proceedings of the National Academy of Sciences of the United States of America	11		Letter
39	T 2	Kalaugher E., Beukes P., Bornman J.F., Clark A., Campbell D.I.	Modelling farm-level adaptation of temperate, pasture-based dairy farms to climate change	2017	Agricultural Systems	10	Adaptation; Climate change; Dairy; Farming systems; Impact assessment; Modelling	Article

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
40	Nexus	Wheeler S.A., Zuo A., Loch A.	Water torture: Unravelling the psychological distress of irrigators in Australia	2018	Journal of Rural Studies	10	Farm exit; Farm stress; Mental health; Murray–Darling Basin plan; Water scarcity	Article
41	T 2	Bonfante A., Impagliazzo A., Fiorentino N., Langella G., Mori M., Fagnano M.	Supporting local farming communities and crop production resilience to climate change through giant reed (Arundo donax L.) cultivation: An Italian case study	2017	Science of the Total Environment	10	Climate change; Giant reed; Sustainable Development Goals (SDGs); SWAP; Water productivity (WP)	Article
42	T 2	Harrison M.T., Cullen B.R., Armstrong D.	Management options for dairy farms under climate change: Effects of intensification, adaptation and simplification on pastures, milk production and profitability	2017	Agricultural Systems	8	Drought; Extreme climatic events; Grazing; Heat wave; Rainfall; Representative concentration pathway; Simulation	Article
43	T 2	Ghahramani A., Bowran D.	Transformative and systemic climate change adaptations in mixed crop-livestock farming systems	2018	Agricultural Systems	8	Adaptation; Climate change; GHG; Integration; Land use change; Mitigation; Modelling	Article
44	T 2	Godde C., Dizyee K., Ash A., Thornton P., Sloat L., Roura E., Henderson B., Herrero M.	Climate change and variability impacts on grazing herds: Insights from a system dynamics approach for semi-arid Australian rangelands	2019	Global Change Biology	8	climate change; climate variability; grasslands; greenhouse gas emissions; intensification; livestock modelling; system dynamics; vulnerability	Article
45	T 2	Chapman D.F., Dassanayake K., Hill J.O., Cullen B.R., Lane N.	Forage-based dairying in a water-limited future: Use of models to investigate farming system adaptation in southern Australia	2012	Journal of Dairy Science	8	Forage crop; Irrigated dairy system; Pasture; Profitability	Article
46	T 2	Ghahramani A., Moore A.D.	Systemic adaptations to climate change in southern Australian grasslands and livestock: Production, profitability, methane emission and ecosystem function	2015	Agricultural Systems	7	Adaptation-mitigation tradeoffs; Agro-ecosystem; ANPP; Intensification; Modelling; Soil environment	Article
47	T 2	Sacchelli S., Fabbrizzi S., Bertocci M., Marone E., Menghini S., Bernetti I.	A mix-method model for adaptation to climate change in the agricultural sector: A case study for Italian wine farms	2017	Journal of Cleaner Production	7	Adaptation strategy; Climate change; Complex system; Decision Support System; Metaheuristic model; Wine farm accounting	Article
48	T 1	Lieffering M., Newton P.C.D., Vibart R., Li F.Y.	Exploring climate change impacts and adaptations of extensive pastoral agriculture systems by combining biophysical simulation and farm system models	2016	Agricultural Systems	6	Adaptation; Climate change; Modelling; Pastures	Article

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
49	T 1	Hanigan I.C., Schirmer J., Niyonsenga T.	Drought and distress in south-eastern Australia	2018	EcoHealth	6	Climate; Distress; Drought; Mental health; Rainfall	Article
50	T 3	Mas F.S., Handal A.J., Rohrer R.E., Viteri E.T.	Health and safety in organic farming: A qualitative study	2017	Journal of Agromedicine	6	Agricultural injuries; Health and injury; Occupational health; Organic agriculture; Sustainable agriculture	Article
51	T 1	Powers J.R., Loxton D., Baker J., Rich J.L., Dobson A.J.	Empirical evidence suggests adverse climate events have not affected Australian women's health and well-being	2012	Australian and New Zealand Journal of Public Health	5	Adverse climate events; Climate change; Drought; Women's health	Article
52	T 2	Muller A., Aubert C.	The potential of organic agriculture to mitigate the influence of agriculture on global warming - A review	2014	Organic Farming, Prototype for Sustainable Agricultures: Prototype for Sustainable Agricultures	5	Carbon dioxide; Carbon sequestration; Climate change; Global warming; Greenhouse gas; Methane; Mitigation; Nitrous oxide; Organic agriculture	Book Chapter
53	T 2	de Frutos Cachorro J., Gobin A., Buysse J.	Farm-level adaptation to climate change: The case of the Loam region in Belgium	2018	Agricultural Systems	4	Agro-economic model; Climate change; Crop choices; Farmers' adaptation; Irrigation	Article
54	T 1	Perceval M., Kõlves K., Ross V., Reddy P., De Leo D.	Environmental factors and suicide in Australian farmers: A qualitative study	2019	Archives of Environmental and Occupational Health	4	Environmental factors; farmer; suicide; suicide prevention	Article
55	T 1	Acharya M.P., Kalischuk R.G., Klein K.K., Bjornlund H.	Health impacts of the 2005 flood events on feedlot farm families in southern Alberta, Canada	2007	WIT Transactions on Ecology and the Environment	4	2005 flood events; Canada; Feedlot farm families; Health care services; Health impacts; Isolation and helplessness; Mental health problems; Southern Alberta	Article
56	T1	Congues J.M.	Promoting collective well-being as a means of defying the odds: Drought in the Goulburn Valley, Australia	2014	Rural Society	4	Agriculture; Climate change; Drought; Risk management; Rural policy	Article
57	T 3	Khan K.M., Baidya R., Aryal A., Farmer J.R., Valliant J.	Neurological and mental health outcomes among conventional and organic farmers in Indiana, USA	2018	Annals of Agricultural and Environmental Medicine	3	Conventional farming; Depression; Health effects; Neurological symptoms; Organic farming	Article
58	T 2	McMartin D.W., Hernani Merino B.H.	Analysing the links between agriculture and climate change:Can 'best management practices' be responsive to climate extremes?	2014	International Journal of Agricultural Resources, Governance and Ecology	3	Agriculture; Beneficial management practices; BMPs; Climate; Vulnerability; Water	Article

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59	T 1	Shorthouse M., Stone L.	Inequity amplified: Climate change, the Australian farmer, and mental health	2018	Medical Journal of Australia	3		Editorial
60	T 3	Brigance C., Soto Mas F., Sanchez V., Handal A.J.	The Mental Health of the Organic Farmer: Psychosocial and Contextual Actors	2018	Workplace Health and Safety	3	mental health; organic farming; protective factors; risk factors; sustainable agriculture	Article
61	T 1	Beautrais A.L.	Farm suicides in New Zealand, 2007–2015: A review of coroners' records	2018	Australian and New Zealand Journal of Psychiatry	2	coroners' records; economic recession; farm; firearms; New Zealand; Suicide	Article
62	T 1	Yazd S.D., Wheeler S.A., Zuo A.	Exploring the drivers of irrigator mental health in the Murray-Darling Basin, Australia	2019	Sustainability (Switzerland)	2	Certified organic agriculture; Irrigator; Murray-Darling Basin; Psychological distress; Wellbeing	Article
63	T 2	Williams A., Mushtaq S., Kouadio L., Power B., Marcussen T., McRae D., Cockfield G.	An investigation of farm-scale adaptation options for cotton production in the face of future climate change and water allocation policies in southern Queensland, Australia	2018	Agricultural Water Management	1	APSIM; Climate change; Climate change policy; Cotton; Farming systems	Article
64	T 2	Kalaugher E., Beukes P., Clark A., Bornmand J.F.	Adaptation strategies for New Zealand dairy farms under climate change scenarios	2012	iEMSs 2012 - Managing Resources of a Limited Planet: Proceedings of the 6th Biennial Meeting of the International Environmental Modelling and Software Society	1	Adaptation; Climate change; Dairy; Impact assessment; Modelling	Conference Paper
65	T 2	Colley T.A., Olsen S.I., Birkved M., Hauschild M.Z.	Delta Life Cycle Assessment of Regenerative Agriculture in a Sheep Farming System	2020	Integrated environmental assessment and management	1	Carbon neutral sheep production; Carbon sequestration; Comparative life cycle assessment; Greenhouse gas emissions; Regenerative agriculture	Article
66	T 2	Zhang H., Mu J.E., McCarl B.A.	Adaptation to climate change via adjustment in land leasing: Evidence from dryland wheat farms in the U.S. Pacific Northwest	2018	Land Use Policy	1	Adaptation; Agriculture; Climate change; Land leasing; Rental contract; Wheat	Article
67	T 2	Prato T., Qiu Z.	Vulnerability and adaptation of crop production to future climate change: A case study for representative farms in Flathead Valley, Montana, USA	2014	Proceedings - 7th International Congress on Environmental Modelling and Software: Bold Visions for Environmental Modeling, iEMSs 2014	1	Agricultural adaptation; Climate change; Flathead Valley; Montana	Conference Paper

No	Theme	Authors	Title	Year	Source title	Cited by	Author Keywords	Document Type
68	T 3	Brožová I.	Financial health of agricultural enterprises in the organic farming sector	2011	Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis	1	Conventional farm enterprises; Economic result of an enterprise; Financial analysis; Financial health; Legal entities; Organic farm enterprises; Ratios	Article
69	T 2	Skewes M.A., Dyson C., McCarthy M.G.	On-farm management of citrus in drought-a statistical analysis	2016	Acta Horticulturae		Canopy area; Cultivar; Irrigation water use index; Rootstock; Wetted area; Yield	Conference Paper
70	T 2	Huang Y., Ren W., Grove J., Poffenbarger H., Jacobsen K., Tao B., Zhu X., McNear D.	Assessing synergistic effects of no-tillage and cover crops on soil carbon dynamics in a long-term maize cropping system under climate change	2020	Agricultural and Forest Meteorology		Agroecosystem modeling; Climate resilience; Climate-smart agriculture; Management practices; Soil organic carbon	Article
71	T 2	Adamides G., Kalatzis N., Stylianou A., Marianos N., Chatzipapadopoulos F., Giannakopoulou M., Papadavid G., Vassiliou V., Neocleous D.	Smart farming techniques for climate change adaptation in Cyprus	2020	Atmosphere		Agriculture 4.0; Climate change; Cyprus; Internet of Things; Irrigation; Potato; Sensors; Smart farming	Article
72	T 1	Matthews V., Longman J., Berry H.L., Passey M., Bennett-Levy J., Morgan G.G., Pit S., Rolfe M., Bailie R.S.	Differential Mental Health Impact Six Months After Extensive River Flooding in Rural Australia: A Cross-Sectional Analysis Through an Equity Lens	2019	Frontiers in Public Health		indigenous populations; inequality; low income populations; mental health; natural disasters	Article
73	T 2	Clark S.	Organic farming and climate change: The need for innovation	2020	Sustainability (Switzerland)	111	Climate change; Greenhouse gas emissions; Life cycle assessment; Organic farming	Article