Understanding the knowledge evolution and research-policy interaction of climate change research in South Africa

[Master Thesis]

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CWTS
Meaningful metrics

List of Abbreviation

ARC	Agriculture Research Council
CGS	Council for Geoscience
CPUT	Cape Pennisula University of Technology
CSIR	Council of Scientific & Industrial Research
DA	Department of Health
DAFF	Department of Agriculture, Forestry and Fishier
DE	Department of Energy
DEA	Department of Environmental Affairs
DEPCP	Environmental Planning and Climate Protect Department
DUT	Durban University of Technology
DWA	Department of Water Affairs
GGSA	Government Gazette of South Africa
NMU	University of Nelson Mandela
NPC	National Planning Commission
NRF	National Research Foundation
NWU	University of North West
SAMRC	South Africa Medical Research Council
SANBI	South Africa National Biodiversity Institution
SASRI	South Africa Sugarcane Research Institute
SSA	Statistics South Africa
SU	University of Stellenbosch
TUT	Tshwane University of Technology
UCT	University of Cape Town
UFH	University of Fort Hare
UFS	University of the Free State
UJ	University of Johannesburg
UKZN	University of Kwazulu Natal
UL	University of Limpopo
UMP	University of Mpumalanga
Unisa	University of South Africa
Univen	University of Venda
UNIZULU	University of Zululand
UP	University of Pretoria
UR	University of Rhodes
UWC	University of Western Cape
VUT	Vaal University of Technology
Wits	University of Witwatersrand
WSU	Walter Sisulu University
WUT	Mangosuthu University of Technology

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Abstract

Scientific research is an important channel to provide valuable and feasible information for policymaking to tackle the complex social issues. Identifying a clear knowledge framework in the science and policy communities could make better use of scientific knowledge in addressing social issues. Climate change is one of the most severe social issues faced by South Africa, and the human beings as well, in the recent decades. It is reported that the implementation of policy regarding climate action in South Africa faces a range of challenges, partly due to the lack of data and information, as well as the inefficiency communication between governmental and non-governmental stakeholders. Until now, a lack of research has been conducted in South Africa to explore the knowledge structure and interaction of the science and policy communities in the field of climate change.

In response to the knowledge gap, this study aims to trace the knowledge evolution on climate change study in South Africa with bibliometrics keyword and subtopics analysis, as well as the policy progression in climate governance with documentary analysis. Subsequently, the interaction between the science and policy communities is explored through keyword analysis and citation analysis. Furthermore, the performance of research institutions and the leading authors in this research field is quantified, which contributes to provide valuable information for the policymaker to select the most suitable scientific partnership according to the policy need.

The results show that the scientific publication in South Africa increases dramatically from 1980 to 2019 with a significant shift of research focuses. 12 subtopics within climate change study are identified. The subtopic analysis exhibits that increasing publication ratios have been split from the natural-related topics to the anthropocentric-related topics in the recent 10 years. The research institutions UCT, SU, UP, UKZN and Wits have maintained remarkable scientific capacities on climate change study since 1980, and NMU, UR, UJ and NWU catch up in the recent 5 years. Chown S is the most productive author in field of climate change in South Africa. The research-policy interaction analysis indicates that the implementation of policy could steer research development, while no sufficient evidence is found the influence of scientific research on policymaking from the citation analysis of the policy documents.

Keywords: climate change, knowledge structure, bibliometrics analysis, climate policy, research-policy interaction

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1. Introduction

Nowadays, society is facing tremendous challenges. Scientific research serves as a significant channel to provide valuable and forward-looking information to tackle the intractable social issues and reveal the complexity of social dynamics. Previous studies once assumed that scientific evidence could inform policy process linearly and instrumentally, and that credible publications could be directly transferred into policy use (Kothari et al., 2005; Weiss, 1979; Blewden et al. 2010). However, this assumption was later shown to be too simplistic and the use of scientific research by the policy in addressing societal issues would be a more complex and contested process (Hanney et al., 2003; Blewden et al. 2010). The recent argument believes that the utilization of scientific knowledge for building up better society has long been shackled (Cornell et al., 2013). As the two distinct communities holding different overarching values, the communications between the research and policy institutions are not always smooth. A further mechanism needs to be identified to make better use of scientific knowledge to tackle societal challenges.

Climate change is one of the most severe social issues faced by human beings in recent decades. By the end of the 21st century, the inhabitants of the Earth will live in a very difficult climate if the tendency of climate change cannot be mitigated. The potential catastrophic effect caused by climate change has raised highly global concerns. In 2015, the United Nations launched 17 Sustainable Development Goals (SDGs) with Climate Action (SDG13) as one of the important goal aiming to "take urgent action to combat climate change and its impact". Policymakers and scientists are expected to work together to achieve the goal. Although the Climate Action of SDGs is oriented towards all the countries, the implementation of the goals should be in combination with contextual knowledge, resources and capability (Chataway et al., 2019). The national government supposes to identify priorities and formulate appropriate policies according to the contextual climate condition, and the scientists are expected to conduct research to reflect the reality and in response to the national priorities.

In this study, I will specifically focus on South Africa, a country with one of the most elaborate and sophisticated climate governance system among the developing and emerging economies (Averchenkova et al., 2019). While the implementation of policy regarding SDGs still faces a range of challenges, partly due to the lack of data and information, as well as the inefficiency communication between governmental and non-governmental stakeholders (Averchenkova et al., 2019). A transparent and informative structural of knowledge composition of scientific and political communities is beneficial for researchers and policymakers to understand each other and to facilitate cooperation. Until now, a lack of research has been conducted in South Africa to explore the development and interaction of these two communities in the climate change field. This study aims to fill up the research gap by tracing the evolution of climate change knowledge and policy progression in climate governance. Furthermore, the performance of

research institutions in this research field will also be quantified, which contributes to inform research institution its position in climate change research field, and meanwhile, provide valuable information for the policymaker to select the most suitable scientific partnership according to the policy need. The method and indicators developed in this study could also apply to other research fields to examine the knowledge evolution, science-policy interaction and the scientific performance of research institution in South Africa.

2. Research objectives and research question

The research aims to understand how scientific research in the climate change field evolves in South Africa, who are the leading authors in this research field, and what are the scientific performance of the main research institutions in South Africa in this research field. It tends to identify the research hotspots of climate change from the scientific perspective, and probes into the main research institutions to grasp the strengths of them in this research field. Following that, the research also examines the progress from the policy side. It tends to understand how the national climate policy strategies evolve to address the SDGs Climate Action, how the scientific research interact with policy, and to what extent are the knowledge evolution aligned with the national Climate Action (SDG13) priorities. Despite the SDGs were launched in only 5 years, the climate change research field has existed for over 40 years. This study will focus on a 40-year timeframe to understand the development of climate change research from a historical perspective and how it corresponds to address SDGs. By visualizing the dynamics and trends of scientific knowledge and policy in the climate change research field, the research could guide future research in climate change in South Africa. It can also inform the policymaker of the research frontier in climate change research, which provides evidence support to formulate feasible policy strategies in the future. Furthermore, the result can provide valuable recommendations for the policymaker to reallocate funding on climate change research to address research priorities and fill the research gaps.

The study is designed to answer the following research questions:

RQ1. What are the dynamics of climate change research in South Africa in the past 40 years?

- How does knowledge evolve in the climate change research field in South Africa in the past 40 years?
- Who are the leading authors in the climate change research field?
- What are the scientific performances of the main research institutions in the climate change research field in South Africa?
- To what extent is the scientific performance in the research institution in alignment with its claims in climate change research field?

RQ2. How does climate change research interact with climate policy in South Africa?

- What are the national climate action priorities corresponding to SDGs Climate Action in South Africa?
- To what extent is the knowledge evolution in the climate change research in alignment with national climate action priorities?

3. Theoretical Framework

3.1 Development of climate change research

Le Treut et al. (2005) examined the evolution of climate change research from a historical perspective and concluded that the Earth's climate and climate change science have continued to evolve over the last decades. The climate science started from the fundamental nature of earth science, and in recent years, increasing attentions have been shifted to the anthropogenic influences on climate change (Le Treut et al, 2005). Consequently, the number of studies on the socioeconomic and policy perspectives of climate change has increased rapidly since 2010 (Härtel & Pearman, 2010). Before that, around 95% of scientific papers related to climate change were written from a natural science perspective (Grieneisen & Zhang, 2011). Haunschild et al. (2016) applied bibliometrics method and provided a comprehensive picture in climate change research based on 222,060 papers published between 1980 to 2014. They classified climate change research into 10 subfields and found that biomass and climate modelling caught the most scientific attention, followed by water issues. Researches tackling atmosphere, adaption and vulnerability of global warming were relatively small, but the research has increased exponentially since 2005. Studies focused on the ice, snow and ocean currents were comparatively lacking (Haunschild et al., 2016). Likewise, Wang et al. (2014) adopted the same methods with 3,004 academic papers from 1991 to 2012 and specifically focused on global scientific performance in the topic of climate change vulnerability. They found the research in this field has soared since 2006, and the research hotspots in the climate change vulnerability field include food security, health issues in the socio-economic system, ecological diversity, ecosystem service and water resource management (Wang et al., 2014).

Pasgaard and Strange (2013) examined climate change research distribution across the world and found diverse global concerns in this field. The research in the developed countries was more inclined to mitigation perspectives, while in the developing countries issues associated with adaptation, human-induced impacts and social impacts dominated (Pasgaard & Strange, 2013). Ziervogel et al. (2014) investigated current climate change research status in South Africa. They lauded the high-quality research established in the subfields of climate scenarios and biophysical impacts on climate change and suggested more researches should be concentrated on adaption strategies (Zieryogel et al., 2014). The above-mentioned evidence suggests the following hypotheses:

Hypothesis 1: The research on climate change have diverged in the past decades and more attentions have been shifted to human-induced climate change in recent years.

Hypothesis 2: Climate change research demonstrates a contextual difference across the world. In South Africa, the climate change research is increasingly centralized in climate adaptation, anthropogenic and social impacts research fields.

3.2 National innovation system

Various empirical studies prove that an efficient national innovation system plays a determinant role in facilitating knowledge transmission, regional innovation and economic growth. The idea of developing national innovation system has come up since the 1960s when system dynamics and system analysis dominated among social scientist, and many scholars began to apply a systematic approach to evaluate the choice of technology, science and innovation (Hughes and Hughes 2000; Godin, 2009). The national innovation system typically consists of multiple sectors such as government, university, organization, industry and their environment. The performance of the innovation system can be largely attributed to relationships and interaction between the components or sectors (Godin, 2009).

Countries will develop their national innovation system depending on the context. The national innovation system in South Africa comprises multiple actors including ministries, research councils, think tanks, interest groups, consultancies, university and international actors, wherein ministries, research councils and universities are the main actors within the research system. The Department of Science and Technology is the responsible ministerial actor who provides funding to research institutions. Research councils are the government-funded research institutions, the research conducted by whom should be in line with the specific outcome identifies by the National Development Plan. Similarly, universities are the research institutions responsible for knowledge production. Compared to research councils, universities have more autonomy in conducting research, although they should also undergo some control by the government due to subsides (Grimm et al., 2018). Understanding the structure of the national innovation system in South Africa leads to the following hypotheses:

Hypothesis 3: The scientific performance of research institutions exhibits a diverse interest and scientific capacity in the climate change research field.

3.3 Scientific research and policy interaction

Previous studies have traced the development of knowledge and policy interaction models (Jones, 2009; Best and Holmes, 2010). In general, the historical flow of the traceries can be summarized into three paradigms, from linear models to more complex and systematic models (Nutley et al. 2010; Cozzens & Snoek, 2010). The first stage is 'one-way' and 'knowledge-driven' models, wherein knowledge is considered as providing meaningful input to the policy decision, while policymakers are naturally seen as information seekers (Kothari et al., 2005; den Butter & Morgan, 1998). The typical study in this stage focus on how high-quality scientific publications contribute to the different stages of decision making. While substantial kinds of literature have recognized the shortcomings of the 'knowledge-driven' model in policy decision. They argue that policymaking is never a linear and uptake process, rather, knowledge used in policymaking should be selected and categorized.

Evolving from the linear 'knowledge-driven' model, the second paradigm more focused on the proper dissemination of the 'useful' research findings in policymaking, which is defined as 'relationship' or 'dissemination' models (Best and Holmes, 2010; Kothari et al, 2005). In this stage, the research use is developed within a relationship that knowledge producers and users collaborate, and thus a specific type of research findings are picked to percolate to the policy community at a specific time and/or to the specific policymakers (Best and Holmes, 2010; Kothari et al, 2005). Furthermore, various actors including non-academic knowledge producer and the citizens are involved in the interaction (Jones, 2009). However, although this paradigm stresses the importance of communication between knowledge producers and users, little attention has been given to the acceptance of policymakers to the disseminated knowledge, and the feedback from the policymakers are barely incorporated in the further scientific research (Lomas, 1997; Landry et al., 2001). The interaction in this paradigm is still unidirectional (Landry et al., 2001).

The third and the most current paradigm is the 'system' model, which stress the negotiation and contest process of policymakers to the knowledge producers (Jones, 2009). Furthermore, knowledge to be applied needs to be intertwined with culture, regional priorities and the organizational context (Best and Holmes, 2010). One of the examples of research in these models can be that knowledge adds a legitimate argument to political action, while what is defined as 'legitimate knowledge' is politically determined (Jones, 2009). Knowledge in this stage is thus processed in a more complex adaptive system (Cozzens & Snoek, 2010). Two-communities model is one of the commonly used models as the basis of knowledge transfer in this stage. The model bridges the gaps between two distinct communities, the scientists (knowledge producers) and policymakers (knowledge consumers), who have different overarching values and language of communication (Lindquist, 2001). It contributes to promote understanding of each community to the others and facilitate the better use of research findings (Kothari et al, 2005). As a typical policy-oriented research model, the value of research finding in the two communities model is determined by the policymakers considering its fit and timeliness for the decision making (Lindquist, 2001). According to the scientific-policy interaction theory in combination with the theory developed in section 3.2, hypotheses are formulated as follows:

Hypothesis 4: Although the research institutions and ministry hold different overarching value, they collaborate tightly with each other. As the funding provider, the ministry is quantified to determine the direction of scientific research to some extent in South Africa.

Hypothesis 5: Scientific research could provide meaningful information and add a legitimate argument to political action. High-quality scientific publications are more likely to catch policy attention.

4. Methodology

4.1 Research strategy

Fig 1. shows the theories and methods used to answer the research question. RQ1 focuses on knowledge evolution and the performance of research institutions in the climate change research field. Bibliometric analysis will be used to map the evolution of climate change research and be applied to compute productivity and scientific impact of research institutions. To tackle the RQ2, analyzing the relationship between scientific research and policy dynamics in climate change field in South Africa, a mixed method combining quantitative and qualitative approach will be applied. The progression of climate policy in response to climate action will be extracted using a documental analysis, and to analyze the research-policy interaction, bibliometric analysis and policy citation analysis will be used.

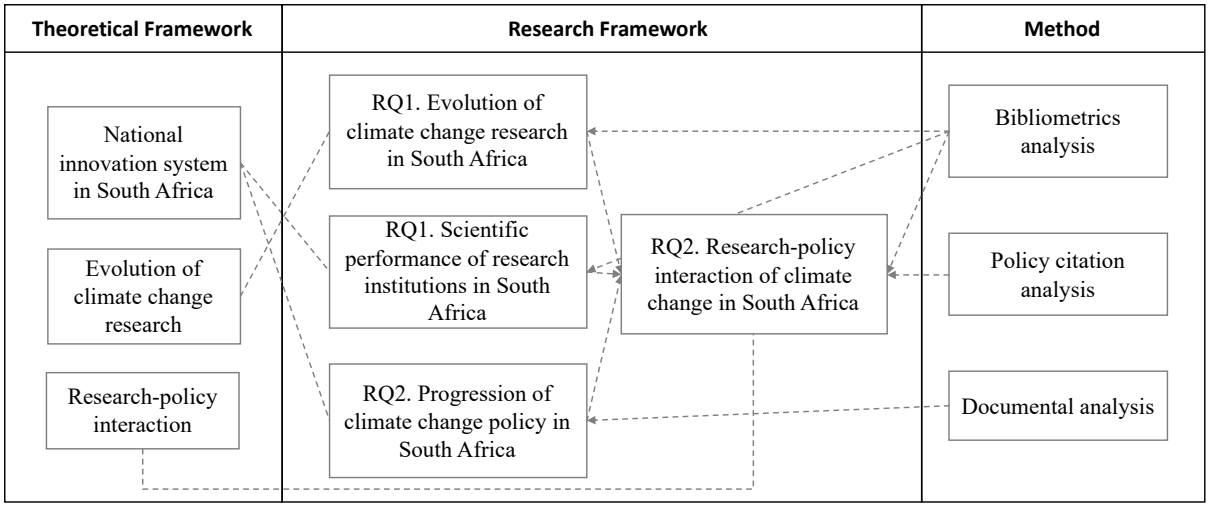


Fig 1. Research strategy

4.2 Data collection and operationalization

Constructing climate change research database in South Africa

In this phase, bibliometric approach was applied to visualize the development of climate change research in South Africa. Data used for bibliometric analysis were retrieved from Science Citation Index Expanded (SCI-E) and Social Science Citation Index (SSCI) databases in the Web of Science (WoS). Since climate change research is a broad field that contains multidisciplinary knowledge, no clear categorization by keywords or index terms is defined to represent this research field (Haunschild et al., 2016). Haunschild et al. (2016) applied a four-step backward strategy, which is proposed by Wang et al. (2014), to identify the main index terms (Table.1) for climate change research.

Table 1. Index terms of climate change research

Index terms	Phrases
climat* chang*	climate/climatic change/changes/changing
climat* warming	climate/climatic warming
global temperature*	global temperature/temperatures
global warming	global warming
greenhouse gas*	greenhouse gas/gases
greenhouse effect*	greenhouse effect/effects
greenhouse warming	greenhouse warming

These index terms were used in this study for topical retrieval of climate change research in the WoS. The time span was set from 1980 to 2019 and all types of documents were included. The result was refined by limiting the country to South Africa. Finally, 4,176 papers met the selection criteria. Article (3,519) is the most frequent document type, followed by reviews (485). These two document types are the most influential scientific publications, accounting for 84.3% and 11.9% of the total publications. The rest 3.8% of the documents consist of the proceedings paper, editorial material, meeting abstract, early access, book chapter, data paper, letter, book review, correction, new item and reprint.

Mapping the evolution of climate change research in South Africa

Bibliometrics is a widely used statistical method to map the output of scientific publications (Mingers & Leydesdorff, 2015). The amount of publication is the most common indicator to measure the research output and citation is another important indicator to quantify the research impact. Besides, the analysis of keywords can explore the hot topics of a research field. In this study, I will use the keyword analysis to identify the knowledge evolution and the predominant subtopics of climate change research in South Africa using the database constructed in the step above. The leading authors in South Africa, both in the general climate change study and in each subtopic will be identified. It aims to provide a potential contact list for policymaker to select the suitable partnership based on the policy need.

Assessing the scientific performance of South African research institutions in climate change research

In this study, the performance of research institutions in South Africa will be assessed by the productivity and scientific impact of scientific publications of the institution. The productivity of research institution is gauged by a relative number of publication, which is computing by using the fractional count of publications of each research institution divided by the average fractional publication of the whole country. The relative number of publication is a decimal number showing the relation to the normalized world, where 1 is set as the average. Furthermore, the measurement of the relative number of publication in the recent 5 years serves as supplementary to capture the current productivity of the research institution. Similarly, the

scientific impact is measured by the relative count of citation, which is computed by using the fractional citation of the research institutions divided by the average fractional citation of the whole country, over the 40 years and in the recent 5 years.

Understanding climate change policy in South Africa

South Africa has been working diligently to tackle climate change issues globally and domestically. It has participated in the United Nations Framework Convention on Climate Change since 1997. The national and regional governments have framed a wide range of policies, strategies and plans to address climate change issues over the two decades (Averchenkova et al., 2019). In this step, I will do a documentary analysis for the policy documents considering climate change issues related to SDGs in South Africa. The selection criteria of policy documents is based on the previous researches and the documents posted on the government websites. A flow chat will be created to visualize the dynamics of the national climate change policy. Subsequently, a citation analysis will be conducted for the reference lists on the policy document to understand the influence of scientific research on policy formulation.

5. Dynamics of climate change research in South Africa

5.1 Productivity of climate change research in South Africa

The number of scientific publications is one of the most straightforward indicators to assess the research capability in a specific field of a country. Fig 2. shows the change in the productivity of climate change research in South Africa from 1980 to 2019, and the percentage of South Africa climate change research in the world. The annual research publication has increased dramatically from 0 in 1980 to 609 in 2019. A sudden spiking up was experienced in 2006 when the numbers of publication grew 60% from 44 in the previous year to 70. Since then, the annual publication has kept expanding at a rate of 7% to 45%. In the 1980s when climate change started to obtain public concerns and to be developed as an emerging research field, despite the finite numbers of publications, climate change research in South Africa took up a certain proportion of the world publications, signifying South Africa is one of the few countries involved in climate change research in the early stage. After 1990 when the global publications of climate change research started to speed up, the percentage of South Africa climate change research in the world fluctuated between 0.7% to 1.9%, and an inconspicuous climb was seen after 2012.

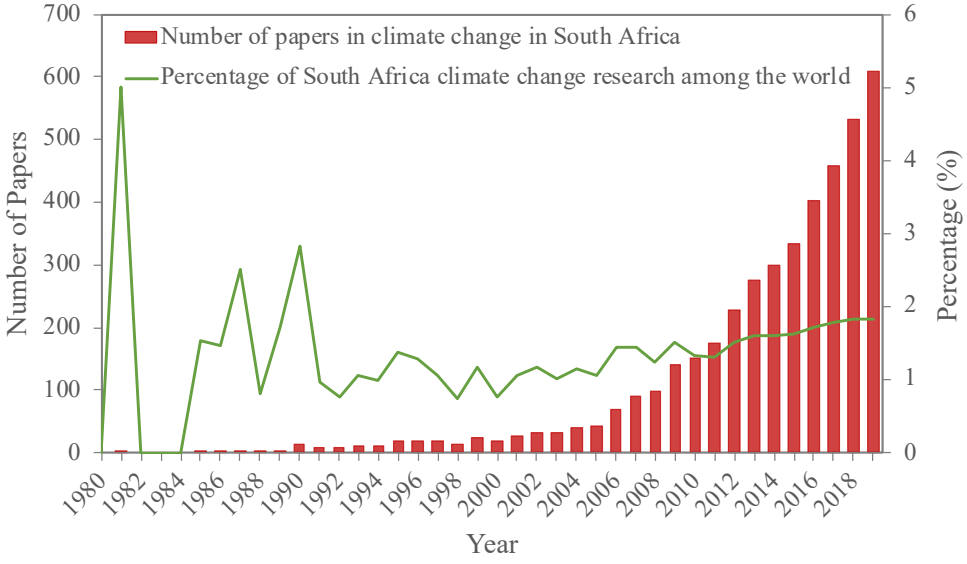


Fig 2. The productivity of climate change research in South Africa from 1980 to 2019.

Fig 3. shows the compound annual growth rate (CAGR) of publications in South Africa. It describes the rate at which the number of publication would have grown, and could provide a reasonable explanation of the long-term trend of research development (Korotky, 2013). The value of CAGR in percentage, denoted by f(y), is calculated according to the total number of publications for the year $y-1$ and the year y since 1980. The equation is written as:

$$f(y) = [\frac{T(y)}{T(y-1)} - 1] \times 100$$

The result shows that the CAGRs of climate change publication was vigorous from 1985 to 1990 and reached its pick in 1990 at 118.2%. After that, the value rapidly plunged in 1991,

kept decreasing to 11.5% in 1998, and then fluctuated between 11%-15% from 2000 to 2005. In recent years after 2006, it slightly recovered and held steady at around 20%. The result implies that the productivity of climate change research is highly likely to sustain a relative robust CAGRs at over 10% in the near future.

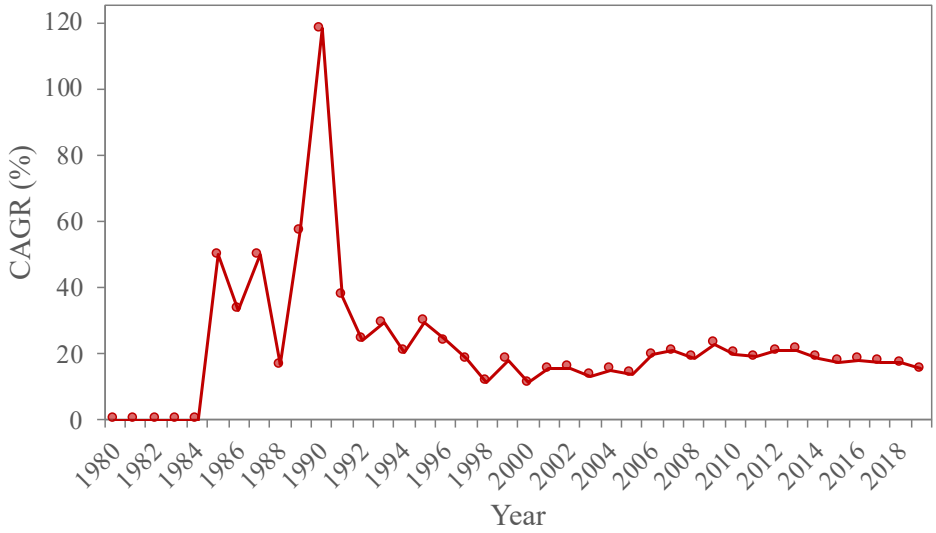


Fig 3. The compound annual growth rate of climate change research publication in South Africa.

5.2 The keyword analysis of research profile on climate change study in South Africa

Mapping keyword co-occurrence is an effective way to reflect the dynamic of research hotspots in the discipline field over time (Liao et al., 2018). Author keyword and KeyWords Plus are commonly used in identifying research hotspots. Author keywords are formulated by the author to represent the content of the article, while keyword plus are generated from the titles of the cited articles using a special algorithm, which exhibits its advantage in capturing an article's content with greater depth and variety (Garfield & Sher, 1993; Zhang et al., 2016). They are both effective in identifying research trends and are complementary to show a general picture of the research focus (Garfield & Sher, 1993). In this study, author keyword and KeyWord Plus are used together for mapping keyword co-occurrence of the climate change research in South Africa.

To present the dynamic of how the research profile on climate change evolves in South Africa, I visualized the keyword co-occurrence network in four periods: 1990 – 1999, 2000 – 2009, 2010 – 2014, 2015 – 2019 (Fig 4.). The map consists of nodes and the links between the nodes, with each node representing a keyword. The size of the node reflects the weight of the keyword. The larger the node, the higher frequency the keyword is mentioned in these papers. The nodes are linked with line if they appear together. The widths of the line reveal the frequency of the co-occurrence of the keywords. The distance between the nodes demonstrates the strength of relation between the nodes. The node placed in the centre indicates it has short average distance and strong relation to all the other nodes. The node situated in the periphery reflects the

marginal position of the keyword. The colour of the node indicates the cluster it belongs to, which is automatically classified by VOSviewers based on the association strength and the distance between the nodes. Detailed explanation on how the cluster mechanism can be found in the paper Waltman et al. (2010).

Figure 4a shows the keyword network of climate change study in the 1990s, where 3 clusters are identified by the VOSviewer. The red cluster contains the papers concerning paleoclimate with main keyword terms *Holocene*, *late quaternary* and *late Pleistocene*, and plant-based ecosystem. The blue cluster includes papers about ocean issues and the publications in the green cluster mainly focuses on greenhouse gases emissions. Climate models are widely applied in the publications within the green and blue clusters. Six clusters are identified in the period 2000 to 2009 (figure 4b). The red cluster combines papers related to climate change and biology. The purple cluster illustrates the influence of climate change on biodiversity and the habitat. The yellow cluster concerns climate change impact and vulnerability, and the blue cluster concerns precipitation, greenhouse gases emission and oscillation. The green cluster relates environmental change to the paleoclimate. The brown cluster is relatively marginalized to others, which merely contains keywords *energy* and *ecosystem*. Five clusters are classified in 2010 to 2014 (figure 4c). The blue cluster refers to the papers concerning climate variability and the effect on precipitation with climate models being applied in the study. The yellow cluster reflects climate adaptation and management with policy and governance approach. The red cluster consists of keywords related to conservation and biodiversity. The brown cluster involves knowledge in climate biology and evolutionary theory, and the purple cluster settles in paleoclimate and plant-based ecosystem.

The research profile of climate change in the most recent five years is displayed in figure 4d, where the keywords of climate change publications are divided into 6 categories by VOSviewer. The main keyword terms in the red cluster are *climate change, temperature, biodiversity, ecology* and *species distribution*. This cluster tends to reflect the influence of climate change on temperature and how the species and the ecosystem cope with the warming habitat. The blue cluster combines the publications associated with the impacts of climate change on macro-level ocean issues (e.g. sea-surface temperature, El-Nino, oscillation, etc.), marine ecosystem (e.g. fish, ocean acidification, etc.), precipitation and water circulation. The green cluster addresses problems on agricultural production, climate change impact, greenhouse gas emission and renewable energy. It is noteworthy that the keyword terms *model* and its related terms (e.g. *simulation*, *calibration, scenario*) are closely classified in the blue and green clusters, suggesting that the researchers focused on ocean, climate impact, greenhouse gas emission issues are more inclined to use model to predict or simulate the phenomenon. The yellow cluster is composed of the papers concerning the vulnerability and resilience of the environment, and aiming to find out the solution to adapt to the changing climate through smart governance and policies. These four clusters takes up the majority proportion of the climate

change publications in this period. The brown cluster tends to display the hazards of climate change on the human health, such as disease transmission and infection. The purple cluster includes papers talking about paleoclimate.

The keyword co-occurrence networks in the four different periods show a significant shift of research focus on climate change study, and the diversification and more comprehensive composition of the research focus over the last 30 years (Fig 4 and Table 2). Paleoclimate is the main research focus on climate change study in the 1990s, where the keyword terms like *paleotemperatures* and *late quaternary* place in the centre in figure 4a. The share of research on this topics dropped significantly in the recent decade, and the positions of the paleoclimate related terms gradually marginalize (Fig 4cd.). What is more, in the early period (Fig 4a), greenhouse gases emission and ocean issues dominate the climate change study, where the related keyword terms *carbon-dioxide*, *greenhouse gas*, *ocean* and *sea-surface temperature* rank front on the list (Table 2). In the period 2000 through 2009, biodiversity and ecosystem becomes the predominant research focus with the keyword terms *biodiversity*, *conservation*, *pattern* and *species distribution* having a high frequency of occurrence and link strength. Also in this period, researchers started to pay attention to the impacts and vulnerability of climate change. In the recent ten years (figure 4cd), publications on climate change are inclined to address the impacts (e.g. anthropogenic impacts) of climate change and what needs to be done to respond to or mitigate the changing climate. The associated keyword terms *impacts*, *management*, *adaptation, vulnerability* and *responses* have a high ranking on the list, and are clustered in the middle closely behind *climate change* on the map. Besides, it is worth noting that the keyword term *energy* shows up in the period 2000 to 2009, but with a remote position and being isolated from other keywords. It becomes increasingly significant in climate change study in recent years, which are always mentioned in the publications in combination with policy, greenhouse gas emissions and biomass. Likewise, *agriculture, food security, policy, governance* and other keyword terms concerning socio-economic aspects of climate change exhibit similar growing importance on climate change study.

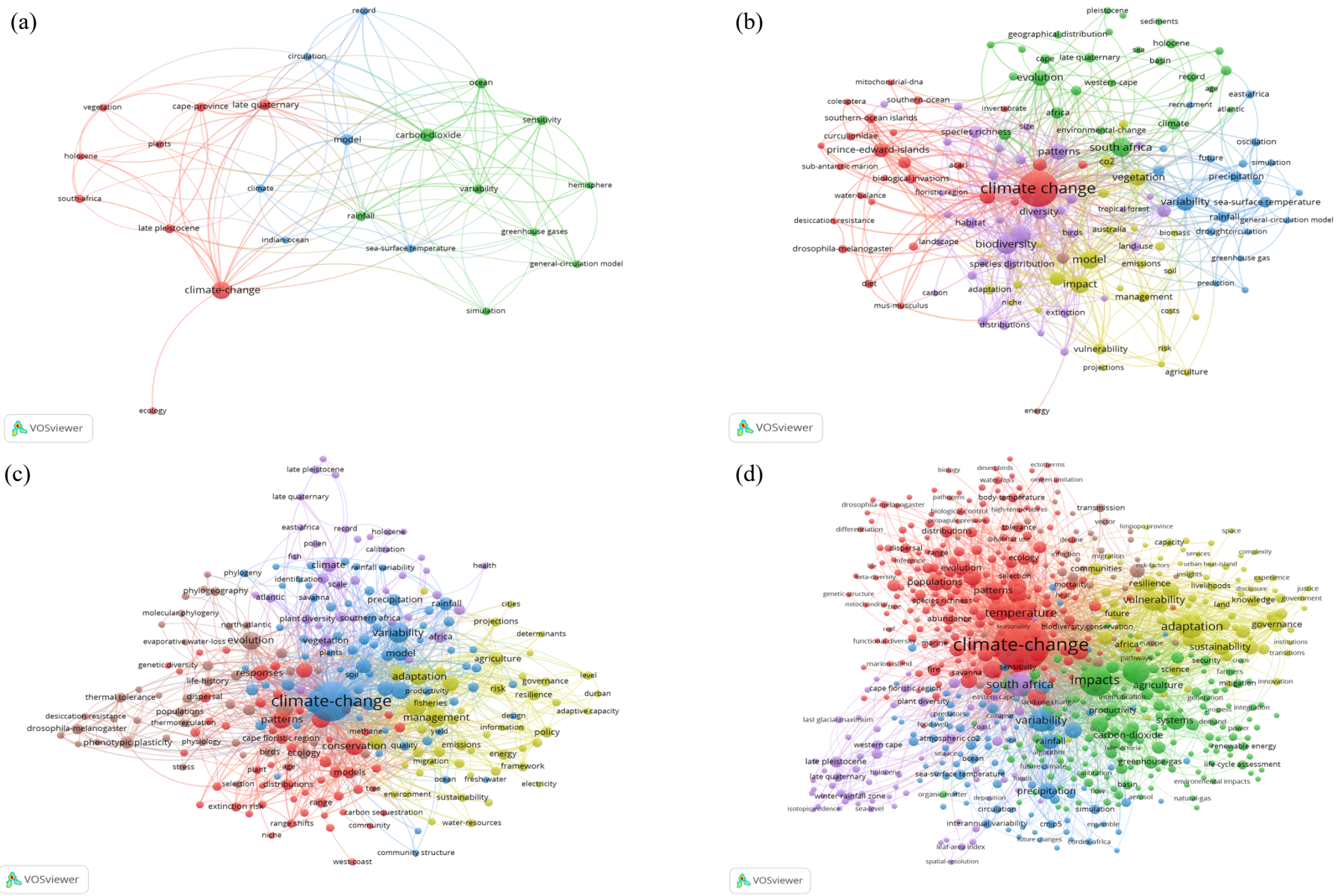


Fig 4. Keyword co-occurrence network of the climate change publications in South Africa (a) 1990 - 1999, (b) 2000 - 2009, (c) 2010 - 2014, (d) 2011 - 2019. The cluster of the keywords is automatically identified by VOSviewer and the colour of each cluster is different for each map.

Table 2. **Top 20 keywords of the climate change publications in the four time periods**

1990-1999			2000-2009			2010-2014			2015-2019		
Keyword	Occurrence	Link strength	Keyword	Occurrence	Link strength	Keyword	Occurrence	Link strength	Keyword	Occurrence	Link strength
climate change	34	58	climate change	193	533	climate change	351	1105	climate change	997	4352
carbon-dioxide	20	53	biodiversity	52	233	variability	70	278	impacts	279	1388
late quaternary	13	46	conservation	48	192	impacts	58	232	management	187	984
ocean	11	35	impact	40	158	management	59	224	South Africa	179	867
model	13	33	model	42	156	patterns	50	218	temperature	175	822
sensitivity	9	33	pattern	33	140	South Africa	53	218	variability	151	789
variability	10	32	South Africa	47	129	conservation	48	210	adaptation	169	761
rainfall	9	31	diversity	26	126	biodiversity	47	203	biodiversity	120	672
cape-province	8	26	vegetation	34	118	adaptation	43	186	vulnerability	124	661
climate	7	24	variability	36	115	evolution	54	182	patterns	91	489
Late Pleistocene	8	24	ecology	26	114	temperature	40	161	dynamics	84	448
Sea-surface temperature	7	22	responses	23	105	vulnerability	35	158	conservation	80	438
greenhouse gas	6	20	prince-edward-island	25	102	diversity	34	156	responses	79	437
record	6	20	evolution	31	100	responses	37	155	systems	92	413
hemisphere	5	18	species distribution	15	77	dynamic	33	133	diversity	72	392
paleotemperature	4	17	temperature	17	76	land-use	28	131	sustainability	72	379
Atlantic	4	16	dynamics	20	74	model	36	127	precipitation	70	361
circulation	6	16	marion-island	17	69	trends	30	116	rainfall	64	360
circulation model	6	14	vulnerability	16	68	impact	37	113	populations	75	354
Holocene	5	14	rainfall	16	67	agriculture	24	111	resilience	63	340

5.3 Identify the subtopics of climate change research in South Africa

In this step, I continue using author keyword and KeyWord Plus to identify the subtopics in climate change research. The research subtopics and their searching terms were identified based on (1) the frequency of keywords of the publication dataset in this study and the keyword co-occurrence analysis. (2) the classifications of climate change subtopics from various sources (e.g. Wang et al., 2014; Haunschild et al., 2016; de Wit, 2001; USDA, 2020). (3) the research claim of universities in climate change research in South Africa. In total, 12 subtopics are identified, as listed in Table 3. It should be mentioned that keywords related to the paleoclimate are not included in the classifications since the modern climate change study normally won't solely concentrates on paleoclimate, and it is assumed that the papers on paleoclimate that are literally tackling climate change issues, are covered by other subtopics classifications, such as ocean, biodiversity and terrestrial ecosystem. Overall, the research subtopics comprise 3,558 papers (85.2%) of the publication dataset (n = 4,176). Paper is counted multiple times if it relates to more than one subtopics.

Table 3. **Classifications of climate change research subtopics using KeyWord Plus as the searching index.**

Subtopics	Searching terms	Frequency
Atmosphere	atmospher*, aerosol*, carbon-dioxide, CO_2, greenhouse gas*, nitrous-oxide, nitrogen, methane	468
Ocean	marine, ocean*, EL-NINO, ENSO, sea-level	529
Continental water	rainfall, precipitation, snow, *water (exclude seawater), glacier*, hydrolog*, rive, lake	1095
Biomass & Biodiversity	species, biomass, biodiversity, wildlife*, animal*, bird*, insect*, plant*, vegatat*, tree*	1364
Terrestrial ecosystem	ecosystem (exclude marine ecosystem), conservation, grassland, forest, desert, basin, national park	989
Agriculture	agricultur*, crop*, vegetable*, farm*, food	474
Natural disaster	drought*, flood*, disaster*, hazard*	257
Energy	energ*, solar, nuclear, biofuel	256
Socio-economic perspective	governance, polic*, polit*, econom*, health*, povert*, livelihood, settlement	517
Impact	impact*, influence, effects	624
Adaptation	adapt*, mitigat*, response*	749
Vulnerability	vulnerab*, risk*, extinct*, uncertain*	533

Fig 5. shows the change in the proportion of research on each subtopic in 6 different periods from 1990 to 2019. In general, climate change research in South Africa kept diversifying over

the last 30 years. In the 1990s, over 90% of research on climate change is associated with atmosphere, ocean, continental water, biomass & biodiversity and terrestrial ecosystem issues, implying that the research in this period mainly focuses on ecosystem and the natural world. After 2000, the shares of research on continental water, biomass & biodiversity and terrestrial ecosystem are still salient, but the proportion of research related to atmosphere and ocean decrease significantly. In the 21st century, research concerning agriculture, renewable energy and socio-economic perspective emerges and the share grows stably by year. The increasing publications ratio signifies more focus on climate change research have been shifted from nature to the anthropocentric world, such as agriculture production, food security, economic activity, public health, as well as shifted to apply technology and smart policy to tackle climate change issues. Likewise, the share of research on natural disaster sustains a stable growth after 2000, suggesting the increasing frequency and intensity of extreme weather events and natural hazards induced by climate change has raised scientific concerns.

While the abovementioned subtopics can be classified into the first category regarding the objects affected by climate change, the topics associated with impact, adaptation and vulnerability are classified into the second category, which considers climate change as a fact and is oriented to address the impacts and the possible solutions (Haunschild et al., 2016). In general, the share of research on this category increases rapidly from less than 6% in the 1990s to over 25% in the recent 5 years. More specifically, the proportion of climate change impact research grew significantly in around 2000, followed by a visible growth of research proportion on climate adaptation and vulnerability researches between 2005 to 2009. In the recent decade, the shares of research on impact and vulnerability remain unchanged, while the research concerning climate change adaptation expands steadily. The tendency signifies researchers in South Africa are inclined to probe the impact and identify ways to cope with the changing climate proactively.

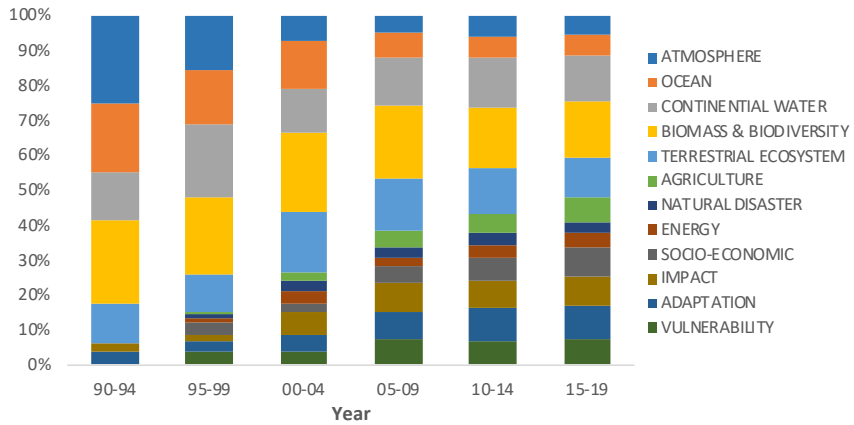


Fig 5. Comparison of research on climate change subtopics in the 6 different periods.

5.4 Leading authors on climate change study

Fig 6. outlines the top 10 contributing authors in South Africa in the climate change research with the fractionalized count of the number of publications. The brackets behind the name show the affiliation the author currently belongs to. The productivity of these 10 leading authors accounts for 3% scientific publications among all the 16,006 authors. Chown S is the most productive author in climate change research field in South Africa, who has engaged in climate change research since 1990 with 36.3 publications far ahead of the others. He maintained a robust and evenly distributed productivity over the last 30 years and is still active in the research field. Likewise, Midgley G, Jury M and Meadows M started involving in climate change research in the 1990s and have maintained a relatively high scientific output since then. They contributed to climate change research with 17.4, 14.1 and 13.5 publications ranking behind Chown S. Terblanche J, Winkler H, Grab S and Abiodun B become the main contributors to the development of climate change research in the 21st century, especially Abiodun B, who has retained more than 2 annual publications for three consecutive years since 2017, becoming the most productive author recently. Schulze R and Tyson P are the significant promotors in climate change research at an early age with totally 11.4 and 10.7 publications, although they have been gradually faded out the stage in recent years.

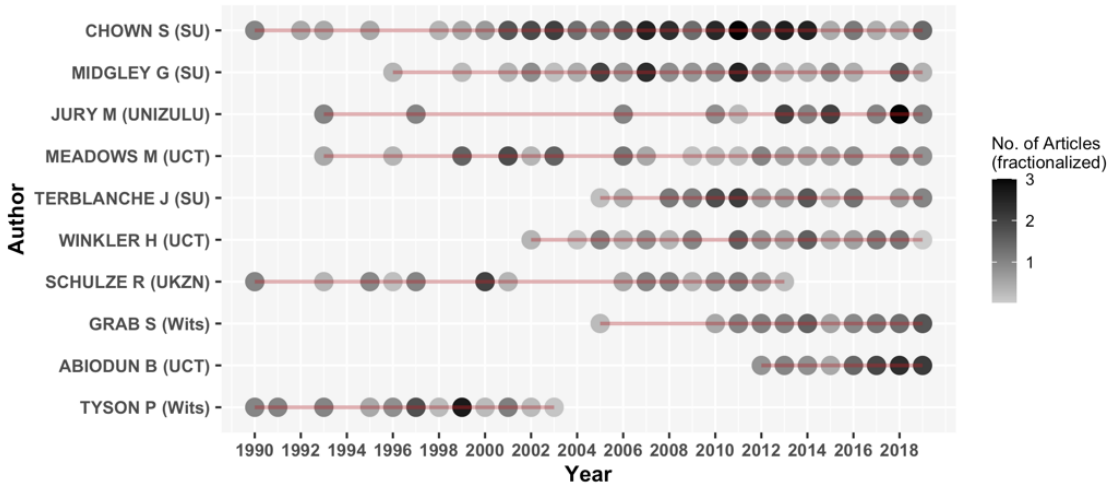


Fig 6. Top 10 production author on climate change research in South Africa. *The productivity of author is ranked with a fractional count of publication from top to bottom. The affiliation that the author currently belongs to is indicated in the brackets right after the name. A dot indicates the author published papers in that particular year. The deeper color the dot, the higher number of publications.*

Subsequently, I visualized the 10 leading authors in each climate change subtopic, as displayed in Fig 7. As we can see, Chown S and Midgley G have a broad spectrum of research interests. The research domain of Chown S is associated with oceanic issues, continental water, biodiversity and ecosystem, and after 2000, he started addressing climate change impact and adaptation in his research. Similarly, since 2002, Midgley G has paid attention to climate change impact, adaptation mitigation and vulnerability on top of his domains regarding ecosystem, biodiversity and atmospheric CO_2 in his publication. In general, the research domain of the top 10 authors in climate change research overall cover almost all aspects of climate change topics, except for the topic related to agriculture and socio-economic

perspectives. Ziervogel G is the one involving in these two subfields, who dip into climate change and agriculture issues from 2004 to 2015 and has shifted her attention to the topics related to climate governance, justices and policies since 2010. She is also a significant contributor in climate change adaptation and vulnerability research fields.

Fig 7. Leading author in each subtopic of climate change in South Africa. *Each block displays the top 10 leading authors in one research subtopic. (a) Atmosphere; (b) Ocean; (c) Continental water; (d) Biomass; (e) Ecosystem; (f) Agriculture; (g) Natural disaster; (h) Energy; (i) Socioeconomic; (j) Impact; (k) Adaptation; (l) Vulnerability.*

5.5 Conclusion on hypotheses 1 and 2

The results in this section are in line with the hypotheses 1 and 2 that the climate change research in South Africa have diverged in the past decades and more attentions have been shifted to anthropogenic climate change in recent years, such as the topics related to agriculture, renewable energy and socio-economic perspective. The share of research on climate adaptation grows from less than 3% to over 10%。

6. Scientific performance of the research institutions

In this section, I am going to proceed the research through evaluating the scientific performance of research institutions in South Africa in climate change research. By indexing the research affiliation in the database, 32 research institutions (in this study, research institution is the generic term of university, government agency and ministry) in South Africa, including 23 universities, 6 government agencies and 3 government ministry, were found to be active in the climate change research field during the period from 1980 to 2019.

6.1 Comparison of the scientific impact and citation of the research institutions

Fig 8. Compares the relative scientific publication and impact of the 32 research institutions in the 40-year timespan. The affiliation of the institution is separated by colour. Universities are filled with green, government agents are marked with red and the government ministries are coloured with yellow. The values are computed with fractional counts of publication and citation and normalized by the country average. UCT stands out among others in scientific publication and the impact, both of which are almost two times higher than the second-highest institution. SU, UP, Wits and UKZN also exhibit a remarkable scientific capacity with the relative publication index clustering over 3.4 and the relative citation index situating above 2.9, suggesting the scientific capacity of these institutions, together with UCT, are far superior to the country average. What is more, with 5 out of 32 research institutions taking up 65.6% of the total publication and 71.0% of the total citation, the scientific capacity in South Africa demonstrates an uneven distribution across research institutions. Despite a relatively small number of publications, the publication revealed by SANBI has a commendable scientific impact, which implies SANBI have been dedicating on producing high-quality papers on climate change. Similarly, concerning the cluster with small amount of publication and impact, as shown in the inner figure, under the comparable publication volumes, the government agencies and ministries perform better in terms of scientific impact than universities.

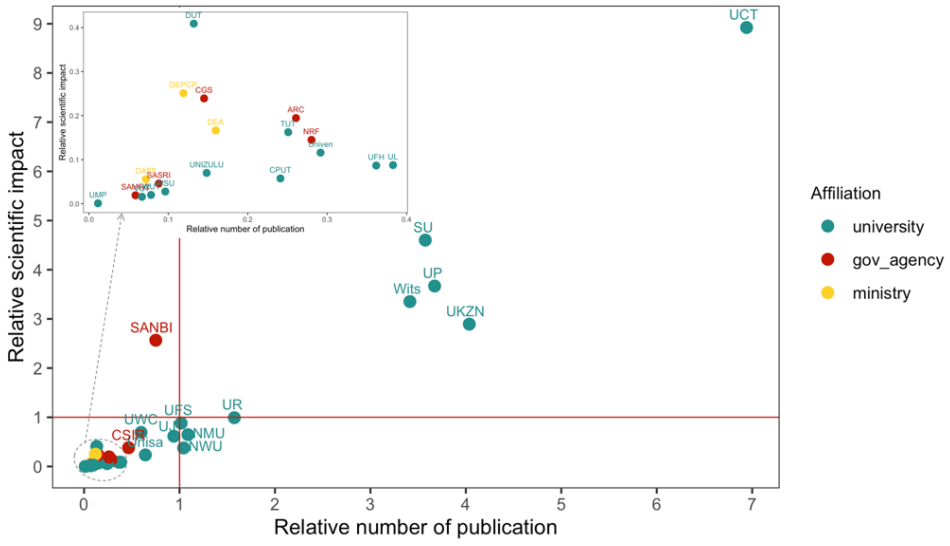


Fig 8. Comparison of scientific publication and impact of research institutions in South Africa from 1980 to 2019. *The x-axis shows a relative index of publication, with the red vertical line implying the country average publication. Institution exceeding*

the line indicates a higher number of publications than the country average, and the one falling behind the line is inferior to the country average. A similar explanation can be applied to the y-axis. Each circle represents a research institution. The affiliation of institutions is distinguished by colour. Universities are filled with green, government agencies with red, and government ministries with yellow. The inner graph is a zoom in on the small publication and impact cluster.

Fig 9. Shows the comparison of the scientific performance of the 32 research institutions in the recent 5 years. In general, the scientific performance of universities is better than governmental research institutions (both government agency and government ministry). The performance of UCT, SU, UP, UKZN and Wits are still prominent, and meanwhile, NMU, UR, UJ and NWU catch up, with both publication and citation amount exceeding country average. On the contrary to the rapid development of the university in climate change research, none of the governmental research institutions performs above the country average. CSIR grew up beyond SANBI and became the most contributed governmental institutions in climate change research in the near 5 years.

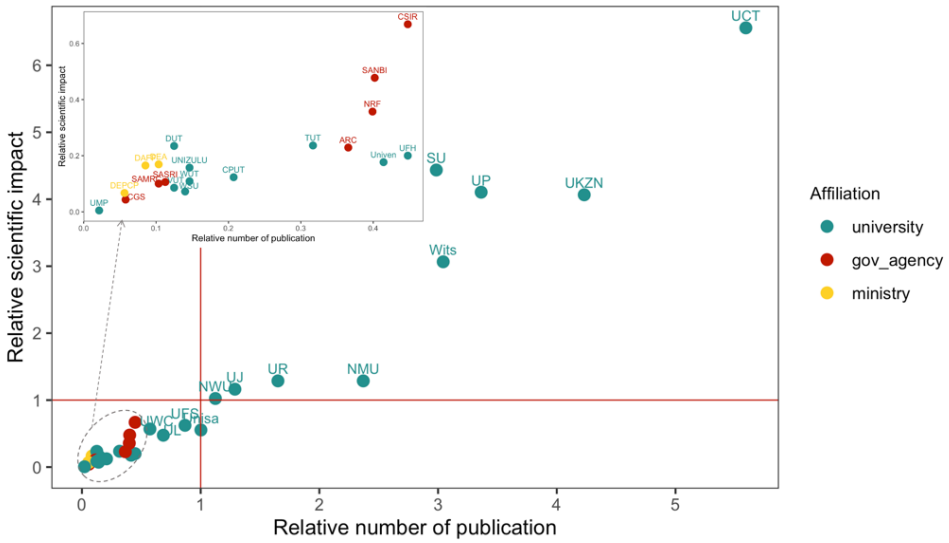


Fig 9. Comparison of scientific publication and impact of research institutions in South Africa from 2015 to 2019. *The x-axis shows a relative index of publication, with the red vertical line implying the country average publication. Institution exceeding the line indicates a higher number of publications than the country average, and the one falling behind the line is inferior to the country average. A similar explanation can be applied to the y-axis. Each circle represents a research institution. The affiliation of institutions is distinguished by colour. Universities are filled with green, government agencies with red, and government ministries with yellow. The inner graph is a zoom in on the small publication and impact cluster.*

From the assessment of the overall performance of research institutions involved in climate change research, nine universities are identified as the leading institutions in climate change research field in South Africa, with both publication and impact exceeding the country average. In this step, I probe into the research profile of these nine leading institutions by exploring the research focuses and strengths of these institutions. Fig 10. provides an insight into the scientific performance of the top nine institutions in each climate change subtopics from 2015 to 2019. These leading institutions are characterized by diverse interests and strengths in the climate change research field. Not surprisingly, UCT has strong scientific capacity in all the subfields of climate change, with the research associated with oceanic issues and socioeconomic aspects the most prominent. UP also shows a solid performance in the majority of research subfields, and has a remarkable volume of publication and scientific influence on the topics related to energy, atmospheric issues, agriculture and climate change adaptation. It

is noteworthy that papers published by SU have a relative high scientific influence presented by a steeper slope compared to the others. Ecosystem, atmosphere, biomass and biodiversity, impact, adaptation and vulnerability are the advantage fields of SU, which suggests that the climate change research in SU are inclined to address impacts on the natural world. The climate change research is polarized in UKZN, with agriculture the most influential and ocean issues far lagging behind. The research strengths of Wits range from natural disaster management, vulnerability, impact and continental water issues. UJ, NMU, UR and NWU are the emerging institutions in climate change research in the recent 5 years. Topics related to vulnerability, energy and nature disaster are the priorities in UJ. The oceanic issue is the strength of NMU and UR, and natural disaster induced by climate change is the research priority in NWU. Besides of these nine leading universities, UL has advantageous in climate-related natural disaster and energy topics, and Unisa outperforms other institutions in agriculture and energy research fields (Appendix A).

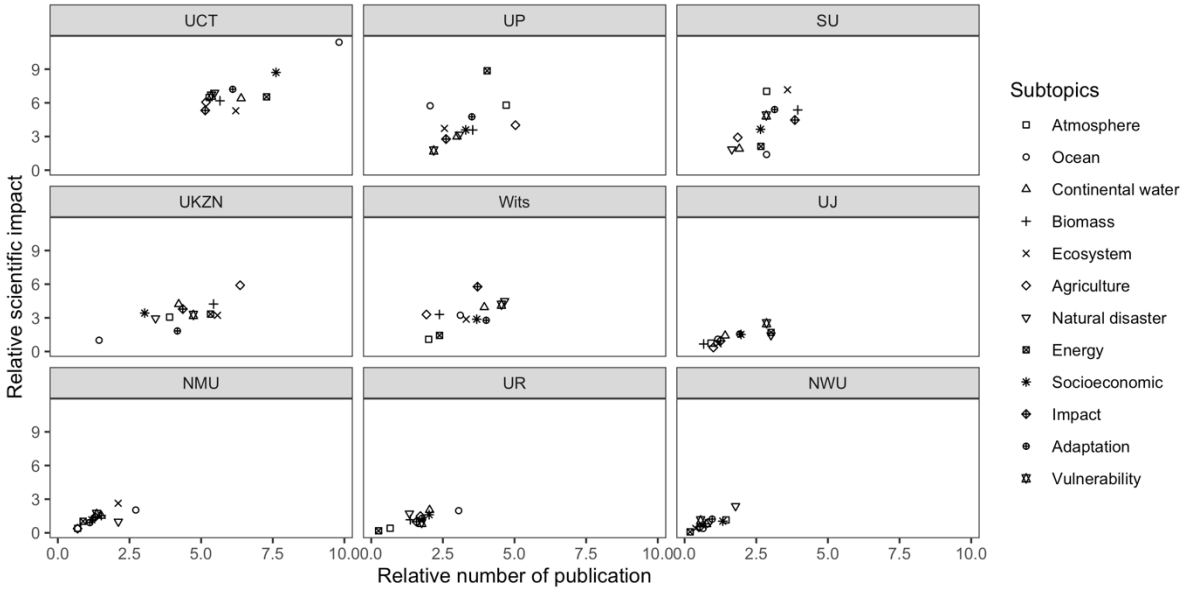


Fig 10. Scientific performance of the top nine institutions regarding each subtopic of climate change field. *Each small block represents a research profile of one institution, and the subtopics are labelled by different shapes.*

6.2 Conclusion on hypothesis 3

The results in this section support the hypothesis 3. In general, universities have better scientific performance than the government agencies and ministries in terms of publication volume and scientific citation. UCT, SU, UP, UKZN and Wits have maintained remarkable scientific capacities on climate change study since 1980, and NMU, UR, UJ and NWU catch up in the recent 5 years. These nine leading institutions are characterized by diverse interests and strengths in the climate change research field.

7. Linking knowledge evolution to the climate policy

7.1 Climate change policy in South Africa

The objective of this step is to understand the climate policy in South Africa. Figure 11 summaries a framework of climate change policy in South Africa. Before the 2010s, the majority of climate and environmental policies in South Africa are developed merely concerning natural and biodiversity protection, and a lack of coherent regulatory integrating economic, social and environmental perspectives to address climate and environmental issues (OECD, 2013). As a result, only a small part of ecological hotspots had been well-preserved, and most areas, especially those with frequent human activities, had suffered from severe environmental degradation (OECD, 2013).

The country's attention on establishing climate-resilient and low-carbon society has raised remarkably since 2011 when the National Climate Change Response Policy 2011 (NCCRP) was published, and since then, policy documents, legislation and regulations concerning multiple aspects of climate change were gradually put forwards. The NCCRP report identified short- and medium-term adaptation interventions. Agriculture and forestry, health, human settlements, water and biodiversity are prioritize as the sectors that need to take immediate adaptation actions soon. The report also initialized a list of Near-Term Priority Flagship Programs, including water conservation and demand management, renewable energy, energy efficiency and demand management, transport, wastes management, and carbon capture and sequestration, which covers both climate change adaptation and mitigation measures (DEA, 2011a). In the same year, the National Strategy for Sustainable Development and Action Plan (NSSD1) 2011-2014 was published. It is formulated to support the implementation of the National Framework on Sustainable Development (NFSD), which aims at pushing forward the effective allocation of South Africa's social, economic and natural resources, and promoting the country to achieve sustainable development (DEA, 2002). In the NSSD1, five strategic priorities were identified within the context of sustainable development, among which "Responding effectively to climate change" is one of the five priorities. More specifically, the NSSD1 listed out the overall specific goals under this priority:

> *"1) Decrease greenhouse gas emissions to levels required by science/in line with Cabinet-approved targets – with particular emphasis on the energy sector, which accounts for over 70% of South Africa's emissions;*
> *2) Reduce dependency on fossil fuels and enhance security of electricity supply;*
> *3) Build resilience to climate change in communities;*
> *4) Ensure ecosystem resilience is not disrupted."* (DEA, 2011b)

In 2012, the cabinet approved the National Development Plan (NDP), which set up a goal for the country to eliminate poverty and reduce inequality by 2030 (NPC, 2012). The NDP is closely aligned to the Sustainable Development Goals (SDGs) with achieving environmental sustainability – an equitable transition to a low-carbon economy being an essential part of the

national development plan (NPC, 2012). More specifically, the NDP stated that the country needs to enhance the resilience of people and economy to climate change, and reduce greenhouse gases emission by improving electricity production and energy efficiency (NPC, 2012). The plan also encourages the development of greener technologies and servers, such as renewable energy technologies, with the hope of building up economy-wide society and creating jobs in niche markets (NPC, 2012). The most recent national report related to climate change is the SDGs country report 2019, which addressed that devasting natural disasters caused by climate change is one of the most severe problems faced by South Africa. The report states that South Africa has suffered from a variety of climate-related natural disasters such as drought, flooding, extreme storms and fires over the few decades, and the intensity of these disasters is projected to be upscaled in the future (SSA, 2019). The climate-related disasters have generated adverse impacts on multiple aspects of the society including destroying infrastructure and ecosystem, accelerating water shortage, rising food insecurity and declining public health. To tackle the foreseeable and unavoidable impacts in the future, the report suggests the governments at national, provincial and municipal levels should develop hierarchical disaster management plans and should work together to take urgent actions to respond to the climate-related hazards, making efforts to build up climate-resilient society (SSA, 2019).

Besides of these overarching policy documents, other documents concerning multiple sectors of climate change were put forwards. The following paragraphs outline the policy consideration on the prioritized sectors identified by NCCRP, namely agriculture, socio-economic (health and human settlement), water and biodiversity, alongside with energy and disaster management sectors, which are the sectors with high policy advocacy.

Agriculture

DAFF formulated Agricultural Policy Action Plan (APAP) in 2014, wherein promoting climate-smart agriculture was put forwards in regards to the unsatisfactory and inappropriate agricultural practices and the vulnerability of farming activities to the changing climate. Organic farming, agroecology and conservation agriculture are identified as the ways to approach the climate-smart agricultural practice (DAFF, 2014). In 2018, the National Climate Smart Agriculture Strategic Framework (NCSASF) is drafted by the experts from DAFF, together with experts from DEA, farmers, researchers and other development partners. The framework is developed with the realization of the severe impact of climate change on agriculture production-related issues, such as the changes in vegetation types, the decline in natural resources, the degradation in soil conditions and the spread of infectious diseases (DAFF, 2018). NCSASF states that the agriculture production in South Africa should be integrated with climate change mitigation and adaptation strategies, with the purpose of increasing productivity, enhancing resilience to climatic and weather shocks, reducing GHG emissions, and promoting the achievement of national food security (DAFF, 2018). The

framework calls for more researches and focuses on combining indigenous knowledge and local subsistence into the implementation of mitigation and adaptation strategies on smart agriculture production (DAFF, 2018).

Socio-economic

In 2014, the Department of health formulated National Climate Change and Health Adaptation Plan (NCCHA), which aims to provide a framework for health sector action towards the implementation of strategies identified in the NCCRP (DA, 2014). The plan outlines the main health and environmental risks induced by climate change: a) *heat stress*, which could lead to increased death rates from heart respiratory diseases; b) *natural disaster*, which results in massive life losses and injuries; c) *housing and settlements* become more vulnerable to the changing climate, and thus the poor housing quality and infrastructure becomes a health concern; d) *communicable diseases*, such as diarrheal diseases, typhoid fever and Hepatitis A & E, and *rodent-borne diseases*, become more widespread in the communities with poor water sanitation system due to the climate variation; e) *exposure to air pollution and respiratory disease* due to the intensified GHG emission; f) *non-communicable diseases,* including obesity, diabetes, hypertension and cardiac disease, are projected to increase as a result of the changing climate and polluted dwellings; g) *food insecurity, hunger and malnutrition*; h) *mental illness*, climate change is expected to be a significant threat to the mental health. To cope with the health and environmental risks, the plan proposes several urgent actions, including promoting integrated and cross-sectoral research, model and pilot climate change and health adaptation projects, and build up monitoring and surveillance system, etc. (DA, 2014).

Water

The National Water Resource Strategy (NWRS) was drafted by the Department of Water Affairs (DWA) in 2013 aiming to sustain an equitable, sustainable and secure access and use of water for a better life in the future. The NWRS proposed multiple strategies to ensure the sustainable water supply, including water conservation and water demand management, further utilization of groundwater, desalination, water re-use, rain water harvesting and treated acid mine drainage. Faced with climate change, the strategy raised concerns on the impacts of climate change on escalating country's water shortage and insecurity, and increasing the frequency of water-related hazards such as drought and floods. Thus it suggests the country should develop an adequate capacity for monitoring, detection and adaptation to ensure sustainable water supplies under the changing climate. The strategy also advocates for various research institutions including universities, colleges and universities of technology, to conduct researches on managing water resources for climate change (DWA, 2013).

Biodiversity & ecosystem

DEA and SANBI proposed a National Climate Change Implications for the Biodiversity Sector (CCIBS), which assess the impacts of climate change on South Africa's biodiversity from a

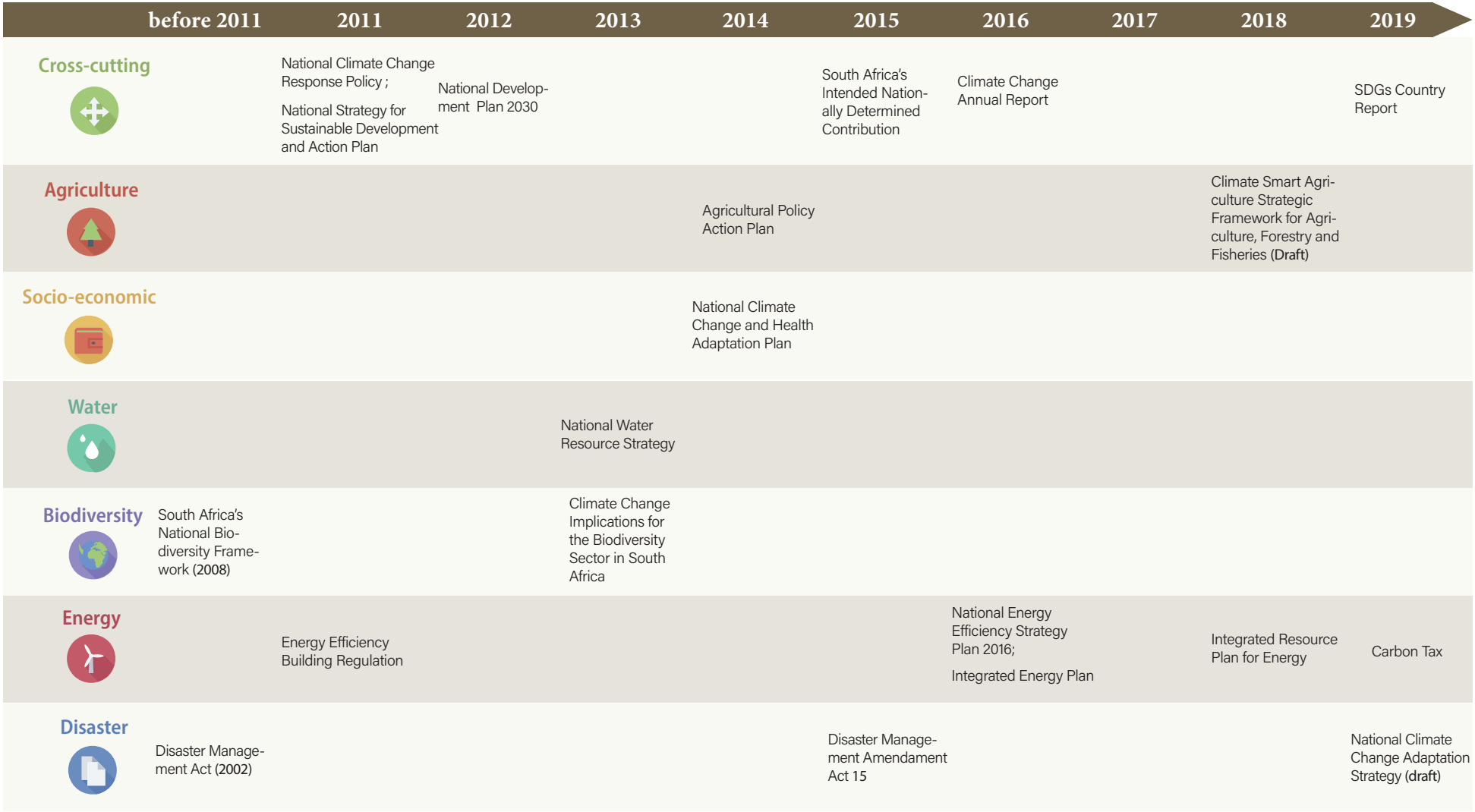
biome-based perspective. The report examines the vulnerability of the nine biomes (geographical areas consisting of several ecosystems with related species) in South Africa using climate models under different scenarios and concludes that the biodiversity in Grassland and Nama-Karoo will suffer from the most severs biomass loss, closely followed by Indian Ocean Coastal Belt, Fynbos and Forest (SANBI, 2018).

Energy

The National Integrated Energy Plan (IEP2016) is approved in 2016 as an extension of the National Energy Act, 2008. The purpose of IEP is to depict a roadmap for South Africa's future energy investment and policy development based on different scenarios (i.e. business as usual, resource constrained, environmental awareness and green shoot), by assessing the current energy consumption in all economic sectors, such as agriculture, industry, transport and residential, etc (DE, 2016a). The IEP specifically addressed that climate change is one of the determinants on the increase of energy consumption in the commercial sector, due to its effect on the number of cooling degree days in winter and heating degree days in summer. Among the four identified scenarios, green shoots is the most ambitious and promising one, which could result in high economic growth outlook and sustainable development path. The awareness of climate change and the orientation towards (renewable) energy mix becomes key imperatives in this scenario (DE, 2016a). In the same year as the release of IEP, the National Energy Efficiency Strategy Plan (NEESP2016) is developed to provide an updated framework to understand and monitor the energy efficiency in all economic sectors (DE, 2016b). In 2019, the Cabinet approved Integrated Resource Plan (IRP2019), which aims at further reducing the country's dependency on carbon-based fuel, and significantly promoting the usage of renewable energies, such as wind, solar and hydro energy (DE, 2019). In this same year, the law of Carbon Tax 2019 has been signed by the president, which aims at levying taxes for the companies and businesses that emit a high level of carbon and rewards the companies that take active actions to control the amount of GHG emissions, to reduce the over-reliance on fossil fuel and to apple cleaner technologies (GGSA, 2019).

Disaster management

In 2002, the national government approved the Disaster Management Act (DMA), which was formulated "to provide an integrated and coordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery" (GGSA, 2002). Following that, an amended version, Disaster Management Amendment Act (DMAA), was published in 2015, which take into account the measures of climate change adaptation to reduce the risk of natural disasters (GGSA, 2015). The SDGs country report 2019 further addressed the accelerating natural disasters events, including drought, flooding, extreme storms and fires, caused by climate change, and called for building up an alarming mechanism to prepare for the potential upscaling events in the future (SSA, 2019).



*Source: self-made, adopted from the policy reports (Averchenkova et al., 2019, RSA, 2019)

Fig 11. The climate change policy framework in South Africa.

7.2 Analysis of research-policy interaction

The analysis of the policy documents reveals that the majority of climate and environmental policies in South Africa are developed merely concerning natural and biodiversity protection before the 2010s. The publish of NCCRP in 2011 was a milestone of climate policy development in South Africa. Since then the climate policy documents concerning multiple sectors within climate change have been gradually formulated. Looking back to the scientific publications (Fig 5.), the research on climate change diversified a bit earlier than policy in around 2000, when a certain proportion of research focuses have been split to agriculture, energy, natural disaster and socio-economic subjects. However, it is too imprudent to conclude that scientific research has influenced policy decision based on the above observation. On the contrary, by tracing the references lists in the policy documents, we can see from Table 4. that a lack of scientific research (which are published by university) was cited when drafting the policy. For those scientific papers that were cited by the policy, some of them were published or co-published by the governmental agencies (e.g. SANBI and CSIR) and the ministry (e.g. DEA and DAFF). Appendix B shows the name of the scientific papers with policy mentions. The result verifies the hypothesis 5 that high-quality papers are more likely to catch policy attention. Furthermore, the South Africa's climate policies tend to cite the papers published in the world reputable journals, such as Lancet, and the papers published by the world authoritative organizations, such as WHO, FAO and IPCC.

Table 4. Citation analysis of the policy document

Published by		Policy citation count
University		12
South Africa's ministry		101
South Africa's government agency		9
Others (other national / international organizations)	Institute for democratic alternatives in South Africa	1
	World Health Organization (WHO)	5
	Food and Agriculture Organization (FAO)	3
	Intergovernmental Panel on Climate Change (IPCC)	6

In the following section, I will focus on analysing how scientific research corresponds to policy advocacy. With regards to the climate change prioritized sectors proposed in the NCCRP (water, agriculture and socio-economic), the proportions of the researches on agriculture and socio-economic aspects grow steadily in the recent 10 years, and the studies on water sustained its dominant role on climate change study. Energy and natural disaster sectors also become increasingly important in climate change study.

Agriculture

Figure 12. visualized the co-occurrence of keywords on agriculture sub-topic. The scientific research has realized the impacts of climate change on soil degradation and the decline in agriculture natural resources, especially water resources. And climate change adaptation,

resilience, mitigation and vulnerability are the main concerns in the agriculture research, which reflect the policy advocacy. Similarly, promoting national food security is simultaneously addressed in both scientific and political communities. However, as the policy calls for promoting climate-smart agriculture practices by applying organic farming, agroecology, conservation agriculture and indigenous knowledge into farming practice, scientific research has not yet been widely involved in these topics. The associated keywords such as climate-smart agriculture, indigenous knowledge, agro-ecosystem and conservation agriculture, are placed in the marginal positions in the map with small circles representing the low occurrence frequency. Only around twenty papers, which takes up around 4% in the agriculture sub-dataset, combine conservation agriculture, ten papers integrate indigenous knowledge into climate-smart agriculture study, eight papers deal with agro-ecosystem, and one single paper involves organic agriculture activities. Almost all the researches related to smart agricultural practices arose from 2014 when the APAP was published, suggesting the steering effect of policy on research development. Future research should continue investigating the utilization of climate-smart agriculture practices and indigenous knowledge to confront climate change.

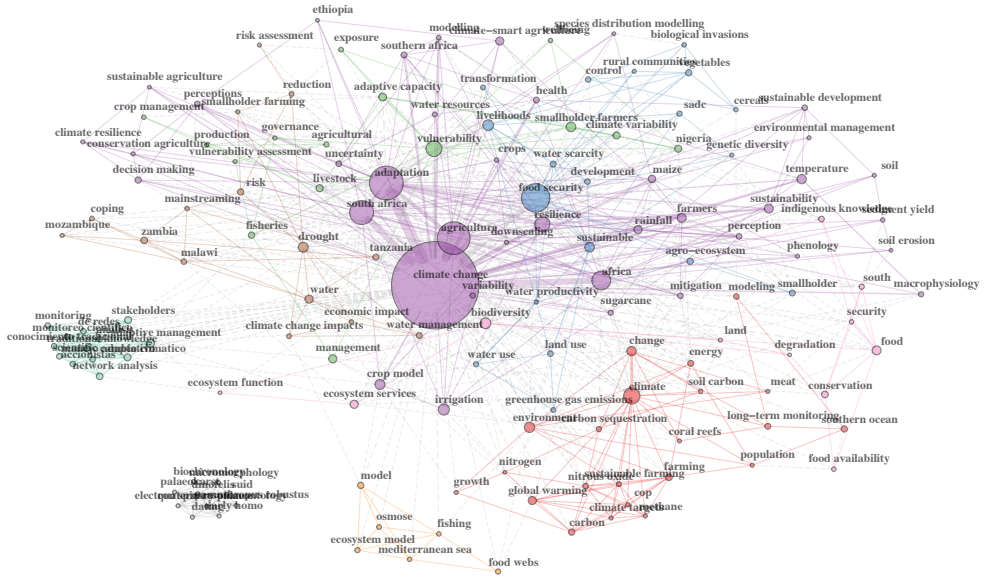


Fig 12. Keyword co-occurrence network of the agriculture sub-topic

Socio-economic

According to NCCRP, health and human settlement are the prioritized sectors on the socio-economic aspects when concerning climate change. The keyword co-occurrence analysis of socio-economic sub-topic (Fig 13.) reveals that the impact of climate change on the public health, more specifically on the diseases such as malaria and epidemiology, has been addressed in the scientific research. Moreover, the keywords *heat* and *temperature* are clustered together with health, implying the researches have noticed the influence of heat stress on human disease. These researches respond to some of the main health risks, such as heat stress, communicable diseases, proposed by NCCHA. It is worth highlighting that all these research appeared after 2010, signifying the importance of policy on steering and promoting scientific development. However, the researches on mental health, non-communicable diseases and malnutrition

induced by climate change are nearly absent, and although some researches addressed environmental health, a lack of research brought attention to the respiratory disease due to the increasing GHG emissions and the exposure to air pollution.

Compared to the health sector, researches focused on human settlement are scarce. The existing researches on the human settlement are associated with informal settlement due to the climate-induced natural disasters. Very few research on investigating the vulnerability of urban and rural settlement, as well as the way in improving living quality and infrastructure in the face of climate change, as advocated in the policy. The future researches are expected to shed more light on this area.

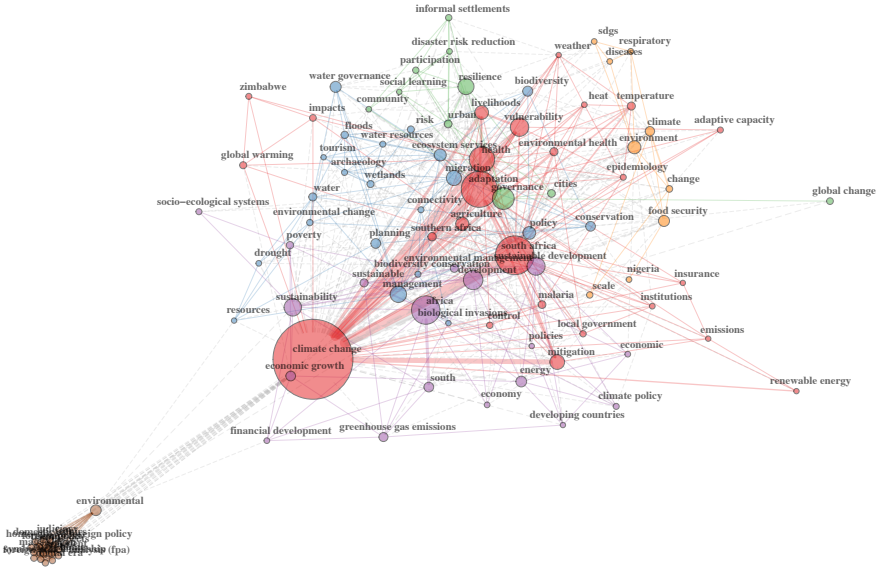


Fig 13. Keyword co-occurrence network of the socio-economic sub-topic.

Water

The policy on water sector suggests the country needs to take urgent actions to ensure national sustainable water supply, and calls for applying sustainable water supply strategies, including water conservation and water demand management, further utilization of groundwater, desalination, water re-use, rain water harvesting and treated acid mine drainage. It is observable from Fig 14. that a certain amount of researches have involved the topics related to national water security, water scarcity and water resources management, with the moderate-size circles of these keywords situating in the middle of the map. Besides, water-related hazards induced by climate change such as droughts (aridity) and floods are covered in the scientific studies, although the research on droughts is far more than floods. Some researches concern the impacts of climate change on rainfall variability, while a lack of research (less than 1%) dips into rainwater harvesting and rainwater re-use. Research on water desalination seems absent on climate change study.

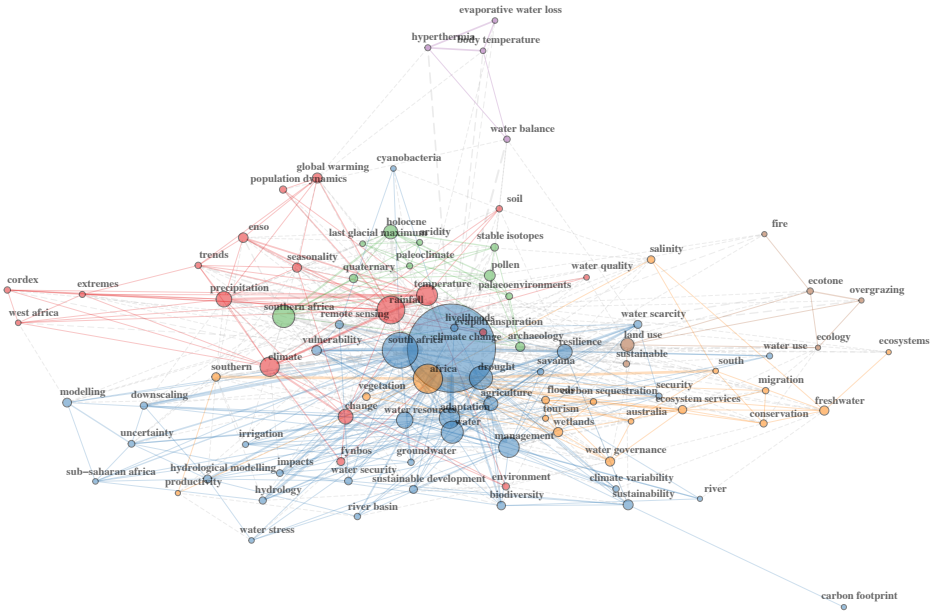


Fig 14. Keyword co-occurrence network of the water sub-topic.

Energy

In general, the share of research on the energy sector does not match the high policy advocacy on increasing energy efficiency and developing renewable energy. It is observable from Fig 5 that the study on renewable energy started late in South Africa and the share of research only took up 3.8% among the climate change study in the recent five years. More researches on climate change – energy nexus should follow up in the near future. Fig 15. shows the keyword map of the research on energy sub-topic. Among the publication dataset, five papers investigate hybrid energy systems, defined as the combination of various types of energy generation equipment including renewable energy sources (Nazari-Heris & Mohammadi-Ivatloo, 2018), which corresponds to the policy advocacy on orienting towards renewable energy mix society. Around 20% of papers in the energy sub-topic involve renewable energy. The occurrence of renewable energy is closely associated with technology and electricity generation. Different types of renewable energy are also studied individually, with bioenergy (also displayed as biofuel and biogas) attracted the most scientific attention, followed by solar energy and hydrogen. Very few research sheds light on wind energy. The green cluster in the map involves keywords related to energy efficiency, energy consumption and GHG emissions, which correspond to the policy concern on mitigating GHG emissions by increasing energy efficiency. However, the studies on exploring energy consumption and energy efficiency in different economic sectors (e.g. agriculture, industry, transport and residential) seem absent.

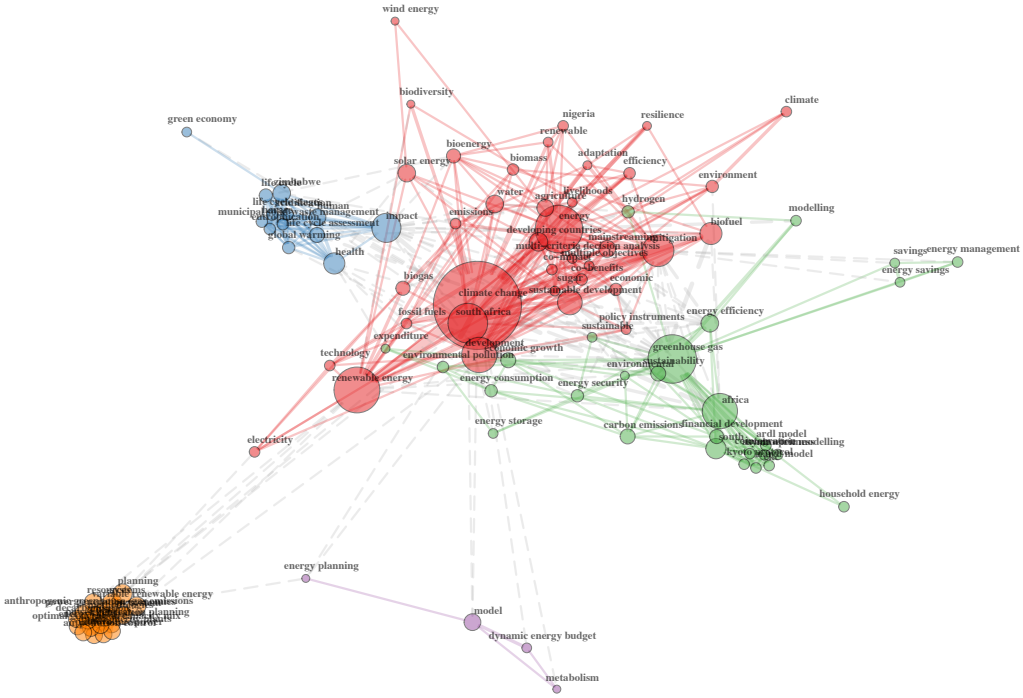


Fig 15. Keyword co-occurrence network of the energy sub-topic.

Natural disaster

Fig 16. shows the keyword map of the climate researches on natural disaster sub-topics. Drought is the research hotspot in regards to the climate-related natural hazards sector, which has the comparable size to the keyword climate change and has the strongest link to climate change, followed by flood. While the research on other natural hazards such as extreme events and fire disasters are relatively scarce. Although the researches have raised concerns on disaster risk reduction, a lack of research involves disaster monitoring and alarming mechanism. The research in this aspect is expected to catch up in response to the policy advocacy on building up a national emergency preparedness system.

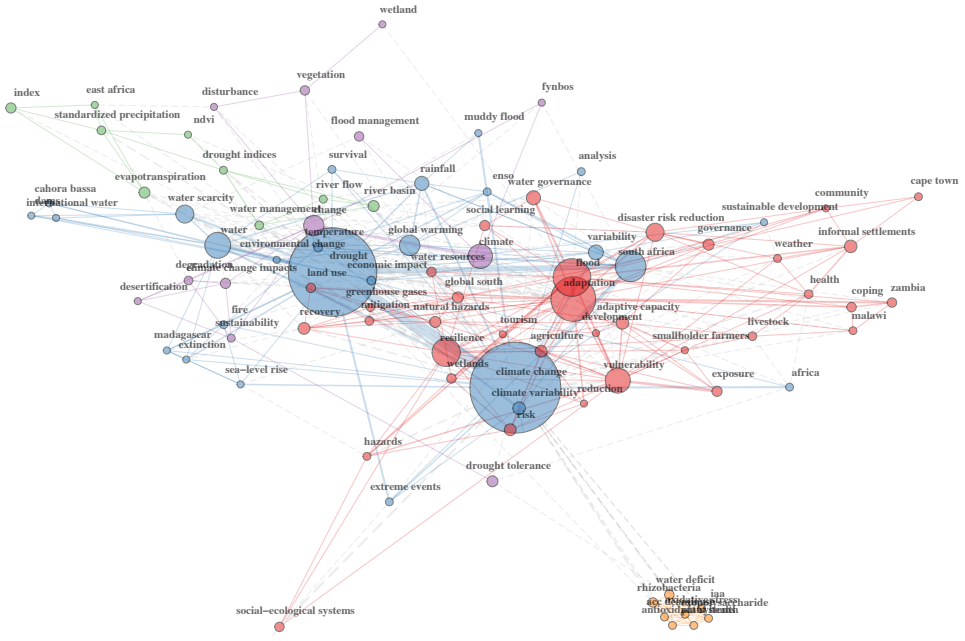


Fig 16. Keyword co-occurrence network of the natural disaster sub-topic.

7.3 Conclusions on hypotheses 4 and 5

The results in this section partly approve the hypothesis 4. The ministry cooperate tightly with government agencies in policy formulation. The policy documentary analysis and the keyword analysis of scientific publications in the prioritized subtopics show only a small amount of scientific papers have been cited by South Africa's climate policy. High-quality papers are more likely to catch policy attention. The implementation of policy could provide directions for scientific research, which is evidently reflected in the agriculture, socio-economic and energy subtopics.

8. Conclusion

The study aims to identify the dynamic of knowledge structure on climate change study in South Africa from 1980 to 2019 through keyword analysis and subtopic analysis, and examine the scientific performance of the main research institutions in South Africa. Following that, the research also tends to understand how the national climate policy strategies evolve to address SDGs, how the scientific research interact with policy, and to what extent are the knowledge evolution aligned with the national climate action priorities. The results show that the annual amount of publication increased dramatically from 1980 to 2019 and the growing tendency is likely to sustain in the future. The keyword co-occurrence analysis of the publication shows a significant shift in the research focuses on climate change study. Paleoclimate, greenhouse gases and oceanic issues are the main research focuses on climate change study in the 1990s, then the hotspots are shifted to biodiversity and ecosystem in the 2000s, and in the recent ten years, the research is inclined to address climate impact and adaptation. The subtopic analysis exhibits that in the recent 10 years increasing publication ratios have been split from the natural-related topics, such as biomass, terrestrial ecosystem and ocean, to the anthropocentric-related topics, such as agriculture, socio-economic activity, energy and natural disaster. The scientific performance analysis of the research institution shows that UCT, SU, UP, UKZN and Wits have maintained remarkable scientific capacities on climate change study since 1980, and meanwhile, NMU, UR, UJ and NWU catch up in the recent 5 years, with both publication and citation amount exceeding country average. The policy documentary analysis reveals that water, agriculture, health, human settlement, biodiversity, energy and natural disaster are the prioritized sectors in the national climate change action. The keyword co-occurrence analyses of these prioritized subtopics indicate that the implementation of policy could steer research development, which is evidently reflected in the agriculture, socio-economic and energy subtopics. While from the citation analysis of the policy documents, only few scientific papers have policy mention and no other sufficient evidence is found the influence of scientific research on policymaking. More qualitative research is expected to be conducted in the next step to reveal the mechanism of research-policy interaction.

9. Discussion

9.1 The research coverage of climate change in South Africa

The study examines the knowledge evolution of climate change study from 1980 to 2019 in South Africa. The results show that the volume of climate change research kept increasing and the research focuses kept diversifying over the last decades, especially after the 20th century. This tendency goes along with world climate change research development. Bhandari (2018) traced the development of climate (change) science from a historical perspective and concluded that since the publication of the first IPCC climate assessment report in 1990, climate change has been regarded as a global agenda. Following that the world climate change research began to accelerate in the 20th century (Bhandari, 2018). The change of South Africa' climate change publications productivity in Fig 2. shows that a sudden growth of publication amount happened in around 2006 and since then the annual publication has kept expanding steadily. Haunschild et al. (2016) examined the global climate change research evolution with title words and found that the sole term *climate* is the most prominent title word in around 1990s, and the term (*climate*) *change* dominates after 2000. They hence concluded that the term *climate change* comes towards with time when the climate researchers gradually realize global warming as a matter of fact (Haunschild et al., 2016). However, the keyword analysis in this study exhibit the keyword term *climate change* has always dominated among others since 1990s in South Africa's climate study. The salient position of the term *climate change* in the early years might be attributed to the certain proportion of research the SA taken among the world in the 1980s to 1990s.

The subtopic analysis in this study shows that although publications on biomass and terrestrial ecosystem have continuously taken up the largest proportion within climate change research, increasing share of publication has shifted from the natural climate research to the anthropocentric world over time, such as the topic related to agriculture production, socio-economic activity, energy and natural disaster. Also, the growing ratio on the climate vulnerability, impact and adaptation categories signifies the researchers in South Africa are inclined to probe the impact and identify ways to cope with the changing climate proactively. This finding is in line with Pasgaard & Strange (2013) that climate change research in the developing countries is inclined to address climate adaptation, human-induced impacts and social impacts. Fig 17. shows the position of South Africa' climate change research in the world regarding each subtopic. The figure shows that South Africa is relatively weak in atmosphere and energy subtopics compared to the world climate change research in terms of the publication volume, and has the advantage in biomass & biodiversity, natural disaster, agriculture and socio-economic subtopics. To fill up the research gap in energy and atmosphere subtopics, government intervention could be helpful. The ministry could relocate funding to those research institutions that have the advantage and sufficient knowledge bases in these research subtopics. For instance, to promote the development of energy subtopic, the ministry can

distribute more funding to UP, UCT, UJ UKZN to facilitate renewable energy research and innovation. Likewise, as UP, SU and UCT have exhibited advantage in atmosphere research subtopic, more funding can be relocated to them to support the research development.

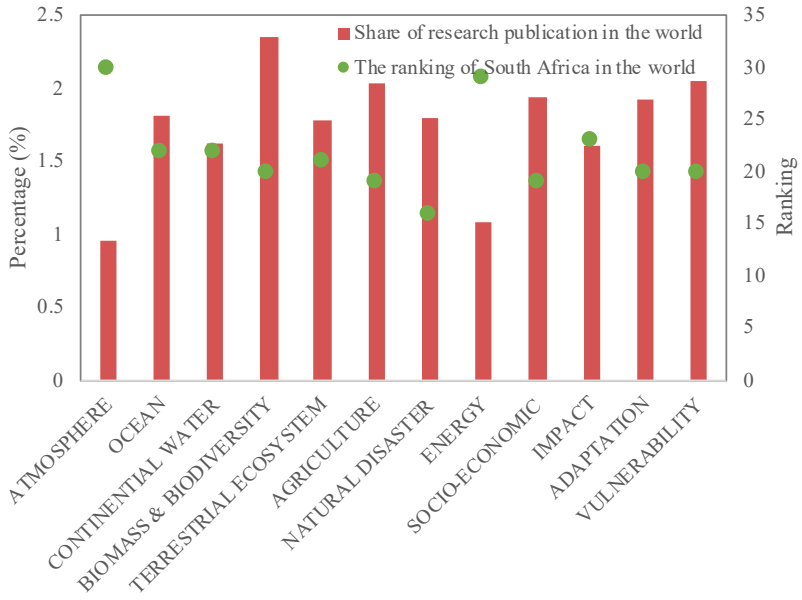


Fig 17. The position of South Africa' climate change research in the world in each subtopic

The policy documentary analysis provides a more clear and detailed picture of what research could be done within the prioritized subtopics and how the policy could potentially influence the direction of scientific research. The keyword analysis of the prioritized research subtopics indicates that the implementation of policy could steer research development, which is evidently reflected in the agriculture, socio-economic and energy subtopics. For instance, in the agriculture subtopic, research concerning smart agriculture practices with the associated keywords *climate-smart agriculture, indigenous knowledge, agro-ecosystem and conservation agriculture* appeared after 2014 when the APAP was published, although the research on this area is still scarce. Similarly, the research concerning public health induced by climate change with the keyword terms *epidemiology, heat stress* and *communicable diseases* arose in the 2010s when the NCCRP and NCCHA were formulated. Nonetheless, some aspects that are addressed in the policy document seem absent in scientific research. For example, the human settlement sector, which is one of the prioritized sectors identified in the NCCRP. Based on the observation in this study, very few research has been conducted to investigate the vulnerability of urban and rural settlement, as well as the way in improving living quality and infrastructure in the face of climate change. In regards to the water subtopic, a lack of research was found to be related to rainwater harvesting, rainwater re-use and water desalination, as advocated in the policy. In terms of the natural disaster subtopic, the research focuses haven been unevenly titled towards drought and flooding hazards, and a lack of research was found concerning other natural hazards such as extreme events and fire disasters. The future researches are expected to shed light on these understudied areas.

9.2 Recommendations on further promoting research-policy interaction

In the previous section, I discussed what needs to be addressed on climate change study in South Africa in the future based on its position in the world climate change research and the finding from the policy documentary analysis. However, it should be kept in mind that the communication between research and policy communities is not a one-way direction. The most current research-policy interaction model addresses the negotiation process between the two communities, and indicates the research community can add the legitimate argument to political action (Jones, 2009). According to the scientific citation analysis on the selected policy documents in this study, a lack of scientific paper is used in the policy decision making. The result suggests more efforts should be made in both research and policy communities to promote the knowledge utilization in the policymaking.

Bornmann (2013) who traced the citation of climate change research in the world policy-related documents, raised the similar concern that only very low coverage of climate change literature (only 1.2%) have at least one policy mention. He further revealed that the papers published in the most prominent journals Science and Nature have comparatively higher frequency to be cited by the policy documents. This finding implies the policymakers in South Africa can look for scientific support from the papers with a high scientific citation or the papers published in the reputable journals. To measure the research citation in the policy, Bornmann (2013) used a platform called Altmetrics, which is a start-up company monitoring scientific mention in a range of sources, including policy documents, news, blog, Twitter, etc. (Bornmann, 2013). I originally wanted to use this platform to measure the research citation in the climate policy document in South Africa, however, the platform scaled back the access to it due to the Coronavirus. Therefore, the citation analysis in this study is done by going through all the reference lists and finding out the cited scientific papers. This way might miss out plenty of papers as only the selected policy documents are examined. The other climate-related policy documents that are not considered as the priorities in this study are excluded in the researched scope. Future research could use the Altmetrics to do a more precise research citation analysis when the tool is accessible.

Although research citation in policy documents can provide straightforward information on how scientific research supports policy formulation, it should be pointed out that assessing research mention in the policy-related documents is just the initial attempt and the simplified way to understand the scientific research influence. This approach should be combined with other qualitative and quantitative methods to examine the interaction. Documentary analysis and in-depth interviews are the two most commonly used qualitative methods. Elliott & Popay (2000) used literature review and case study together with qualitative methods including document analysis and in-depth interviews to identify the factors that facilitate or impede research utilization on policymaking in the UK National Health Service. Other methods, such as questionnaires to researchers and policymakers, insider knowledge, media analysis and

secondary sources review are also commonly applied by researchers to examine the knowledge utilization on policymaking in the previous studies (Lavis et al., 2002; Phoolcharoen, 2002; Hanney et al., 2003).

Several studies revealed the determinants of the research utilization on political decision making. The intent of researchers is the primary element, which reflects the willingness of researchers to generalize and report their results to the policymakers (O'Neil, 2005). Following the interaction or engagement between researchers and policymakers (Lavis, 2006; O'Neil, 2005). Timeliness is another essential consideration of the efficiency of knowledge translation. Besides, the expertise and capacity of policymakers could also determinate the knowledge translation to a large extent (Lavis, 2006; Elliott & Popay, 2000). Financial constrain is the last consideration of the research utilization (Elliott & Popay, 2000). These empirical findings could provide South Africa's climate policymakers and researchers a guideline to make efforts to promote knowledge utilization. In the future, efforts can be made through organizing a regular interactive workshop, researchers providing systematic literature reviews on the specific research domain, holding education program for policymakers and researchers working in partnership with policymakers and so on (Lavis, 2006).

9.3 Limitation and recommendations for future research

There are a few limitations in this study. The first bias comes from the nature of tropical searching in the WOS, which searches the keyword queries in title, abstract and keywords of the publication. Publication retrieved in this way might result in a certain amount of irrelevant papers that only introduce climate change as background information rather than literally tackling climate change issues. Leng et al. (2016) suggested using the keyword as the topical searching index could bring to more precise result. Similarly, Haunschild et al. (2016) used the title word as the topical searching index for the bibliometric analysis of global climate change research. It is undeniable that the use of keyword or title word could bring about more precise retrieval, but it also excludes substantial relevant papers. A promising way might be using tropical searching to construct a preliminary database, and then excluding the irrelevant papers manually with the in-house technique. But the downside of this way is time-consuming. The second bias comes from the database selection. In this study, I used the WOS database for bibliometric analysis, which means the publications not meeting the standard of Thomson Reuters are excluded in the analysis (Reuters, 2012). Hence, this data selection method exclude some kind of knowledge, especially those oriented towards local climate change studies or written in the domestic language (Pasgaard & Strange, 2013). The third bias is associated with policy documentary analysis. Due to the time limit, the study is not able to browse all the related policy documents on climate change and its subtopics. The selection of policy documents is based on the previous researches and the documents posted in the government websites. The policy documents mentioned in this research might not be able to reflect the whole policy concerns on climate change. Lastly and perhaps most importantly, the research

fails to identify a clear mechanism of the research-policy interaction on the climate change research in South Africa. The analysis in this study is simply proceeded by the citation analysis of the policy documents. Research on applying other qualitative methods such as experts interview and questionnaires to study the interaction is expected to follow up in the future. In terms of the research methods and theories on investigating the research-policy interaction, one can refer to the paper written by Hanney et al. (2003), which provides a nice summary of the models and methods for the assessment. Also, this paper identifies South Africa's top 10 authors, both in the general climate change study and in each subtopic (Fig 6. and Fig 7.), which can be the potential contact list to collect expert opinion from the scientific community side.

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Appendix A

Table 5. Scientific performance of research institutions regarding each subtopic (relative score)

Research Institution	total publication_relative_1519												total citation_relative_1519											
	adaptation	agriculture	atmosphere	biomass	conwater	ecosystem	energy	impact	nature_disaster	ocean	socioeconomic	vulnerability	adaptation	agriculture	atmosphere	biomass	conwater	ecosystem	energy	impact	natural_disaster	ocean	socioeconomic	vulnerability
UCT	6.10	5.17	5.28	5.66	6.40	6.21	7.28	5.14	5.47	9.81	7.61	5.36	7.21	6.06	6.48	6.18	6.40	5.29	6.53	5.32	6.90	11.40	8.71	6.64
SU	3.14	1.85	2.86	3.95	1.91	3.59	2.66	3.85	1.65	2.86	2.65	2.85	5.40	2.92	7.03	5.36	1.91	7.16	2.12	4.47	1.85	1.39	3.64	4.87
UP	3.51	5.03	4.71	3.54	2.99	2.55	4.04	2.61	3.07	2.05	3.30	2.18	4.76	4.01	5.79	3.58	2.99	3.72	8.86	2.77	3.17	5.74	3.59	1.75
UKZN	4.17	6.36	3.90	5.43	4.22	5.57	5.33	4.36	3.41	1.44	3.03	4.73	1.83	5.90	3.06	4.23	4.22	3.22	3.33	3.78	2.96	1.00	3.42	3.26
Wits	4.01	1.93	2.00	2.38	3.95	3.31	2.38	3.71	4.66	3.11	3.68	4.54	2.78	3.29	1.08	3.30	3.95	2.88	1.43	5.78	4.51	3.23	2.88	4.17
UR	1.77	1.72	0.66	1.36	2.04	1.76	0.26	1.58	1.33	3.05	2.02	1.76	1.29	1.49	0.41	1.16	2.04	1.05	0.18	0.99	1.72	1.97	1.61	0.88
NMU	1.12	0.69	0.69	1.52	1.51	2.10	0.88	1.30	2.11	2.72	1.19	1.35	0.91	0.38	0.40	1.54	1.51	2.63	1.03	1.42	1.00	2.03	1.16	1.68
UJ	1.92	1.00	0.92	0.66	1.41	1.17	3.02	1.25	3.01	1.16	1.97	2.86	1.56	0.35	0.75	0.67	1.41	0.69	1.70	0.95	1.45	1.10	1.52	2.51
UFS	0.41	1.04	1.17	0.83	0.92	0.57	0.00	0.57	0.64	0.22	0.25	0.63	0.61	1.37	1.51	0.44	0.92	0.38	0.00	0.67	1.68	0.08	0.21	0.37
NWU	0.96	0.81	1.44	0.72	0.77	0.39	0.19	0.54	1.78	0.64	1.33	0.56	1.23	0.87	1.15	0.80	0.77	0.39	0.09	0.54	2.39	0.39	1.04	1.11
UWC	0.11	0.09	0.25	0.56	1.08	1.05	0.41	1.19	0.21	1.07	0.45	0.64	0.06	0.04	0.09	0.17	1.08	0.44	3.25	0.61	0.24	0.79	0.38	0.22
SANBI	0.51	0.11	0.29	1.06	0.32	0.54	0.00	0.28	0.77	0.34	0.31	0.46	0.86	0.07	0.38	1.25	0.32	0.68	0.00	0.85	1.48	0.35	0.30	0.95
Unisa	0.72	1.32	1.30	0.60	0.78	0.35	1.60	1.35	0.77	0.47	0.98	1.04	0.81	1.56	0.68	0.22	0.78	0.07	1.94	0.71	0.14	0.17	0.97	1.04
CSIR	0.61	0.13	0.45	0.81	0.63	1.02	0.00	0.66	0.00	0.62	0.35	1.09	1.36	0.07	0.37	1.26	0.63	1.80	0.00	0.43	0.00	0.27	0.30	2.09
Univen	0.52	0.47	0.51	0.39	0.50	0.17	0.00	0.32	0.30	0.22	0.38	0.69	0.24	0.18	0.15	0.18	0.50	0.07	0.00	0.11	0.31	0.07	0.23	0.15
UL	0.99	0.84	1.86	0.94	0.58	0.33	1.54	1.13	2.13	0.65	1.08	0.44	0.44	1.14	1.53	0.35	0.58	0.14	1.10	0.63	1.57	0.37	0.86	0.23
UFH	0.97	0.93	1.17	0.37	0.25	0.10	0.00	0.54	1.33	0.02	0.88	0.74	0.44	0.29	0.00	0.00	0.25	0.09	0.00	0.16	1.33	0.01	0.22	0.19
NRF	0.23	0.33	0.57	0.78	0.23	0.68	0.00	0.97	0.10	0.57	0.02	0.14	0.17	0.25	0.33	0.74	0.23	0.89	0.00	1.32	0.27	0.35	0.04	0.13
DEA	0.00	0.00	0.01	0.10	0.02	0.26	0.00	0.03	0.00	0.27	0.29	0.08	0.00	0.00	0.00	0.30	0.02	0.13	0.00	0.01	0.00	0.48	0.11	0.01
TUT	0.15	0.22	0.29	0.28	0.53	0.33	2.31	0.60	0.13	0.00	0.00	0.05	0.10	0.09	0.14	0.10	0.53	0.52	0.48	0.95	0.02	0.00	0.00	0.07
CPUT	0.05	0.68	0.36	0.01	0.15	0.02	0.19	0.02	0.00	0.02	0.00	0.00	0.06	0.20	0.03	0.04	0.15	0.06	0.29	0.08	0.00	0.01	0.00	0.00
SAMRC	0.00	0.00	0.05	0.00	0.13	0.00	0.00	0.18	0.00	0.00	0.14	0.34	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.03	0.00	0.00	0.33	0.18
ARC	0.51	0.76	1.29	0.25	0.36	0.40	0.00	0.08	0.13	0.00	0.15	0.00	0.22	0.37	0.85	0.18	0.36	0.30	0.00	0.03	0.02	0.00	0.00	0.00
UNIZULU	0.10	0.08	0.27	0.05	0.34	0.11	0.00	0.08	0.00	0.73	0.00	0.00	0.04	0.03	0.02	0.02	0.34	0.03	0.00	0.04	0.00	0.12	0.00	0.00
DAFF	0.01	0.03	0.03	0.12	0.03	0.15	0.00	0.05	0.00	0.36	0.05	0.00	0.29	0.09	0.35	0.15	0.03	0.26	0.00	0.05	0.00	0.62	0.15	0.00
CGS	0.00	0.03	0.01	0.04	0.05	0.03	0.00	0.00	0.00	0.18	0.00	0.11	0.00	0.09	0.00	0.06	0.05	0.02	0.00	0.00	0.00	0.15	0.00	0.11
DUT	0.00	0.41	0.06	0.16	0.18	0.00	0.13	0.00	0.00	0.44	0.00	0.33	0.00	1.22	0.05	0.30	0.18	0.00	0.13	0.00	0.00	0.90	0.19	0.07
SASRI	0.00	0.28	0.12	0.10	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.38	0.12	0.11	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
DEPCP	0.23	0.00	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.07	0.03	0.30	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.36	0.29
VUT	0.00	0.06	0.12	0.04	0.20	0.06	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.20	0.00	0.00	0.07	0.00	0.00	0.00	0.00
WSU	0.10	0.62	0.35	0.00	0.15	0.06	0.77	0.12	0.00	0.00	0.10	0.00	0.01	0.23	0.23	0.00	0.15	0.04	0.55	0.01	0.00	0.00	0.07	0.00
WUT	0.00	0.00	0.00	0.19	0.34	0.00	0.00	0.23	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.26	0.34	0.00	0.00	0.11	0.00	0.00	0.70	0.00
UMP	0.07	0.02	0.00	0.05	0.06	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.06	0.00	0.00	0.01	0.00	0.00	0.00	0.00

Appendix B

Table 6. Scientific papers mentioned in the policy documents

Paper	Scientific Citation	Policy Citation	Citing Policy Document
South Africa Horticulture: Opportunities and challenges for Economic and Social Upgrading in Value Chain	78	1	South Africa Agriculture Policy Action Plan
The Case for Re-Strategizing Spending Priorities to Support Small Scale Farmers in South Africa	43	1	South Africa Agriculture Policy Action Plan
Comparison of indoor air quality in electrified and un-electrified dwellings in rural South African villages.	75	1	National Climate Change and Health Adaptation Plan
Acid mine drainage arising from gold mining activity in Johannesburg	358	1	National Climate Change and Health Adaptation Plan
The burden of noncommunicable diseases in South Africa	1075	1	National Climate Change and Health Adaptation Plan
Rural electrification in South Africa: Implications for the health and quality of life of women	8	1	National Climate Change and Health Adaptation Plan
Inequity in poverty: the emerging public health challenge in Johannesburg	22	1	National Climate Change and Health Adaptation Plan
Closing the gap in a generation: health equity through action on the social determinants of health.	2792	1	National Climate Change and Health Adaptation Plan
Climate change: the public health response	588	1	National Climate Change and Health Adaptation Plan
Approaches towards practical adaptive management options for selected water-related sectors in South Africa in a context of climate change	44	1	National Water Resources Strategy
Climate change vulnerability and adaptation preparedness in South Africa	39	1	National Water Resources Strategy
Impact of accountability and ethics on public service delivery: A South African perspective.	71	1	National Strategy for Sustainable Development and Action Plan 2011-2014

Appendix C

R CODE: SEE THE ATTACHED FILE *"Thesis_database.R"*

The R file consists of the R code for data preparation, data cleansing, climate change subtopics classification, author analysis, scientific performance of research institutions analysis and subtopic keyword co-occurrence analysis.