

First Biennial Report to Cabinet on

The State of Climate Change

Science and Technology
in South Africa



science
& technology

Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA



State of Climate Change Science and Technology

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PO Box 72135, Lynnwood Ridge, Pretoria, South Africa, 0040
Tel: +27 12 349 6600 • Fax: +27 86 576 9520
E-mail: admin@assaf.org.za

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus adopted in its name the term 'science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its Members are elected on the basis of a combination of two principal criteria, academic excellence and significant contributions to society.

The Parliament of South Africa passed the Academy of Science of South Africa Act (No. 67 of 2001), which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa officially recognised by government and representing the country in the international community of science academies and elsewhere.

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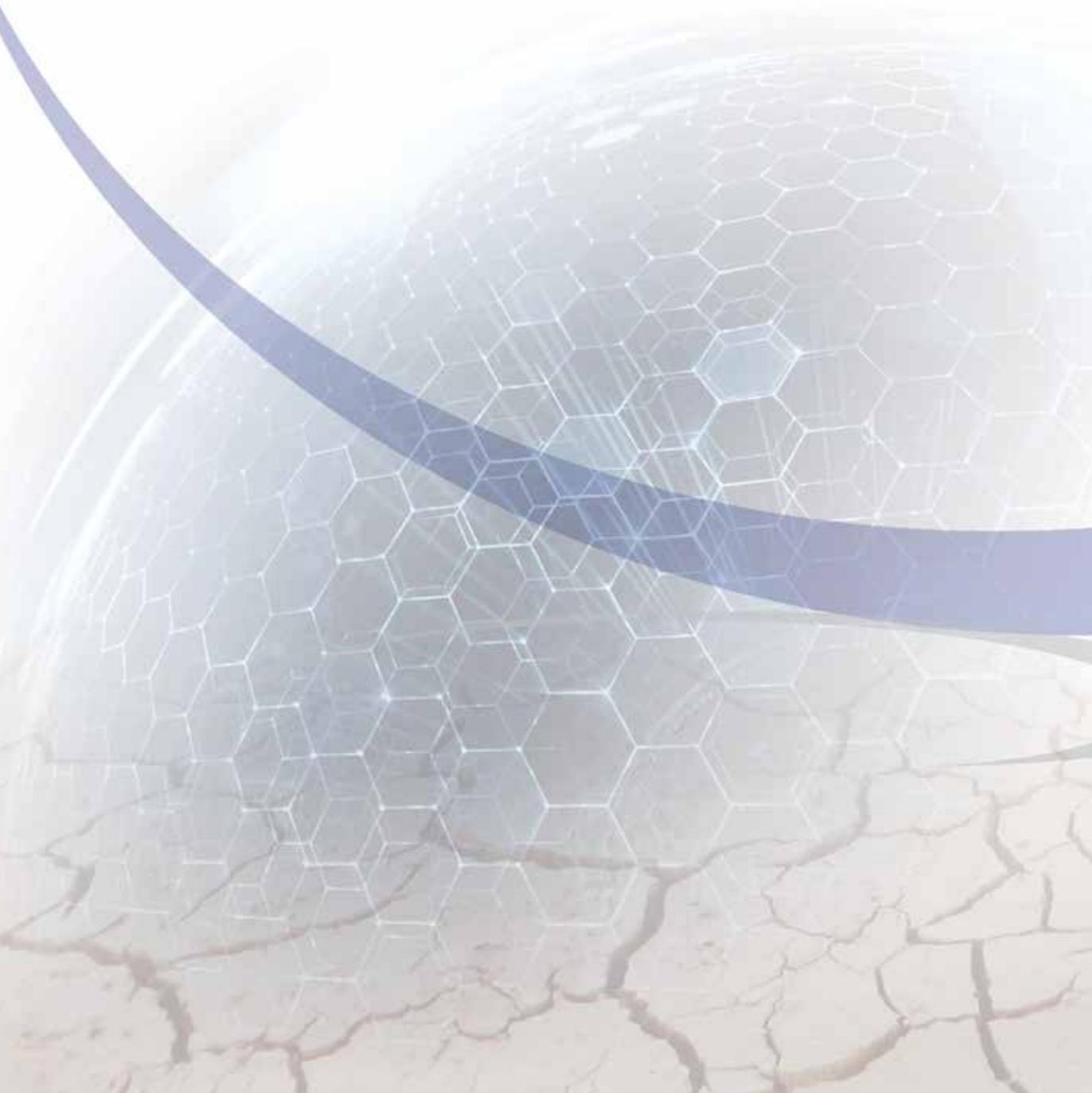


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LIST OF ACRONYMS

| | |
|-----------------|--|
| ACCAI | African Climate Change Adaptation Initiative |
| ACCESS | Applied Centre for Climate and Earth Systems Science |
| AEON | Africa Earth Observation Network |
| ARC | Agricultural Research Council |
| ASSAf | Academy of Science of South Africa |
| BRICS | Brazil, Russia, India, China and South Africa |
| CCAM | Conformal-Cubic Atmospheric Model |
| CCS | Carbon capture and storage |
| CoE | Centre of Excellence |
| COP21 | 21 st Conference of Parties |
| CSAG | Climate System Analysis Group |
| CTCN | Climate Technology Centre and Network |
| CSIR | Council for Scientific and Industrial Research |
| DAFF | Department of Agriculture, Forestry and Fisheries |
| DEA | Department of Environmental Affairs |
| DFID | Department for International Development |
| DoE | Department of Energy |
| DoH | Department of Health |
| DST | Department of Science and Technology |
| DWS | Department of Water and Sanitation |
| EE | Energy Efficiency |
| FP7 | Framework Programme Seven |
| FRACTAL | Future Resilience of African Cities and Lands |
| GEF | Global Environmental Facility |
| GERD | Gross national expenditure on research and development |
| GCGC | Global Change Grand Challenge |
| GCSC | Global Change Science Committee |
| GHG | Greenhouse gas |
| H2020 | Horizon 2020 |
| HSRC | Human Sciences Research Council |
| iCACGP | International Commission on Atmospheric Chemistry and Global Pollution |
| ICFR | Institute for Commercial Forestry Research |
| ICSU | International Council for Science |
| ICSU ROA | International Council for Science Regional Office for Africa |
| IGAC | International Global Atmospheric Chemistry |
| IGBP | International Geosphere-Biosphere Programme |
| IHDP | International Human Dimensions Programme |
| IIASA | International Institute for Applied Systems Analysis |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| IPCC | Intergovernmental Panel on Climate Change |
| LTMS | Long-Term Mitigation Study |
| MAPS | Mitigation Action Plans and Scenarios |
| MRC | Medical Research Council |

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| MTSF | Medium-Term Strategic Framework |
| NBI | National Business Initiative |
| NDP | National Development Plan |
| NEEA | National Energy Efficiency Agency |
| NERC | Natural Environment Research Council |
| NIE | National Implementing Entity |
| NGO | Non-Governmental organisation |
| NMMU | Nelson Mandela Metropolitan University |
| NRF | National Research Foundation |
| NSSD1 | National Strategy for Sustainable Development and Action Plan |
| NSI | National System of Innovation |
| NWU | North-West University |
| ODA | Official Development Assistance |
| OECD | Organisation for Economic Co-operation and Development |
| p.a. | per annum |
| R&D | Research and development |
| R&ST | Research and science and technology |
| R&TD | Research and technology development |
| RECORD | Renewable Energy Centre of Research and Development |
| REEEP | Renewable Energy and Energy Efficiency Partnership |
| RU | Rhodes University |
| RVSC | Risk and Vulnerability Science Centre |
| SA | South Africa |
| SACCCS | South African Centre for Carbon Capture and Storage |
| SADC | Southern African Development Community |
| SAEON | South African Environmental Observation Network |
| SAGEN | South African-German Energy Programme |
| SANBI | South African National Biodiversity Institute |
| SANEDI | South African National Energy Development Institute |
| SANERI | South African National Energy Research Institute |
| SANSA | South African National Space Agency |
| SARChI | South African Research Chairs Initiative |
| SARVA | South African Risk and Vulnerability Atlas |
| SASSCAL | Southern African Science Service Centre for Climate Change and Adaptive Land Use |
| SAWS | South African Weather Service |
| SMRI | Sugar Milling Research Institute |
| SOCCO | Southern Ocean Carbon-Climate Observatory |
| SoE | State-owned enterprise |
| SPARC | Stratosphere-troposphere processes and their role in climate |
| SU | Stellenbosch University |
| TAP | Technology Advancement Programme |
| TD | Technology development |
| the dti | Department of Trade and Industry |
| TIA | Technology Innovation Agency |
| ToR | Terms of Reference |
| TUT | Tshwane University of Technology |

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| | |
|---------------|---|
| UCT | University of Cape Town |
| UFH | University of Fort Hare |
| UFS | University of the Free State |
| UJ | University of Johannesburg |
| UK | United Kingdom |
| UKZN | University of KwaZulu-Natal |
| UL | University of Limpopo |
| UNFCCC | United Nations Framework Convention on Climate Change |
| Unisa | University of South Africa |
| UP | University of Pretoria |
| US | United States of America |
| UWC | University of the Western Cape |
| UZ | University of Zululand |
| VUT | Venda University of Technology |
| WASA | Wind Atlas of South Africa |
| Wits | University of the Witwatersrand |
| WRC | Water Research Commission |
| WWF | World Wildlife Fund |





EXECUTIVE SUMMARY

This report on the *State of Climate Change Science and Technology in South Africa* was compiled by the Academy of Science of South Africa (ASSAf). It was commissioned by the Department of Science and Technology (DST) and aligns with the Medium-Term Strategic Framework (MTSF) of the government of South Africa, which in turn stems from the work of the National Planning Commission and its National Development Plan (NDP). Outcome 10 of the MTSF calls for a report on the state of climate change science and technology in South Africa to be provided to Cabinet by the DST and the Department of Environmental Affairs (DEA) every two years. This is the first such report.

The report aims to:

- provide a critical assessment and comparative overview of climate change scientific research and related technological innovations;
- identify any gaps or barriers in research and technology development value chains;
- suggest ways to improve the current situation and maximise opportunities for South Africa.

A small panel of experts appointed by the ASSAf Council produced the report over the period June to December 2016. Information was sourced from a review of policies, data gathering from published reports and papers, and bibliometric surveys. In addition, a consultative approach was adopted in which information was solicited from semi-structured interviews with 20 key stakeholders; questionnaires that were distributed to 45 individuals, representative of the research community, private sector and civil society; a consultative workshop attended by 26 individuals; and selected stakeholder inputs on the draft report.

To provide a context to the report, the key challenges and impacts related to climate change in South Africa, with a particular focus on the next 30 years, are highlighted. In summary, these are: South Africa will be hotter in all places and drier in most, particularly in the western parts of the country; there will be more extreme weather, droughts and floods; and there will be increased pressure to move the energy mix in South Africa away from its current high dependence on fossil fuels, especially coal. An overview of the regulatory framework in which climate change research and technology development takes place is also given.

The climate change research and technology innovation system is diverse, comprising a range of **funders** (international agencies, many government departments, the private sector and state-owned entities); numerous research and technology **performers** such as universities, science councils, the private sector and state-owned enterprises. The **user** community includes the international research **community**, government (local, provincial and national), civil society and the private sector.

The total funding going into the entire South African climate change research and technology development (R&TD) system is approximately R400 million per year, growing at a nominal rate of 12% per annum (p.a.) over the past decade (a real rate, after inflation, of around 6%). Averaged over the past decade, 58% of this support derives from state funding, 25% from private sector funding and 17% from international sources.

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Funding from Eskom, Sasol and the Green Fund is broadly 'technology' (33%), while the rest are broadly 'research'.

In principle, funding derived from national sources is aligned to national priorities, such as those articulated in the NDP and the MTSF, although there is no rigorous process to ensure this. Funding from international sources, when channeled via state entities involves working within the parameters of policy priorities of both the recipient country and the donor country or entity. Funding from international sources not mediated via a South African state entity reflects only the funding priorities of the source.

Based on expenditure, approximately 40% of the R&TD relating to climate change takes place in tertiary education institutions, 35% in science councils and 25% in the private sector. Based on research output, as measured by peer-reviewed publications, the proportions are 84% universities, 15% science councils and 1% private sector. The contribution by the various sectors to technology development is harder to assess, since much of it is not in the public domain, but it is predominantly conducted and funded in the private sector (including Eskom). Based on expenditures, the balance of effort is about two-thirds research and one-third technology development.

The research-intensive universities produced the bulk of the published output: University of Cape Town (UCT) (23%); Stellenbosch University (SU) (12%); University of KwaZulu-Natal (UKZN) (10%), University of Pretoria (UP) (9%), University of the Witwatersrand (Wits) (9%) and Rhodes University (RU) (5%). The remaining 11 more teaching-oriented universities, which include both formerly white and the historically disadvantaged universities, together add a further 18% to the published output. Clearly, efforts to encourage climate change research in these institutions have been only weakly successful.

The number of peer-reviewed journal articles and book chapters relevant to topics related to climate change and its impact in South Africa has been rising at an average of 16% per year over the past decade; from 131 per year in 2005, to 596 in 2015 (with a further 478 in 2016 up to October). This is much higher than the rate of increase of South African publications on all research topics, which is about 5% p.a., and higher than the rate of increase in nominal funding (12% p.a.) or real funding (6% p.a.). The mean number of times these papers are cited by other authors, a measure of the impact of the paper, is 24.7 times, which is high by global standards in this or any field.

Other outputs include software products (climate models and impact forecasting applications, systems for the support of decision-making, portals and databases for information access), technology demonstrators, new cultivars, published reports, briefing notes and newsletters to users in the public and private sectors not visible to bibliometric services, such as Web of Science, as well as strategies, implementation plans and policy inputs in the public and private sectors.

The output performance of the climate change research area compares favourably to the national average in terms of both publication rate (and citation rate) and high-level skills developed per million Rand invested. On average in South Africa, one publication results from about R1.8 million invested; in climate research, it averages about R670 000 per publication.

South African-based research institutions produced 35% of all publications pertinent to the topic of climate change and the southern Africa region over the past decade, as recorded by a comprehensive bibliometric survey. Of the remaining 65%, generated internationally, no single institution generated more publications than the 11th ranked South African institution, and most of the several hundred international institutions revealed by the survey produced just one to a few outputs related to South Africa.

The number of Masters and PhD graduates in climate change-related fields (according to thesis title) over the period 2006 to 2015 totals 454, of which almost 30% are at the doctoral level. Both Masters and PhD outputs are dominated by the top five institutions (UCT, SU, UP, UKZN and Wits) identified earlier. While the database is imperfect and likely reflects an under-representation of graduates due to search terms used, it provides a useful baseline of high-level human capital development.

It is difficult to determine the current topic balance within the research programmes based on the broad subject classifications in the bibliometric database. For instance, a rough classification suggests the 93% of the recorded output in the 2006 to 2015 period was in the natural and engineering sciences, while 7% was in the humanities and law. However, these two broad branches of research publish in different ways, and are not represented in the Web of Science database equally. Bearing these reservations in mind, only rough profiles can be drawn. Perhaps unsurprisingly, the most active publishing field was the broad category of 'environmental sciences and ecology', at 19% of the output. 'General earth systems' contributed about 11% and 'climatology and meteorology' published about 10%. The cluster around 'biodiversity, including conservation, zoology, freshwater and marine biology' also contributed 10%. Among the impact fields 'agriculture and food security' amounted to about 6%, 'oceanography and fisheries' 4%, 'water resources' about 4% and 'health' 3%, with 'urban and transport' under 1%. The engineering topics such as 'energy systems' contributed only 2%.

The impact measures are less easy to establish for technology development because of the longer period required to achieve measurable impacts, difficulties of attribution of success to individual actors, disagreement on how impact should be measured, and the proprietary nature of some technologies. Nevertheless, it is widely perceived by those responsible for implementing adaptation and mitigation actions that the system as a whole is underperforming in terms of producing South African-developed operational technologies. To some extent this may be an unrealistic expectation of what fraction of the solutions can be produced solely by the South African system, which is very small relative to the global technology performers. It is also partly due to poor coupling between the research and development elements of the South African system (the ideas developed are poorly aligned to market and societal needs, and good ideas are not identified and then nurtured and sustained through the long and expensive development process). It is possible that there is underfunding of development relative to research. The latter deficiency is partly because the South African private sector, with some notable exceptions, apparently provides little development funding, choosing rather to purchase tested technologies internationally.

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Gaps and barriers can develop in many places within the innovation system, reducing the effectiveness of South African adaptation and mitigation efforts. The cycle begins with the problem of global climate change, which is itself evolving in response to new findings, technologies and international agreements. To drive South African innovation, the problem needs to be both well understood and perceived to be important. Climate change is still perceived by many to be a distant problem, displaced by more urgent development challenges; a perception which can be addressed with reliable climate monitoring systems and good communication of the risks of climate change. The mechanisms for translating societal needs into a prioritised research programme largely exist in South Africa, but the loop is not always closed to ensure that promises of alignment between need and outcomes, made at the research proposal stage, are accompanied by actual and effective execution. There is also a mismatch between what the users of research and technology perceive as the key needs in the coming decade, and what has been published in the past decade. The solutions lie in rigorous research governance and an appropriate balance between exploratory and directed research. The bi-directional connection between the South African research community and the global research community is very good (South Africa fares much better than other African countries, and even some Brazil, Russia, India, China, South Africa (BRICS) countries in this respect), but needs to be actively managed and supported to ensure succession within the research networks, particularly as South African science transforms.

It is widely acknowledged that one of the weaker links in the system is the 'technology chasm' which exists between promising ideas developed in the research domain and operational technologies developed by market and implementation-facing institutions. Most innovations fail to cross this gap. The solutions include better coupling between the research and development elements of the system, the application of a phased and scaled funding model, with stage-gates filtering out unfeasible ideas and supporting promising ones, and the creation of a South African venture capital mechanism.

The link between South African technology developers and the world players can be improved. To a degree its weakness is a post-colonial, post-isolationist legacy: on the one hand our development agencies tend to believe we can always do the job better ourselves; while on the other hand the implementing entities in practice access most of their technologies abroad. Where South Africa has been most effective in technology adoption in the past is through developing effective partnerships: South African entities add local value while simultaneously gaining privileged access to world-class technologies. Emphasis is placed on technology co-development and implementation of the locally-adapted version through South African partners, which is more economically sound and more secure. Failure to do so increases the risk of maladapted technologies.

The following key recommendations are made:

Recommendation 1: Ensure inclusion of critical information in future biennial reports in order to provide a comprehensive and consistent ongoing assessment of the status of climate science and technology research in South Africa.

In particular, this relates to funding and outputs in relation to climate change research and development, across the full range of actors. A new data collection body is not proposed, but an enhancement to existing mechanisms, such as this biennial report, explicit detail on climate research in the relevant required annual institutional audited accounts and a specific item on climate research in the annual DST R&D survey.

Recommendation 2: Build on South Africa's research advantages in climate change science, using cross-sectoral, interdisciplinary, inter-institutional and international partnerships where appropriate to steer the R&ST portfolio in greater alignment with perceived needs.

The challenge is to broaden the existing world-class skills base so as to be more inclusive of the remaining higher education institutions and to facilitate the building of research capacity in strategic thematic areas that are inadequately covered. Available mechanisms include requiring certain attributes in the Request for Proposals processes, closing the loop on project completion to ensure those promises were met, and using international bodies and treaties (including inter-African R&TD bilaterals) to promote linkages.

Recommendation 3: Fully use the opportunities for South African researchers and technology developers to access international funding sources.

This requires active intervention by lead government departments responsible for those international processes (particularly, but not exclusively, DST and DEA).

Recommendation 4: Provide financial and diplomatic support to South African scientists involved in high-level international assessment and research bodies and committees.

Consideration should be given to providing financial, technical and diplomatic support to those scientists participating in major international climate-related processes. This could take the form of provision of postdoctoral and/or office support and through advocating for South African candidates in leadership positions. In return, there should be a formal mechanism to ensure that the government can call on their expertise in meeting its treaty obligations and interests.

Recommendation 5: Provide high-level, cross-departmental support for open research, including open data.

This is in accordance with existing Cabinet decisions and national legislation on publicly-funded data, as well as emerging international practice. The commercialisation pressure on institutions holding critical publicly-funded datasets encourages them to either charge a user fee, or make servicing of requests a low priority. This makes little economic sense

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at national scale and is a serious impediment to research. This requires a directive to the data-holding departments, from ministerial level, and a different way of accounting for institutional performance in this regard, other than data sales.

Recommendation 6: Strengthen links between research and business communities.

Silo-formation is impeding the full potential of the innovation system. Deliberate construction of transdisciplinary, multi-sector research programmes, with appropriate incentives and key performance indicators, will help to build the necessary links.

Recommendation 7: Take steps to enable more effective interdisciplinary and multi-disciplinary research, in particular by more effective engagement of social sciences.

Interdisciplinary, multidisciplinary and transdisciplinary approaches are generally increasingly adopted in this field. Social science research, in particular, is a critical component of climate change research and practice. Programmatic funding must recognise, adapt to, and promote these trends.

Recommendation 8: Strengthen research collaborations in climate change science and technology with African countries.

While there is evidence of strong international collaboration in the climate change research community, the links are overwhelmingly with traditional partner countries in the global North, viz. Europe and the United States (US). Given that the climate system and climate change impacts are regional in nature, and the leading role of South African climate R&TD on the continent, it makes sense to strengthen research links with African countries, particularly with those in the Southern African Development Community (SADC) region. R&TD bilateral agreements with African countries should explicitly include collaboration in climate change science and technology where this is not already the case. They should provide opportunities for partnerships that extend beyond traditional university researchers but should include, for example, opportunities for science academy collaborations or practitioner collaborations.





1 INTRODUCTION

The Medium-Term Strategic Framework (MTSF) of the government of South Africa emerges from the work of the National Planning Commission and its National Development Plan (NDP). Outcome 10 of the MTSF calls for a report to be provided every two years by the Department of Science and Technology (DST) and the Department of Environmental Affairs (DEA) to Cabinet on the state of climate change science and technology in South Africa. This is the first such report.

The purpose of this report, as defined by the Terms of Reference (ToR) (Appendix 1) provided by the DST to the Academy of Science of South Africa (ASSAf), who executed the study, is to:

“...provide Cabinet with a critical assessment and comparative overview of climate change scientific research and related technological innovations, identify any gaps or barriers in research and technology development value chains, and suggest ways to improve the current situation and maximise opportunities for South Africa.”

The ToRs go on to say “...coordination of efforts by different role players can be specifically improved, in order to ensure proper knowledge of these efforts and their collective impact”.

The ToRs specifically require the following elements:

- 1 An overview of various national legislative, policy and regulatory instruments governing (climate change) science; systematic observation or monitoring; impact and risks; response measures (mitigation and adaptation, inclusive of technology development); and cross-cutting issues, such as financing, and monitoring and evaluation.
- 2 An overview of various international instruments available to support national climate change responses, with emphasis on scientific research and technology development and deployment, and the degree of South African involvement.
- 3 An analysis of various climate change-related research and technology development programmes and initiatives in different areas, and key stakeholders or role players.
- 4 An analysis of research needs and priorities from climate change/adaptation plans and strategies at national, provincial and municipal level.
- 5 An analysis of the extent to which technological programmes and initiatives are informed by research needs and priorities from climate change/adaptation plans and strategies at national, provincial and municipal level.
- 6 An analysis of the extent to which climate change/adaptation responses are informed by research outcomes/outputs.

For the purposes of this report, a broad definition of climate change research and technology development (R&TD) has been adopted. ‘Climate change’ includes the dynamics of the full climate system (i.e. the atmosphere, the land, the oceans and the cryosphere); the effects of climate change and variability on all aspects of impact relevant to the people of South Africa; adaptation to those changes in order to reduce

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their impact; and mitigation of the emissions of greenhouse gases (GHGs) in order to reduce future climate change. This definition is largely synonymous with, but slightly narrower than, the Global Change¹ Grand Challenge of the DST, and has strong but not perfect overlap with the 'Green Economy' (Appendix 2); for instance, there are green technologies (e.g. in non-GHG pollution reduction, or biodiversity protection), which are not climate-related.

This report adopted a consultative and interactive approach to collecting information, data and opinions from different role players, with a view to compiling a detailed report that gives an accurate account of the state of climate change R&TD in South Africa. Details of this process and the institutions and persons consulted can be found in Appendix 3.

As this is the first of an intended series of biennial (two-yearly) reports, it considers climate change R&TD trends and activities for the period 2006-2015 rather than for just the past two years. It provides information on current actors, institutions, programmes, funding and activities in order to build a comprehensive overview of the landscape of climate change R&TD in South Africa. It does so within the context of the wider knowledge-based economy and in the light of the serious concerns about the nature and impacts of climate change for the inhabitants, economy and environment of South Africa. This and future reports are intended to become part of the mechanism by which climate change R&TD innovation, programmes, projects, interventions and activities are reported on, collated, analysed, and guided.

The report is structured in a manner which allows for consideration of climate change R&TD as activities and processes within the overall national (and in some respects, international) knowledge production system. Following Section One (this introductory section), Section Two highlights key challenges and impacts related to climate change in South Africa, with a particular focus on the next 30 years. Climate scientists and innovators are engaging with these challenges in an effort to gain a better understanding of the processes involved and their implications in South Africa, in order to develop suitable, beneficial responses to climate change at a variety of scales. Section Three describes the regulatory framework in which climate change R&TD takes place. Section Four reports on the overall climate change R&TD landscape in South Africa, outlining the many institutions and roles, including researchers, technology developers, knowledge users, and policymakers and implementers of policy. The system includes a range of technology R&TD outputs. It also provides an overview of the international and local instruments which support climate change science, particularly through funding.

Sections Five and Six address research and technology respectively. These sections provide a more in-depth analysis, as well as considering priorities for future investments and challenges to be overcome to successfully address these priorities. Section Six pays particular attention to the range of climate-related technologies which is needed, and the current challenges in the South African innovation system. Section Seven covers conclusions and recommendations.

¹ 'Global Change' is a syndrome of linked changes to the global system that have occurred since the Industrial Era, including land cover change, ocean resource depletion, biodiversity loss and climate change, among others.

The report was commissioned by the DST and undertaken by ASSAf over the period June 2016 to December 2016. It was conducted by a panel appointed by the ASSAf Council, comprising Prof RJ (Bob) Scholes (Chair), Prof Roseanne Diab and Dr Jane Olwoch. Brief biographies of the panel members are included in Appendix 4. Research support was provided by Dr Jennifer Houghton and bibliometric analyses were contributed by Ms Maryna van den Heever and Mrs Susan Veldsman.

The methods and surveys undertaken, including keywords used in bibliometric surveys and summaries of stakeholder interviews are contained in Appendix 5. In gathering data and information, a rigorous analysis of data, where available, was undertaken. It proved to be difficult to collect data from some sources and where gaps exist, these will be rectified in future reports. A consultative approach was adopted and stakeholders were given an opportunity to provide input into the report.



2 CLIMATE CHANGE CHALLENGES OVER THE NEXT THREE DECADES

Over the next 35 years, between approximately 2016 and mid-century, the following important changes are expected to occur in the South African climate system, and in the technology environment that affects or is affected by climate.

Southern Africa will be hotter in all places and drier in most

There is high scientific confidence that South Africa will continue to warm, at a rate somewhat higher than the 0.15 °C per decade observed over the 20th century (Engelbrecht *et al.*, 2015). In the period up to the middle of this century, this warming will occur regardless of the success or failure of international agreements to curb climate change, such as those reached in Paris in December 2015, although those agreements have important benefits to the climate in the second half of the century. The warming will be especially strong in the already hot north-west interior of southern Africa, and by 2050 will result in a doubling of the number of days of dangerously hot weather over about half of the country, and increasing difficulty in sustaining livestock-based or human outdoor activity-based economies in the most-affected areas.

There is less scientific confidence in projections of rainfall trends (James and Washington, 2013). Most models project less rainfall on average, especially in the west of the country. Coupled with the higher water demand due to warmer temperatures, this provides high confidence that soils will be drier in the future over much of the country, and water supply for agriculture, domestic use and industry will be under increasing pressure.

The strongest impacts of climate change in South Africa in the first half of the 21st century will be on the security of freshwater supplies to industry, towns and agriculture; on crop and livestock agriculture, due to less favourable growing conditions; on human health, due to heat stress and disease spread, particularly in urban areas; and on biodiversity, due to shifting habitat suitability.

More extreme weather and floods

The future climate is very likely to include an increase in the frequency and severity of damage-causing storms, a pattern likely already revealing itself (IPCC, 2014). When coupled with an unavoidable sea-level rise of around 300 mm by 2050 (IPCC, 2014), the likelihood of flooding, especially on the coast, will increase risks to human settlements. Prolonged heat waves and multi-year dry spells will also be more likely than in the past.

Reduced use of fossil fuels

As a result of the conditional and unconditional contributions by South Africa to reducing GHG emissions in terms of the Paris Accord agreed at the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), there will need to be strenuous efforts to shift the energy mix in South Africa away from its current high dependence on fossil fuels, especially coal. Even without these commitments, there will likely be trade pressures for our economy to become less carbon intensive than at present in order to remain competitive. The coal sector, a big part of our energy mix and export earnings, is already struggling to attract finance because of the

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strong belief that it will become progressively less viable within the lifetime of newly-built coal infrastructure.

Impact of these trends on research and technology activity

Climate scientists and technology innovators are already engaging with the challenges of adapting to changes in temperature, seasonality and water availability, more frequent extreme weather events and the necessity of lowering emissions. The need to address these challenges will intensify over the next decade, rather than diminish. The progression from research to technology development typically requires several decades. The alignment of the timeframes for changes in climate and the completion of technology implementation processes thus define the necessary time horizon for state interventions; it is in the order of decades in both cases. Therefore climate change-related R&TD investments need be sustained and directed over decadal planning horizons, not on a yearly basis, although frequent checks on progress and needs, accompanied by adjustments to the rolling plan, are in order.



The image features a complex digital and naturalistic composition. The upper portion is dominated by a dark blue space with a glowing, intricate network of light blue lines and a bright, multi-pointed starburst light source. Below this, a large white curved line separates the space from a blue hexagonal grid pattern. The bottom of the image shows a cracked, brownish-yellow earth surface, suggesting environmental degradation. The overall aesthetic is high-tech and futuristic, with a strong emphasis on blue tones and geometric patterns.

3 THE REGULATORY SYSTEM AS IT RELATES TO CLIMATE CHANGE

This section provides an overview of the various national legislative, policy and regulatory instruments governing climate-related R&TD in South Africa, including those that govern climate change science in terms of systematic observation; impact and risks; response measures (mitigation and adaptation, inclusive of technology development); and cross-cutting issues such as financing, and monitoring and evaluation. Table 3-1 lists the policies that have been included in this overview and which are elaborated upon in Appendix 6.

Collectively, this legislative framework governs climate change-related research and technological development in South Africa through identifying climate change as a national and global priority, outlining overarching and sector-specific responses to climate change and addressing barriers to climate change mitigation and adaptation. In particular, they outline opportunities for leveraging prospects for economic development and job creation. These laws, policies, strategies and plans highlight the need for climate change science R&TD in a broad range of sectors; and provide mechanisms to facilitate research and technology development and initiate increased investment into these activities. In addition, they promote innovation, technology uptake and the furthering of human development and economic goals through scientific research and technology-based responses to climate change.

Table 3-1: List of national policies relevant to climate change R&TD

| Policy Type | Policy |
|----------------------------------|--|
| White Papers | <ul style="list-style-type: none"> • Science and Technology White Paper, 1996 • Energy Policy White Paper, 1998 • Renewable Energy White Paper, 2003 • National Climate Change Response White Paper, 2011 |
| Acts | <ul style="list-style-type: none"> • National Environmental Management Act, 1998 and Amendments • National Skills Development Act, 1998 and Amendments • National Water Act, 1998 • National Environmental Management: Air Quality Act, 2004 • National Environmental Management: Biodiversity Act, 2004 • National Energy Act, 2008 • National Environmental Management: Waste Act, 2008 and Regulations |
| Strategies, Plans and Frameworks | <ul style="list-style-type: none"> • National Industrial Policy Framework and the Industrial Policy Action Plans (IPAP) • National Waste Management Strategy, Water and Waste Roadmaps |

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| Policy Type | Policy |
|----------------------------------|--|
| Strategies, Plans and Frameworks | <ul style="list-style-type: none"> • National Building Regulation and Building Standards Act, 1977 • National Research and Development Strategy, 2004 • National Energy Efficiency Strategy, 2005, 2008, 2012 • Information and Communication Technology (ICT) R&D and Innovation Strategy, 2007 • DST Ten-Year Innovation Plan, 2008 • Framework for South Africa's Response to the International Economic Crisis, 2008 • National Framework for Sustainable Development, 2008 • Global Change Grand Challenge Research Plan, 2009 • New Growth Path, 2010 • National Development Plan, 2011 • National Framework for Green Buildings, 2011 • National Strategy for Sustainable Development and Action Plan (NSSD1), 2011-2014 • Industrial Policy Action Plan, 2012/2013-2014/15 • Carbon Tax Policy Paper, 2013 • ICT Research, Development and Innovation Roadmap, 2013 • Innovative Building Technology Implementation Plan, 2013 • National Water Resources Strategy 2 (NWRS 2), 2013 • Integrated Resource Plan for Electricity (IRP) 2010-2030, Update Reports produced 2013 and 2016 • Medium-Term Strategic Framework, 2014-2019 • Draft Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors, 2015 |





4 OVERVIEW OF THE CLIMATE CHANGE RESEARCH AND TECHNOLOGY DEVELOPMENT INNOVATION SYSTEM

South Africa has a diverse, multi-actor institutional landscape in relation to R&TD to address the challenges of climate change (Figure 4-1). Climate change R&TD takes place within the framework of the national knowledge and innovation system.

The key broad roles within the R&TD system are those of **funders**, research and development **performers** and **users** of research outputs or developed technologies. It is possible for some actors to take on these roles interchangeably or to play multiple roles simultaneously across their designated functions, but typically, one role predominates. For example, metropolitan governments would generally be users of research outputs. However, in some instances members of a metro may be participants within a research production process or the metro may fund research projects in the interests of obtaining specific knowledge for use by the local state as it plans to address the consequences of climate change.

4.1 Funders

R&TD funders in the South African context are mostly national bodies, with a small but significant contribution from international sources, either independently or in collaboration or coordination with South African entities. International funding emanates from international instruments such as the Global Environmental Facility (GEF); the European Commission (where South Africa has favorable partnership agreements with respect to research programmes); certain foreign national research funding entities where international partners are funded, such as Natural Environment Research Council (NERC) and the Department for International Development (DFID) in the United Kingdom (UK); bilateral or multilateral funding structures such as the Belmont Forum, where South Africa is a partner; and international private foundations (Appendix 7 for a detailed discussion of these instruments). The international opportunities and priorities are to some degree influenced by international research coordination bodies (such as Future Earth) or international assessment processes (Intergovernmental Panel on Climate Change (IPCC)), but these are not funding agents themselves. Some international funding, particularly in the adaptation field, emanates from Official Development Assistance (ODA) agencies within the Organisation for Economic Co-operation and Development (OECD) countries. Typically, the agencies of other countries wish to work through and with the South African state, its agencies and other in-country organisations in order most effectively to use available funding.

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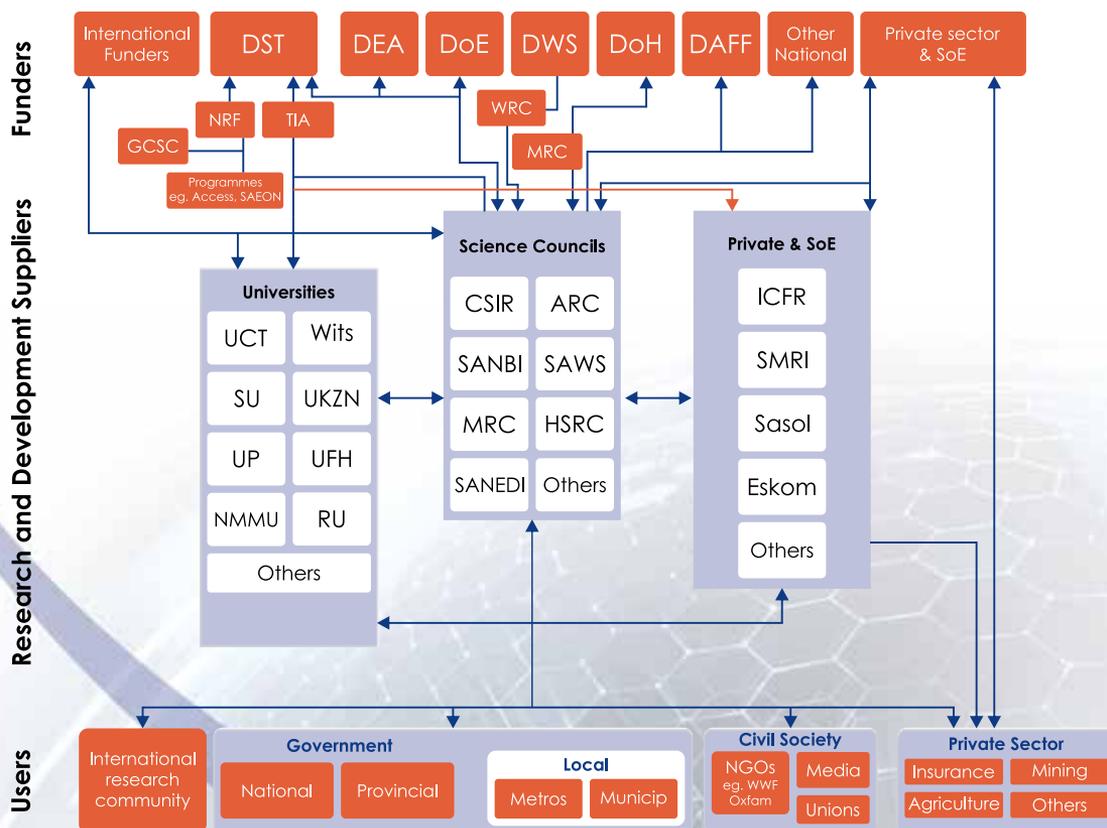


Figure 4-1: The South African science and technology innovation system in relation to climate change. The diagram is indicative rather than comprehensive; only the main actors are shown

Funders from within South Africa consist of national ministries of the state, with budget allocations for R&TD, a portion of which is directed to climate change. The principal governmental actors are the DST with respect to research, and the DEA with respect to issues touching on implementation of the UNFCCC, for which they are the designated national authority. Each department typically has one or more agencies reporting to them with key roles in climate change R&TD. Other sector-specific departments, such as the Department of Agriculture, Forestry and Fisheries (DAFF), Department of Water and Sanitation (DWS), Department of Trade and Industry (the dti), Department of Health (DoH), Department of Energy (DoE) and National Treasury support a portion of the work in their sectors; virtually all national departments are affected in some way by climate change-related issues.

The funding from DST is channeled largely via its agencies, the National Research Foundation (NRF) for research, and the Technology Innovation Agency (TIA) for development. Water and sanitation research is supported by the Water Research Commission (WRC),

a funding agency of the DWS. The South African National Energy Development Institute (SANEDI) is a research development and implementation funding and coordination agency, governed by the DoE that directly implements four of the eight national climate change Near-Term Priority Flagship Programmes.

The science councils, including among others, the Council for Scientific and Industrial Research (CSIR), the Agricultural Research Council (ARC), the Medical Research Council (MRC) (which is partly a funding agency and partly a research body), the South African National Biodiversity Institute (SANBI), the Human Sciences Research Council (HSRC) and the Council for Geosciences are partly funded by the national departments to which they report.

The diversity of funding paths and agencies is on balance a strength of the system rather than an indication of duplication or inefficiency. It reduces wild priority swings and budget volatility, and brings researchers closer to their target users. The complex system does create a coordination challenge, since virtually nobody has a complete overview. Providing this overview is one of the functions of this report.

The DST is the central actor in the National System of Innovation (NSI). The DST is also a significant actor within the climate change research funding space, particularly through support of research and human capital development via the NRF. The NRF has dedicated programmes for global change research², such as the Applied Centre for Climate and Earth Systems Science (ACCESS), the Africa Earth Observation Network (AEON), the Southern Ocean Carbon-Climate Observatory (SOCCO), as well as national facilities, such as the South African Environmental Observation Network (SAEON), and Centres of Excellence and Risk and Vulnerability Science Centres (RVSCs), all with a large role in climate change research.

Within South Africa, funding from the private sector, here defined to include state-owned entities (SoEs), such as Eskom, is focused on knowledge application and technology development that is suited to the specific needs of the enterprise. Much of the indigenous R&TD is conducted internally, but some is contracted from universities, science councils or consultancies, and a large amount is bought in as technologies developed internationally.

The total funding currently (2016) going into the entire South African climate change R&TD system is approximately R 400 million per year, growing at a nominal rate of 12% per annum (p.a.) over the past decade (a real rate, after inflation, of around 6%: Table 4-1; note that the average funding over the decade was closer to R300 million per year, but has been rising; therefore the current funding is higher than the average). Averaged over the past decade, 58% of this support derives from state funding, 25% from private sector funding and 17% from international sources (Figure 4-2). Funding from Eskom, Sasol and the Green Fund is broadly 'technology' (33%), while the rest are broadly 'research'.

2 'Global change' is a slightly broader term than climate change. It includes climate and other changes, such as to land cover, the oceans and biodiversity taking place at large scales in contemporary times (since about 1800).

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In principle, funding derived from national sources is aligned to national priorities, such as those articulated in the NDP and the MTSF, though there is no rigorous process to ensure this. Funding from international sources, when channeled via state entities involves working within the parameters of policy priorities of both the recipient country and the donor country or entity. Funding from international sources not mediated via a South African state entity reflects only the funding priorities of the source.

Table 4-1: Funding (in millions) for climate change R&TD in South Africa over the period 2006-2015 in nominal Rands (in other words, not inflation corrected). Consumer price inflation over this period averaged 6.2%

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2006-15 |
|--|--------------|--------------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|-----------------|
| DST excluding NRF | 25.00 | 37.00 | 85.07 | 110.40 | 101.43 | 121.89 | 139.31 | 155.88 | 152.26 | 188.14 | 1 116.37 |
| ACCESS | | | | 6.30 | 6.30 | 20.00 | 10.10 | 12.64 | 13.54 | 16.20 | |
| AEON | | | | 4.20 | 4.20 | 4.20 | 6.60 | 6.60 | 6.60 | 6.93 | |
| SAEON | | | | 12.00 | 12.00 | 12.00 | 12.07 | 13.58 | 13.58 | 14.26 | |
| FBIP | | | | 7.90 | 7.90 | 7.90 | 7.23 | 7.34 | 10.11 | 10.93 | |
| GCSSRP | | | | 0.00 | 0.00 | 0.00 | 6.00 | 6.21 | 0.00 | 7.00 | |
| SOCCO | | | | 0.00 | 4.50 | 4.50 | 4.50 | 4.50 | 9.00 | 9.00 | |
| SARVA | | | | 6.00 | 6.00 | 6.00 | 6.00 | 0.58 | 0.00 | 3.63 | |
| RVSC's | | | | 0.00 | 0.00 | 0.00 | 0.00 | 6.00 | 6.00 | 6.00 | |
| Support for SA researchers in IPCC (AR5) process | | | | 0.00 | 0.40 | 0.40 | 0.40 | 0.00 | 0.00 | 0.00 | |
| Support GEOBON Chair | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.53 | 0.14 | 0.00 | |
| Belmont Forum CRA grant | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 | |
| Hydrogen on renewable energy | | 12.00 | 60.07 | 74.00 | 60.13 | 66.89 | 86.41 | 97.90 | 92.99 | 112.69 | |
| NRF | 1.77 | 3.28 | 4.76 | 11.17 | 11.18 | 18.53 | 21.19 | 22.39 | 30.65 | 39.62 | 164.85 |
| DEA excluding agencies | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 44.99 | 44.49 |
| SANBI | 0.50 | 0.80 | 1.00 | 1.50 | 1.50 | 1.80 | 1.80 | 1.80 | 2.00 | 2.50 | 15.20 |
| SAWS | 10.37 | 11.44 | 12.01 | 12.49 | 27.32 | 32.00 | 26.47 | 16.02 | 19.35 | 18.83 | 186.31 |
| WRC | 10.00 | 12.00 | 12.00 | 14.00 | 16.06 | 20.58 | 22.00 | 24.00 | 26.00 | 28.00 | 183.64 |
| CSIR | 10.00 | 30.00 | 14.00 | 16.00 | 18.00 | 20.00 | 22.00 | 24.00 | 26.00 | 28.00 | 190.00 |
| SASOL | 25.00 | 26.62 | 35.00 | 40.00 | 45.00 | 50.00 | 55.00 | 58.00 | 60.00 | 60.00 | 458.00 |
| ESKOM | 21.30 | 7.44 | 33.28 | 41.60 | 52.00 | 67.30 | 55.00 | 52.80 | 50.00 | 50.00 | 449.90 |
| Foreign sources | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 24.83 | 91.77 |
| European Union FP7 and H2020 | 7.11 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 7.44 | 4.23 | |

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| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2006-15 |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|-----------------|
| UK DFID/NERC | | | | | | | | | | 20.00 | |
| Adaption fund | | | | | | | | | | 0.60 | |
| Green fund | | | | | | | | | | 63.00 | 63.00 |
| Total | 111.38 | 139.58 | 204.56 | 254.60 | 279.93 | 339.54 | 350.22 | 362.32 | 373.70 | 548.21 | 2 964.04 |

Note: Figures are approximate as there are data gaps; estimates are shown in italics and the bold values are sums of programmes listed in normal text below the item.

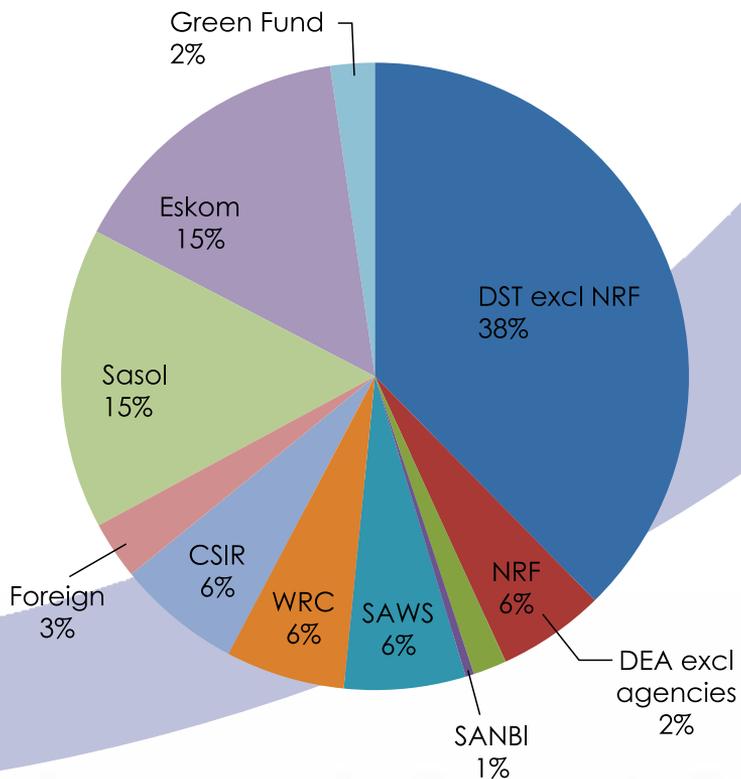


Figure 4-2: Breakdown of funding sources into South Africa's climate-related R&TD system over the period 2006-2015

Note: The breakdown is approximate due to the difficulty in extracting exact values for the period from many institutions.

The South African expenditure on climate-change related research amounts to around 1.7% of the gross national expenditure on research and development (GERD) (HSRC, 2014), a figure more-or-less in line with the developed country range (Table 4-2). The outlier is the European Union (not a country) which has set a much higher target, most of which is in development rather than research.

Table 4-2: Spending on climate change R&TD, averaged over the past decade and expressed in 2015 USD terms (0.85 Euro, 14 Rand and 8 NOK per dollar). Sources: Research Council of Norway; US Federal Climate Change Office, European Union

| Country | GDP | R&D Spend | R&D/GDP % | CC R&D (Bn USD) | CC R&D/GERD % |
|--------------|---------------|-----------|-----------|-----------------|---------------|
| | (Billion USD) | | | | |
| South Africa | 312.8 | 1.7 | 0.5 | 0.0 | 1.7 |
| US | 17 947.0 | 70.0 | 2.5 | 2.5 | 3.5 |
| EU H2020 | 154.3 | 8.3 | 5.4 | 1.9 | 23.0 |
| Norway | 48.5 | 0.8 | 1.7 | 0.0 | 1.1 |

4.2 Research and technology development performers

The main R&TD performers within the arena of climate change consist of universities, science councils and private sector research laboratories (including those in SoEs). A detailed analysis of these entities is found in Sections Five and Six. Based on expenditure, approximately 40% of the R&TD relating to climate change takes place in tertiary education institutions, 35% in science councils and 25% in the private sector. Based on research output, as measured by peer-reviewed publications, the proportions are 84% universities, 15% science councils and 1% private sector (Section Five). The contribution by the various sectors to technology development is harder to assess, since much of it is not in the public domain, but it is predominantly conducted and funded in the private sector (including the SoE, Eskom). Based on expenditures, the balance of effort is about two-thirds research and one-third technology development.

South African researchers are active within the international researchers' community, as well as within science-policy interface bodies, such as the IPCC; South African researchers play an important leadership role in directing the global climate change science agenda (Section Five). Many research projects involve collaboration between South African and international scientists in multinational and multidisciplinary teams (Box 1 for example).

Box 1. MAPS: A South African-led international research and policy support programme

Following the success of the Long-Term Mitigation Study (LTMS) in South Africa, the Energy Research Centre at the University of Cape Town (UCT) and the development non-governmental organisation (NGO) SouthNorthSouth were invited to guide similar processes in four Latin American countries, in a project called MAPS (Mitigation Action Plans and Scenarios). This process was key in developing well-informed indicative National Contributions in the run-up to the COP21 meeting in Paris in 2015.

The research community is made up of individuals and independent institutions, but the South African R&TD landscape is characterised by high levels of inter-individual and inter-institutional collaboration within a wide range of networks, groups and collaborative projects. Collaboration is viewed as critical, given the urgency and importance of the

topic and its multi and inter-disciplinary nature. There is a much greater willingness to cooperate than to compete.

4.3 Users of climate-related research and technology development

R&TD outputs are used by national, provincial and local government; by civil society; by the private sector; and by the international R&TD community.

All local governments (municipalities) have a need for climate change impact, adaptation and mitigation information, but the majority of smaller municipalities have very little capacity to articulate or source their information needs. An international climate change and urban sustainability NGO called Local Governments for Sustainability has been acting as a broker, sometimes through the South African Local Government Association (a state entity). The larger metropolitan areas (Gauteng, eThekweni, Nelson Mandela Bay and Cape Town) are substantial users of climate change information, and all conduct R&TD internally and fund universities, science councils and consultancies to undertake research. The metros have teams of employees working in a dedicated fashion on climate change adaptation and mitigation issues. These teams generally operate across departments within the municipal structures.

The demand for climate change information at provincial level is concentrated in provincial biodiversity conservation and environmental protection agencies. At national government level, the key departments with a high need for climate change information are:

- 1 DEA (with a mandate for environmental quality and biodiversity protection, but also the national focal point for the UNFCCC and IPCC). It is the responsible department for both the SA Weather Service (SAWS) and SANBI. It sources much of its climate change information from these entities and also uses the latter to coordinate climate change studies such as the Long-Term Adaptation Strategy and National Communications (to the UNFCCC). SANBI has also been used to channel research funding from the GEF and other international donors. DEA also sources information from universities, science councils and consultants. SA National Parks also reports to DEA, and conducts, hosts and uses climate change-related research.
- 2 DAFF (has a mandate to promote and regulate crop and livestock agriculture, fisheries and plantation forests). All these activities are climate sensitive, and agriculture is a significant source of GHGs, accounting for around 5% of the South African total emissions as documented in the Second National Communication. The information was sourced from the ARC and universities with agricultural faculties.
- 3 DoE (the South African energy mix is strongly coal-dependent, and therefore vulnerable to pressure on fossil fuels). Their technology agency, SANEDI, is designed to inform policy and focuses on, among other areas, advanced fossil fuel technologies (including carbon capture and storage (CCS)), clean energy (through energy efficiency (EE) and renewable energy programmes), green transport (emissions reduction) and smart grids (energy systems integration); through national and interna-

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tional collaboration, coordination and some funding of research, development and innovation, monitoring of national targets and resource research.

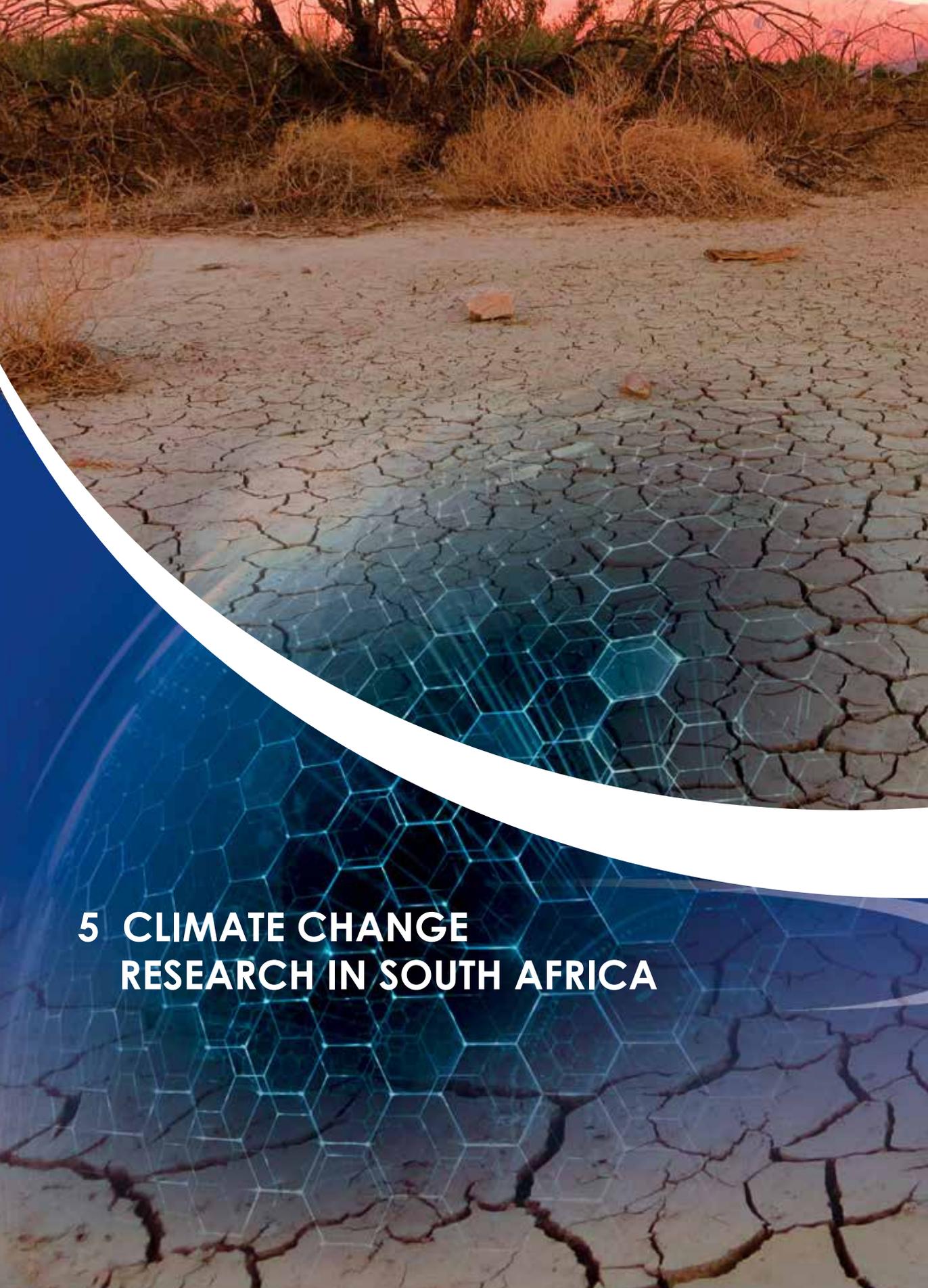
4. DWS (responsible for freshwater supplies and sanitation). It has a funding agency, the WRC, which supports climate change research related to water issues, largely conducted by universities, science councils and consultants.
5. DoH (heat stress is an emerging issue, along with climate-linked increased exposure to vector-borne disease). They source much of their climate information from the MRC, which is both a research institution and a funding agency, primarily for universities.

Virtually all other national government departments have some call on climate-related R&TD: the Presidency (through the NPC), National Treasury (carbon taxes), Department of Land Affairs (land cover change), and the dti (trade rules, green economy). To a significant extent, they, and the above-mentioned departments, rely on the DST to identify and fund research to meet these needs proactively. The SA Risk and Vulnerability Atlas (SARVA) consolidates, curates, and supplements global change research outputs for the benefit of planners, decision and policymakers, and the general public. It is hosted in SAEON's Open Data Platform and offers decision support tools based on dynamic web-based mapping.

As with government, the private sector is both a user and funder of research. Private sector users of research are concerned about the impacts of climate change on supply chains (for instance agricultural produce, or water for power generation and industry) and the risks associated with extreme events (a particular concern in the insurance and finance sector). The private sector is an important role-player in the development, manufacturing and roll-out of green technology, such as renewable energy.

Among the civil society organisations, the World Wildlife Fund (WWF-SA) has long been active as a funder, provider and user of climate information, and advocate of adaptation and mitigation, and a key knowledge broker to the private sector, and Oxfam has been active in relation to the impacts of climate on poverty and human well-being.





5 CLIMATE CHANGE RESEARCH IN SOUTH AFRICA

The following section briefly outlines the organisations most active in climate change research in South Africa, together with their main interests. 'Research' includes the Basic, Applied and Experimental Development activities as defined in the Frascati categories (OECD, 2007). The knowledge outputs primarily take the form of journal articles, books and book chapters. Especially in the South African context, the generation of advanced human capacity, in the form of PhD and Masters dissertations, is also important.

5.1 Institutions conducting research on climate change in South Africa

South African-based research institutions produced 35% of all publications pertinent to the topic of climate change and the southern Africa region over the past decade, as recorded by a comprehensive bibliometric survey (Figure 5-1). Of the remaining 65%, generated internationally, no single institution generated more publications than the 11th ranked South African institution, and most of the several hundred international institutions revealed by the survey produced just one to a few outputs related to South Africa.

The publication units generated by South African-based researchers originated from 28 institutions, of which half were produced by the top five.

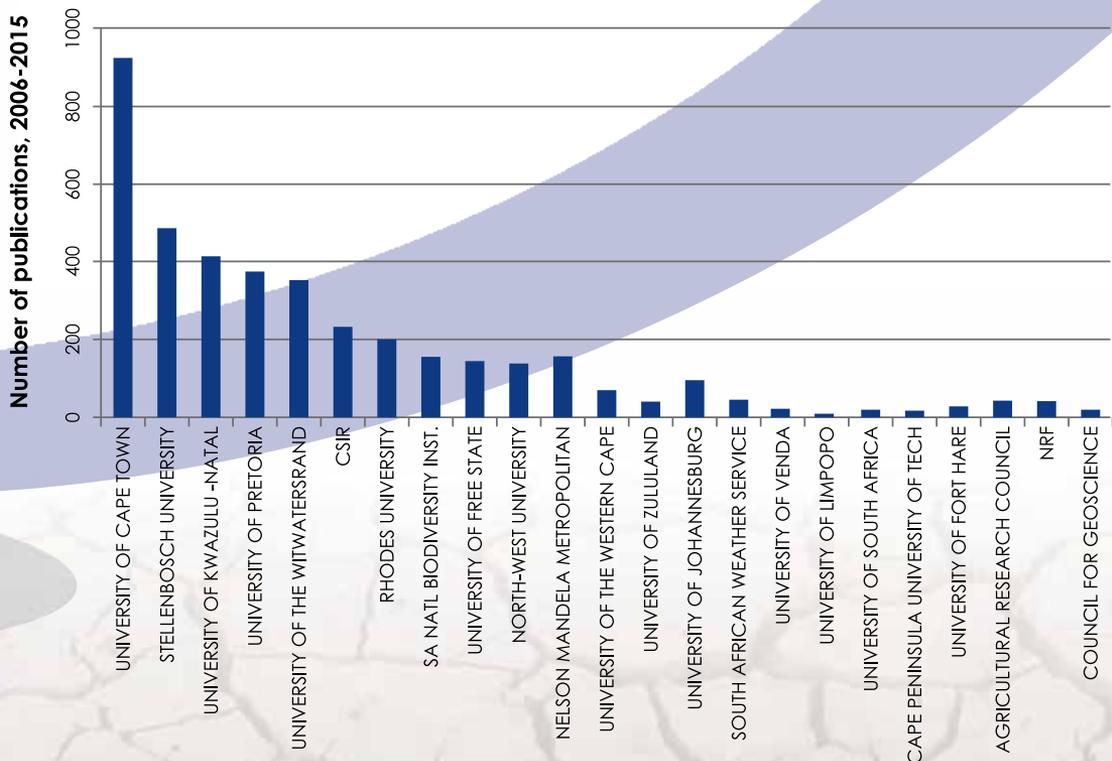


Figure 5-1: Publication unit outputs by South African research institutions during the period 2005-2015, as recorded in the international publication database Web of Science, and revealed using the search criteria listed in Appendix 5

5.1.1 Universities

The universities collectively generated 86% of the South African publications relating to climate change in the period 2006-2015. By nature, climate change research topics are wide-ranging; thus large, multi-faculty, research-intensive universities are well positioned to address them. University-affiliated research centres (Table 5-1) and research chairs (Table 5-2) focused on climate change are listed below. The research-intensive universities produced the bulk of the published output: University of Cape Town (UCT) (23%); Stellenbosch University (SU) (12%); University of KwaZulu-Natal (UKZN) (10%), University of Pretoria (UP) (9%), University of the Witwatersrand (Wits) (9%) and Rhodes University (RU) (5%). The remaining 11 more teaching-oriented universities, which include both formerly white and the historically disadvantaged universities, together add a further 18% to the published output. Clearly, efforts to encourage climate change research in these institutions have been only weakly successful.

Table 5-1: University-affiliated research centres for climate change science in South Africa

| Centre/Unit name | Institutional affiliation | Current core research areas |
|--|---------------------------------|--|
| Climate System Analysis Group (CSAG) | University of Cape Town | Climate system research and climate modelling, especially downscaling |
| Energy Research Centre | University of Cape Town | Energy sector planning, mitigation and adaptation strategies |
| Centre for Renewable and Sustainable Energy Studies | Stellenbosch University | Solar, wind, ocean and bioenergy |
| Department of Geography, Geo-informatics, and Meteorology | University of Pretoria | Meteorological and atmospheric observation, monitoring, and research |
| Global Change and Sustainability Research Institute (GCSR) | University of the Witwatersrand | Ecosystems, biodiversity, food security, urban and industrial adaptation, science-policy links |
| African Climate and Development Initiative | University of Cape Town | The interface between climate and development |
| Centre for Water Resources Research | University of KwaZulu-Natal | Impacts of climate change on water supplies, flooding, droughts and water quality |

Table 5 2: South African Research Chairs Initiative (SARChI)-funded university chairs in the area of climate change

| Chair title | Discipline | University | Chairholder |
|--|--------------------------|------------|--------------------|
| Regional Ocean Influences on Southern African Climate Change | Earth and Marine Science | UCT | Vacant |
| Climate Change | Earth and Marine Science | UCT | Prof B Hewitson |
| Global Change and Systems Analysis | Global Change | Wits | Prof M Scholes |
| Rural Agronomy and Development | Agricultural Science | UKZN | Prof PL Mafongoya |
| Earth Systems Science | Earth and Marine | NMMU | Prof DR Bell |
| Climate Change and Social Learning | Social Sciences | RU | Prof H Lotz-Sitika |

5.1.2 Science councils and programmes coordinated by them

The state-affiliated science councils conduct mostly applications-oriented research ('contract research'), on behalf of both government departments and the private sector, with a small component of non-directed ('basic') research. Collectively, they contributed about 12% of the recorded published output on climate change in South Africa; to which the CSIR contributed 6%, SANBI 4%, ARC 1% and SAWS 1%, with minor contributions by the Council for Geosciences, the MRC, the HSRC, Mintek, the South African National Space Agency (SANSA) and others. It is recognised that there may be additional reports, traditionally comprising the 'grey' literature, that are not recorded as part of the bibliometric survey undertaken.

Council for Scientific and Industrial Research (CSIR)

The CSIR plays multiple roles within the supply of climate change science research, including running a Global Climate Model known as CCAM (Conformal-Cubic Atmospheric Model), originally developed by CSIRO Australia but subsequently collaboratively coupled by the CSIR to an ocean model developed by the Japan Agency for Marine-Earth Science and Technology, and customised in other ways. This remains the only 'southern hemisphere-based' model among the 30 Global Climate Models in the world. The CSIR performs high-resolution climate projection down-scaling for Africa and South Africa. Together with the Department of Oceanography at UCT, the CSIR hosts most of South Africa's Southern Ocean research capacity. They are also active in monitoring the carbon cycle and in climate change impact and adaptation studies, as well as in several mitigation technology areas discussed in Section Six.

Applied Centre for Climate and Earth Systems Science (ACCESS)

ACCESS is a virtual Centre of Excellence funded by the DST via the NRF and hosted at the CSIR. ACCESS comprises a community of scientists and students working on global change. As such it could have been classified as a 'funder' in the previous section, and most of its outputs are claimed by the participating institutions; but it is also very active in training postgraduate researchers, hence placement here. ACCESS coordinates and undertakes a research programme which concentrates on climate change science from the perspective of integrating ocean-atmosphere-terrestrial systems in southern Africa; understanding these systems in the light of global scale processes and within long times frames that incorporate analysis of palaeo-climatic cycles. ACCESS is active in research capacity building in climate change science through the support and skills development of postgraduate researchers. ACCESS has recently been reviewed and the key findings of this review are presented in Appendix 8.

South African Environmental Observation Network (SAEON)

SAEON was established as part of the NRF in 2002, and it aims to be a national facility residing under the NRF, though it does not yet have this status. SAEON is affiliated to the international Group on Earth Observations in its role in observational science. SAEON supports the availability and sharing of long-term environmental observational data which are being collected by diverse organisations. The effects of climate change are pervasive across all earth systems and accordingly, SAEON undertakes *in situ* observations relevant to climate change and its environmental impact through a marine offshore node, a coastal node in the Eastern Cape, and nodes which focus on the fynbos biome, savanna biome, grassland biome and arid lands areas of the country. Atmospheric and oceanic data are generated by automated instruments from as high as 300 m above sea level in the Drakensberg to as deep as 4 000 m in the Agulhas Current near East London. During the period 2006 to the present, SAEON contributed to 14 international and 11 local committees relevant to climate change. Climate change was embedded in the research topics of 13 of SAEON's postgraduate students between 2011 and 2015. SAEON will host two of the climate change science relevant Research Infrastructures announced by the DST in October 2016: the Enhanced Freshwater and Terrestrial Observation Network and the Shallow Marine and Coastal Infrastructure.

South African National Biodiversity Institute (SANBI)

The mandate of SANBI is to "explore, reveal, celebrate and champion biodiversity for the benefit and enjoyment of all South Africans". It defines biodiversity in its broadest sense, including flora and fauna and the relationships between society and biodiversity. SANBI conducts research on many issues relating to the interaction between biodiversity and climate change. This research supports biodiversity management policy and planning in South Africa, as well as actions aimed at adaptation, particularly the field of ecosystem-based adaptation. SANBI acts as the South African national implementing entity of the UNFCCC Adaptation Fund, facilitating access to funding for projects which address the climate change adaptation needs in South Africa.

Agricultural Research Council (ARC)

The ARC addresses national priorities relating to agriculture and related food security. Research which supports agricultural productivity is of central concern: adaptation to changing seasonality, temperature and water availability, as well as resilience and climate-smart agriculture are key areas. There is also a research focus on the generation of new climate and disease-adapted cultivars. Seasonal climate and yield forecasting have been a long-term interest at the ARC. The ARC (like other science councils) produces some of its outputs in the form of publications aimed at farmers or the agricultural industry, or as technologies (such as new, climate-ready cultivars), neither of which is visible to the bibliometric survey conducted by this report. The contribution by ARC and other similar bodies to climate R&TD in South Africa is therefore arguably underestimated relative to universities, whose outputs as papers and graduates are well captured.

South African Weather Service (SAWS)

SAWS is a national statutory body, funded by the DEA and through the provision of commercial forecast services. It operates the largest array of meteorological observations in South Africa. One of the revenue streams for SAWS involves selling data. South African climate change scientists repeatedly raised concerns with regard to difficulties in accessing observational data and the prohibitive cost of data.

The SAWS Climate and Environment Research and Monitoring Unit is engaged in climate change-oriented research. The unit conducts research on the meteorological fundamentals of climate change, has a concern for local scale understanding of climate change impacts and has an important role in weather forecasting in the short and medium terms.

Medical Research Council (MRC)

The MRC undertakes and coordinates health and medical research in South Africa, working primarily with the public health sector. There is an active group within the MRC that focuses on research into the health implications of climate change and the necessary systemic and supply chain responses within the public medical sector. This research is focused, for example, on pneumonia, diarrhea, heat exhaustion and malaria.

Other science councils

The SANSA contributes to the observation and monitoring of the atmosphere and climate, particularly through satellite imagery and remote sensing. SANEDI and the WRC are discussed in Section Four under research funders, since they mostly operate in this mode.

5.1.3 Private sector and state-owned enterprises

This grouping includes, among others, Sasol laboratories, Eskom research and development sections, the Sugar Milling Research Institute (SMRI) and the Institute for Commercial Forestry Research (ICFR). The National Business Initiative (NBI), a voluntary coalition of

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South African and multinational companies working towards sustainable growth and development in South Africa and the shaping of a sustainable future through responsible business action, represents major industry players. It has an active climate change division, mostly focusing on information brokering rather than research.

Private sector-associated institutions produced virtually no discoverable publications in the open, peer-reviewed literature, and the NGOs produced only a handful. The key outputs of these bodies are proprietary (and include technology demonstrators), or else take the form of application-oriented reports in the 'grey literature', not visible to bibliometric surveys.

5.1.4 Collaborations, networks and co-production

Much climate change science research is collaborative, within and across disciplines, and takes place in universities, research centres, institutions and councils in South Africa and beyond its borders (Second National Communication, 2012). An important attribute of the producers of research in South Africa is that although there are identifiable organisations which conduct research or which are national leaders within specific aspects of climate change science, there is extensive interlinkage between organisations, and within and across sectors and disciplines. There is also a shared infrastructure: supercomputing through the Centre for High Performance Computing, and the two new Research Infrastructures announced in October 2016, to be hosted by SAEON.

Future Earth

Future Earth was formed in 2015 through the amalgamation of several pre-existing International Council for Science (ICSU) and International Social Science Council global change research programmes, such as the International Geosphere-Biosphere Programme (IGBP), Diversitas and the International Human Dimensions Programme (IHDP). It is an international research platform providing the knowledge and support to accelerate transformations to a sustainable world. It is mostly a coordination and idea-sharing network, but is linked to the Belmont Forum, which is a funding network to which South Africa belongs (via the NRF). Many South African research projects are affiliated to Future Earth, and several South African researchers hold leadership positions in their programmes. South Africa hosts one of the African regional offices of Future Earth.

ICSU Regional Office for Africa (ROA)

ICSU ROA was formed to promote the participation of African scientists and institutions in international activities, including in climate change. It is headquartered in South Africa and since 2015 has been hosted by ASSAf. To date, it has been only marginally effective in its task.

Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL)

SASSCAL is a collaboration between Germany and Angola, Botswana, Namibia, South Africa and Zambia in response to the challenges of global change. It supports research in those countries, but also has its own infrastructure and programmes.

African Climate Change Adaptation Initiative (ACCAI)

Currently housed within the University of Ghana, ACCAI is a network of researchers from universities across Africa with the purpose of building capacity and knowledge in the field of climate change and food security. South African partners are SU and Wits.

European Union (FP7 and Horizon 2020)

The European Union Framework Programme Seven (FP7) for Research and Development, preceded by Horizon 2020 (H2020), is Europe's major support instrument in the field of science, research and innovation. South African researchers have participated actively in this large scale collaborative research and innovation programme that has a dedicated thematic area on resource efficiency, environment and climate action. The objective of the Societal Challenge "Climate action, environment, resource efficiency and raw materials" is to achieve a resource and water efficient and climate change resilient economy and society, the protection and sustainable management of natural resources and ecosystems, and a sustainable supply and use of raw materials, in order to meet the needs of a growing global population within the limits of the planet's natural resources and ecosystems. South African participants collaborated in more than 28 environment research and innovation actions in FP7 and to date, have participated in over 16 research, innovation, coordination and support projects in H2020.

The pattern of international links

Countries that South African researchers interviewed for this report identified themselves as being linked to within research teams that are working on joint projects include Japan, Germany, Australia, Brazil, India, UK, US, Southern African Development Community (SADC) countries, Norway, Belgium and Egypt. The bibliometric survey revealed these, and many other countries, as authoring papers relevant to climate change in southern Africa, many co-authored with South Africans. Half of the linkages are provided by six countries: USA (14%), UK (13%), Australia (7%), France (7%), Germany (6%) and Canada (4%); and four-fifths by a further 17 countries. Links to BRICS countries combined to 4.3%, and to African countries 8.9%. The list of linked countries is growing: it was around 40 in 2006, but by 2015 had grown to 135 countries.

The value of co-production (i.e. the generation of knowledge collectively by researchers and users) is suggested to be high in the field of climate change because of the strongly applied focus of co-produced knowledge. Particularly in the sphere of adaptation, there are many benefits evident. At the city-scale, for example, skilled officials in Cape Town

work together with UCT researchers on flood adaptation and disaster management research in a project called FRACTAL (Box 2).

Box 2: An example of knowledge coproduction: Future Resilience of African Cities and Lands (FRACTAL)

Through co-production, those who are traditionally knowledge users also become generators of knowledge, improving the relevance and uptake of the work. The FRACTAL project, involving CSAG and the City of Cape Town, aims at improved understanding of decision-making related to climate change within an urban context. Across a wide spectrum of decision-making concerns, the FRACTAL Project facilitates the coordinated use of cutting-edge data analysis, mapping and focused data sets to plan for flood impact amelioration, for example. Here emphasis is placed on the interlinkage between technical climate science information with urban management and future city development. A co-produced book on urban resilience, governance and climate change adaptation is set for release in 2017. Each chapter has been co-authored by a city official and an academic working in partnership.

5.2 Research outputs 2005-2015

It was reported in the Second National Communication (DEA, 2009, 2nd National Communication, 2011) that the number of researchers and the number of peer-reviewed publications produced in South Africa remained static from 1999 to 2009. In contrast, the present study finds the South African climate change science research community to be productive, internationally well respected and growing over the period 2006-present.

The number of peer-reviewed journal articles and book chapters relevant to topics related to climate change and its impact in South Africa (for search criteria, Appendix 5) has been rising at an average of 16% per year over the past decade, from 131 per year in 2005, to 596 in 2015 (with a further 478 in 2016 up to October). This is much higher than the rate of increase of South African publications on all research topics, which is about 5% p.a., and higher than the rate of increase in nominal funding (12% p.a.) or real funding (6% p.a.). The mean number of times these papers are cited by other authors, a measure of the impact of the paper, is 24.7 times, which is high by global standards in this or any field. During the 2006-2015 period the number of times any given South African climate change paper was cited rose more-or-less linearly year by year, reaching a plateau after about eight years. Therefore, to test whether the citation rate is rising or falling over the period, the number of citations after five years was calculated, for the papers published in 2006 to 2010. The 5-year citation rate rose at a rate of 11.7% p.a. over this period.

There are outputs other than published papers generated by the research community. This assessment did not assess participation in national or international conferences, where those did not result in a full published and peer-reviewed output. Other outputs include software products (climate models and impact forecasting applications, systems for the support of decision-making, portals and databases for information access), technology demonstrators, new cultivars, published reports, briefing notes and newsletters to users in

the public and private sectors not visible to bibliometric services, such as Web of Science, as well as strategies, implementation plans and policy inputs in the public and private sectors.

The output performance of the climate change research area compares favourably with the national average in terms of both publication rate (and citation rate) and high-level skills developed per million Rand invested. On average in South Africa, one publication results from about R1.8 million invested; in climate research, it averages about R670 000 per publication (a value similar to output efficiency in Norway, for instance). It also compares favourably with international benchmarks in terms of quality and productivity. The citation rate for South African authored climate-related publications is high and rising.

5.3 Production of postgraduate students

The numbers of Masters and PhD graduates in climate change-related fields (according to thesis title) per institution over the period 2005 to 2015 are presented in Table 5-3 and Table 5-4 respectively. While the database is imperfect and likely reflects an under-representation of graduates due to search terms used, it provides a useful baseline of high-level human capital development.

Both Masters and PhD outputs are dominated by the top five institutions (UCT, SU, UP, UKZN and Wits) identified earlier. The total number of graduates over the period is 454, of which almost 30% are at the doctoral level.

Table 5-3: Production of MSc graduates in climate-related fields from South African universities in the period 2005-2015, from the NRF database of graduates

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | TOTAL |
|--------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|
| UCT | 3 | 0 | 2 | 3 | 5 | 8 | 9 | 8 | 8 | 18 | 7 | 71 |
| Wits | 0 | 1 | 1 | 6 | 5 | 1 | 5 | 2 | 6 | 6 | 0 | 33 |
| UP | 3 | 7 | 11 | 5 | 3 | 6 | 5 | 5 | 10 | 5 | 4 | 64 |
| UJ | 0 | 2 | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 1 | 0 | 8 |
| UKZN | 2 | 0 | 1 | 0 | 6 | 2 | 6 | 7 | 7 | 3 | 0 | 34 |
| SU | 4 | 7 | 4 | 7 | 1 | 6 | 8 | 9 | 3 | 6 | 5 | 60 |
| UWC | 1 | 0 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 12 |
| NWU | 0 | 0 | 0 | 3 | 0 | 2 | 3 | 4 | 2 | 3 | 3 | 20 |
| NMMU | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| RU | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 |
| UFS | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 6 |
| UL | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Unisa | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 2 | 7 |
| UZ | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| VUT | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| TUT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 |
| TOTAL | 16 | 18 | 21 | 27 | 28 | 28 | 39 | 41 | 38 | 47 | 23 | 326 |

Table 5-4: Production of PhD graduates in climate-related fields from South African universities in the period 2005-2015, from the NRF database of graduates

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | TOTAL |
|--------------|----------|-----------|-----------|----------|----------|-----------|-----------|-----------|-----------|-----------|----------|------------|
| UCT | 0 | 1 | 2 | 2 | 1 | 3 | 3 | 1 | 4 | 4 | 1 | 22 |
| Wits | 0 | 2 | 2 | 0 | 1 | 2 | 2 | 0 | 0 | 2 | 0 | 11 |
| UP | 2 | 4 | 6 | 3 | 4 | 3 | 5 | 1 | 1 | 2 | 3 | 34 |
| UJ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| UKZN | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 3 | 5 | 0 | 0 | 12 |
| SU | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 4 | 2 | 5 | 3 | 22 |
| UWC | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 |
| NWU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| UFH | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| RU | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 |
| UFS | 1 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 1 | 0 | 9 |
| Unisa | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 1 | 7 |
| TOTAL | 5 | 11 | 11 | 9 | 7 | 15 | 15 | 11 | 15 | 20 | 9 | 128 |

5.4 Representation of South African researchers in international bodies

The number of South African researchers who are represented or serve in leadership positions on international research coordination or assessment bodies in climate change-related fields is an important indicator of South Africa's research standing in the field and presents an opportunity for South Africa to shape and contribute to international research agendas and assessment reports.

Although it has not been possible to extract comprehensive statistics for this first report, indications are that since South African researchers make up no more than 1% of global researchers, their presence on many international bodies as reflected in Table 5-5 is indicative of their significant international role. South Africans are sought-after in this role because of their competence and African perspective.

Table 5-5: Number of South African researchers represented on international research coordination or assessment bodies in the field of climate change, 2006 to present

| Body | Number |
|---|--------|
| IPCC | 29 |
| Future Earth | 4 |
| International Commission on Atmospheric Chemistry and Global Pollution (iCACGP) | 5 |
| IGBP | 1 |
| IHDP | 12 |
| World Meteorological Organisation (WMO) | 3 |

| | |
|--|-----------|
| Intergovernmental Board on Climate Services | 1 |
| International Global Atmospheric Chemistry (IGAC) | 3 |
| Stratospheric Processes and their Role in Climate (SPARC) | 2 |
| Climate and Ocean – Variability, Predictability and Change | 9 |
| TOTAL | 69 |

5.5 Priorities for future research

It is difficult to determine the current topic balance within the research programmes based on the broad subject classifications in the bibliometric database (Figure 5-2). For instance, a rough classification suggests that 93% of the recorded output in the 2006 to 2015 period was in the natural and engineering sciences, while 7% was in the humanities and law. However, these two broad branches of research publish in different ways, and are not represented in the Web of Science database equally. Bearing these reservations in mind, only rough profiles can be drawn. Perhaps unsurprisingly, the most active publishing field was the broad category of ‘environmental sciences and ecology’, at 19% of the output. ‘General earth systems’ contributed about 11% and ‘climatology and meteorology’ comprised about 10%. The cluster around ‘biodiversity, including conservation, zoology, freshwater and marine biology’ also contributed 10%. Among the impact fields ‘agriculture and food security’ amounted to about 6%, ‘oceanography and fisheries’ 4%, ‘water resources’ about 4% and ‘health’ 3%, with ‘urban and transport’ under 1%. The engineering topics such as ‘energy systems’ contributed only 2% (but engineers typically make prototypes rather than publish in the peer-reviewed literature).

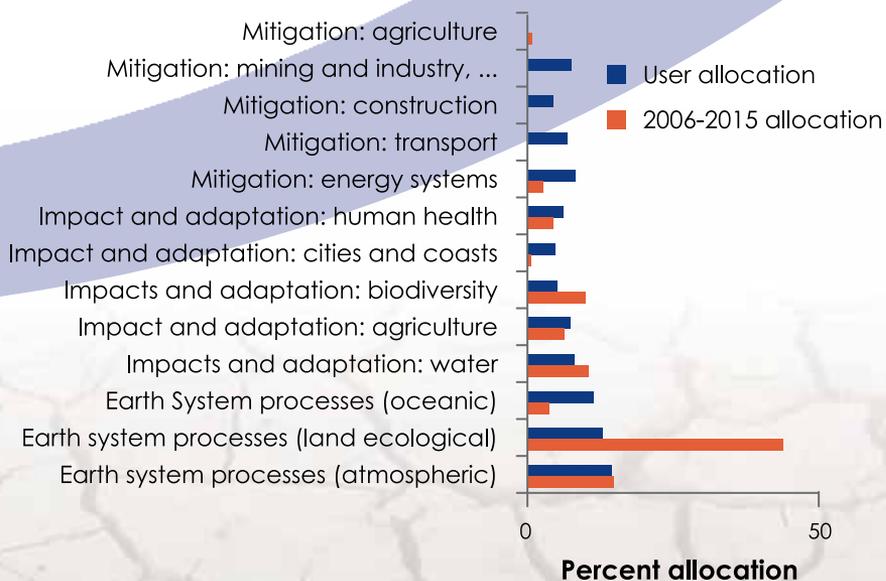


Figure 5-2: The pattern of research outputs over the past decade in broad fields, and the pattern indicated by 10 key stakeholders for the future period

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Note: The future preferences were elicited through structured interviews with key institutional users of climate research (Appendix 5). Neither the output nor the preference dataset is perfect, so this graphic must not be over-interpreted. What it shows, with some confidence, is that the users consider mitigation research as requiring relatively more attention than in the past.

An analysis of research needs and priorities extracted from climate change reports, adaptation plans and strategies at national, provincial and municipal level provides another way of determining priorities. The prioritisation of areas of research in the next five to ten years given by researchers and research organisations is closely aligned to the priorities of state policy (Table 5-6).

Table 5-6: Policy-based priorities for future climate change science research

| Research Priority National Document | Prioritisation of research | Prioritisation of technology development and uptake | Focus on impact and adaptation | Prioritisation of a shift to a low carbon economy | Land, air and ocean, and interrelationships | Water resources and water scarcity | Human health implications | Energy and renewable energy | Agriculture and food security | Access to data and information | Observation and monitoring | Urban development and resilience | Modelling capabilities and alignment of models |
|--|----------------------------|--|-----------------------------------|--|--|---------------------------------------|---------------------------|--------------------------------|-------------------------------|-----------------------------------|----------------------------|-------------------------------------|---|
| National Development Plan (2011) | X | X | X | X | X | X | X | X | X | | | X | |
| New Growth Path (2010) | X | X | | X | | | | | X | | | | |
| Medium-Term Strategic Framework, 2014-2019 | X | X | X | X | X | X | X | | X | X | X | X | X |
| National Strategy for Sustainable Development and Action Plan (NSSD1), 2011- 2014 | X | X | X | X | X | X | X | | | | | X | X |
| National Climate Change Response White Paper (2011) | X | X | X | | X | X | | X | X | X | X | X | X |
| Draft Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors (2015) | X | X | X | | X | | | | X | X | X | | |
| National Skills Development Act (1998), with Amendments | | X | | | | | | | | | | | |
| Ten-Year Innovation Plan (2008) | | | | | | | | | | X | | | |
| Carbon Tax Policy Paper (2013) | | | | | | | | X | | | | X | |
| Energy Policy White Paper (1998) | | | | | | | | X | | | | | |
| Framework for South Africa's Response to the International Economic Crisis (2008) | | | | X | | | | | | | | X | |

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| Research Priority National Document | Prioritisation of research | Prioritisation of technology development and uptake | Focus on impact and adaptation | Prioritisation of a shift to a low carbon economy | Land, air and ocean, and interrelationships | Water resources and water scarcity | Human health implications | Energy and renewable energy | Agriculture and food security | Access to data and information | Observation and monitoring | Urban development and resilience | Modelling capabilities and alignment of models |
|---|----------------------------|--|-----------------------------------|--|--|---------------------------------------|---------------------------|--------------------------------|-------------------------------|-----------------------------------|----------------------------|-------------------------------------|---|
| ICT Research, Development and Innovation Roadmap (2013) | | X | X | X | | | | | | X | | | |
| Industrial Policy Action Plan, 2012/2013 – 2014/15 | | X | | | | | | X | | | | X | |
| Integrated Resource Plan for Electricity (IRP) 2010-2030, Update Report (2013) | | X | | X | | | | X | | | | X | |
| National Energy Act (2008) | | X | | X | | | | X | | | | | |
| National Energy Efficiency Strategy (2005, 2008, 2012) | | X | | X | | | | X | | | | X | |
| National Environmental Management Act (1998), and Amendments | | | | | X | | | | | | | | |
| National Environmental Management: Air Quality Act (2004) | | | | | X | | | | | | X | | |
| National Environmental Management: Biodiversity Act (2004) | | | | | X | | | | | | | | |
| National Framework for Green Buildings (2011) | | | | | | | | | | | | X | |
| National Water Resources Strategy 2 (NWRs 2) (2013) | | X | X | | | | | X | | | | | |
| Renewable Energy White Paper (2003) | | X | | X | | | | X | | | | | |

| Research Priority National Document | Prioritisation of research | Prioritisation of technology development and uptake | Focus on impact and adaptation | Prioritisation of a shift to a low carbon economy | Land, air and ocean, and interrelationships | Water resources and water scarcity | Human health implications | Energy and renewable energy | Agriculture and food security | Access to data and information | Observation and monitoring | Urban development and resilience | Modelling capabilities and alignment of models |
|--|----------------------------|--|-----------------------------------|--|--|---------------------------------------|---------------------------|--------------------------------|-------------------------------|-----------------------------------|----------------------------|-------------------------------------|---|
| Strategic Plan for the Department of Agriculture, Forestry and Fisheries (2015) | | | | | | | | | X | | | | |
| Sub-national Priorities | | | | | | | | | | | | | |
| Eastern Cape (Province) | | X | X | X | X | | | | | | | X | |
| Gauteng (Province) | X | X | X | X | | X | X | | X | X | X | | |
| Limpopo (Province) | X | X | X | | | X | X | | X | | | | |
| Mpumalanga (Province) | X | X | X | X | X | X | X | X | X | X | | X | |
| North West (Province) | | X | X | X | X | X | X | X | | X | | | |
| Northern Cape (Province) | | X | X | X | X | X | X | X | | X | | | |
| Western Cape (Province) | X | X | X | X | X | X | X | | X | X | X | | X |
| Cape Town (City) | X | X | X | X | X | X | X | X | | X | X | X | X |
| eThekweni (City) | X | | X | X | X | X | X | X | | | | | |
| Ekurhuleni (City) | | | | | | | | X | | | | | |
| Johannesburg (City) | | X | X | X | X | | X | X | | X | X | X | X |
| Tshwane (City) | | X | X | X | X | X | X | X | X | X | | X | |
| Msunduzi (Municipality) | | X | X | | | | X | X | X | | | X | |

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In the process of interviewing stakeholders from across the climate change R&TD system, and including a deliberately representative sample of the spectrum of funders, research performers and users, all drew attention to the following priorities for research:

- A focus on adaptation (as opposed to demonstrating climate change or elaborating on its causes)
- The technology and policy needs for a shift to a low carbon economy
- Linkages between the land, air and ocean parts of the climate system
- Impacts of climate change on water resources
- Sustainable urban development and urban resilience
- Energy and renewable energy systems
- Agriculture and food security
- Human health implications of climate change

In addition, the following broad issues relating to building research capacity were raised:

- Attention to adequate observation and monitoring of climate system variables and impacts
- The ability to access and process data
- Modelling capabilities and alignment of models
- Science-policy-practice interface

A slightly more quantitative elicitation (but weakened by the low response percentage) involved asking key institutional research users a number of clear questions: for example, what fraction would they allocate to fundamental versus applied research (40 and 60% respectively); to oceans, land and atmosphere (almost exactly a third each); how much to natural sciences versus social sciences (about half-half), and to impact and adaptation work versus mitigation work (also half-half). In terms of impact areas, the priorities were water (25%), food and agriculture (23%), human health (19%), biodiversity (17%) and urban areas (16%). On the mitigation side, energy led with 31%, then mining and industry (30%), transport 24% and construction 17%. The sample was small (ten) but representative of major categories of users, and the variation between respondents was very small. These elicited priorities are in several ways quite different to the activity pattern imperfectly revealed by the published outputs described above; particularly in the mitigation area, but the use of published papers as the only metric of past focus is not directly comparable to the approach for eliciting future needs.

It is argued by many stakeholders that the sources of current climate change patterns are relatively well understood, and the broad outlines of mitigation needs are reasonably clear, but there needs to be a greater understanding of the potential responses to climate change at local scales. The complexity of the social-ecological system is recognised.

The ongoing need for observation and monitoring of basic meteorological, oceanographic, ecosystem and human system variables is a priority of researchers and is noted in several places in national-level policy and in the Second National Communication. The poor availability of observational data and information for use by various stakeholders is viewed as a critical constraint to implementation of climate adaptation measures in agriculture, water resource management, health care and disaster management. The systematic coordination and management of these observations is also a priority for research

funders and the researchers themselves. The need for better access to data includes weather station observation and aspects such as hospital intake records, which are often unavailable, incomplete or dispersed across various parts of the health care system. Careful, extensive and costly data-capture is required before many of the datasets are able to be used. Other data types frequently mentioned as costly or unavailable are climate records and high resolution satellite imagery.

The newly announced DST-funded Research Infrastructures, particularly those for terrestrial and shallow marine (coastal) research, will go a long way toward alleviating these data constraints.

A strong climate modelling capacity, including computing power, storage and bandwidth, with an African perspective, is a current and future research priority. The overwhelming majority of global circulation models are based in the northern hemisphere (more land than ocean, in contrast to the southern hemisphere, which is predominantly oceanic) and are all focused on the concerns of developed countries, which is politically problematic. The advanced modelling capacity acquired by South Africa will need to be further supported in the medium term in order to fully develop and test the models and to analyse the results of the modelling and their implications. A better understanding of the decadal timeframe changes and impacts on seasonal weather are key objectives. Improved forecasting is important from the point of view of predicting seasonal changes that affect agriculture, industry, water availability. The ability of models to provide down-scaled projections is a key requirement for the advancement of climate modelling.

Each sector affected by climate change or which is engaged in mitigation and/or adaptation considerations has their own specific priorities for research in the next five to ten years. The financial and economic implications, drivers and processes of the shift to a low carbon economy is of importance. Other priorities include deeper and more expansive research on the linkages between land, air and ocean systems; shifts in climatic zones; the inter-relationship between climate change, water resources and water security; sustainable urban development and urban resilience; energy and renewable energy systems; agriculture and food security; biodiversity and plant genetics, and the human health implications of climate change. Across this multi-sector range of priorities is the concern that climate science needs to be relevant to the needs of South African society, for example, concern for employment and poverty alleviation through the green economy.

5.6 The interface between climate science, policy, the economy and society

There is a relatively strong link between policymakers, and implementers of research findings and the researcher community in South Africa (compared with many other countries), but in some respects, there is room for improvement. The interface between policy and science is a relationship much discussed and debated around the world, but the relatively small size of the South African research community, and its willingness to address policy-domain issues, means that the gap between research and practice is smaller in South Africa than in many other countries. There are many people working

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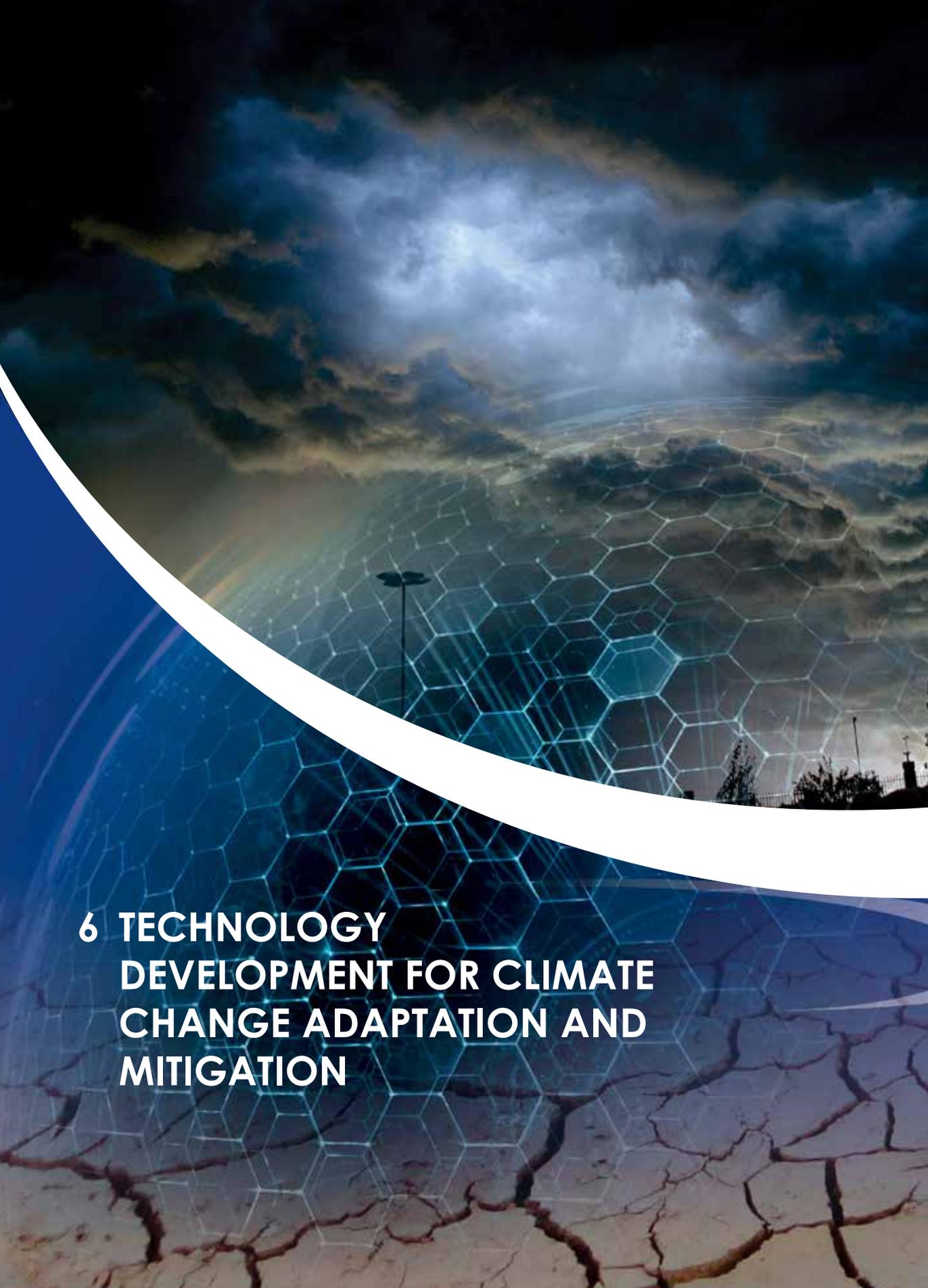
together across research and government institutions. Much of this engaged work is focused on policy support and development. The research councils regularly report research outcomes and progress to standing committees at the provincial and national scale. Research programmes within the science councils in particular, but also in several university-based centres, are designed in consideration of the national development priorities and ministerial mandates. Researchers have major input into global reporting required by South Africa's commitments to the United Nations and other multinational organisations. There are cases where university-affiliated research centres and national departments cooperate in staff exchanges to build research capacity, foster knowledge sharing and integrate science and governance processes, for example, between the Energy Research Centre and DEA. Not all relationships within and between government and the research community are equally good. At times, differences in the mandates of different national departments create challenges for cross-sectoral researchers who wish to engage across multiple departments.

Notwithstanding the above partial successes, it has been argued that a further step in science-policy engagement needs to take place – notably in the area of regulation as a means of policy implementation.

There are debates regarding the best form of engagement between science and policy in South Africa. Historically, it is evident that the natural sciences have dominated the discourse of climate change from science to policy. The emergence of co-production as an approach to improving the science-policy interface is not supported by all scientists: it is an uncomfortable and unfamiliar mode for many natural scientists. The benefits of co-production in the applied domain, that integrates practitioner, government and science experiences of climate change mitigation and adaptation need to be complemented by traditional research modes in the more fundamental domain. A spectrum of enquiry-driven science to applied science is thus accepted as necessary, but strenuous efforts are needed to keep it seamless and integrated. The growing use of 'citizen science' is a further trend. Historically, the long-term weather data in South Africa were collected by volunteer observers. In the present time, much biodiversity data are collected this way.

The science-policy interface should also be considered from the perspective of the receiving environment within the state, the economy and civil society. The capacity of potential users of research to understand, interpret and apply climate science research outputs is critical to the effective use of research in climate change response, including within the area of policy formulation and implementation. Furthermore, the apparent lack of urgency, and the insistence on the research-generating side of the system on ever-more accurate detail rather than fit-for-purpose confidence in the big picture can be frustrating for those in the user environment. They need information quickly, and often a broadly correct answer supplied timeously is much better than a detailed one which is too late. Research outputs in academic publications take time and may not be immediately useful to policymakers. Grey literature and contract-based research reporting are forms of research output more suited to this task, but need to be recognised by the research system as legitimate products. Funding structures and research priorities and capacity need to be aligned for the science-policy interface to work well.



The background is a composite image. The top half shows a dramatic sky with dark, heavy clouds and a bright rainbow arching across the horizon. A hexagonal grid pattern, resembling a molecular or crystalline structure, is overlaid on the sky. The bottom half of the image shows a close-up of cracked, dry earth, with the same hexagonal grid pattern overlaid. A white curved line separates the sky from the cracked earth. In the middle ground, a street lamp and some trees are visible against the sky.

6 TECHNOLOGY DEVELOPMENT FOR CLIMATE CHANGE ADAPTATION AND MITIGATION

Technology development (TD) (including the notion of technology transfer), which is the refinement and upscaling of research-inspired ideas to the point of market readiness or widespread adoption, is a crucial element of the innovation system if it is to deliver on its promises to promote economic growth, social benefits and employment. This is particularly true within the emerging 'green economy', which is knowledge and innovation-intensive. There is thus a demand for the technology sector to play an increasing role within the South African response to global change.

South African Technology Development policy has tended to focus on what technology is needed in the country, and impediments in the TD process, rather than placing much emphasis on TD in South Africa itself. In its Second National Communication to the IPCC, South Africa adopted the IPCC (2000) definition of technology transfer in relation to climate change: a "broad set of processes covering the flows of know-how, experience, and equipment for mitigating or adapting to climate change amongst different stakeholders such as governments, private sector entities, and financial institutions" (2nd Communication, 2011, p 194). TD is somewhat broader: it includes identifying and researching appropriate technology, the development of technology, the adaptation of existing technologies, access to technology and the uptake of technology.

There is a general perception that more technology is used in relation to climate mitigation than climate adaptation programmes, but this does not necessarily follow. Some adaptation activities may also be technology-intensive, and some mitigation activities (carbon taxation, for instance) may be technology-light. The technology used for mitigation purposes has typically been imported into the country from performers based in developed countries and is then integrated into South African energy systems, industrial processes, transport, waste disposal and agriculture to reduce emissions, improve energy and water efficiency and minimise waste. The use of these technologies helps South Africa to meet its target of reducing carbon emissions while growing the economy. Failing to take a larger role in the development of such technology misses an opportunity to benefit fully from a new market. For instance, the rapid expansion of renewable energy technology, can be entirely based on imported technology, or can be partly locally sourced. For example, wind turbines (other than the tower bases) are not manufactured in South Africa, despite several startup attempts. Building an industry such as this requires policy certainty.

6.1 Actors in the South African technology development landscape

The following section outlines the key role players in the area of climate change-related TD.

Department of Science and Technology (DST)

The DST drives innovation through the following programmes³ (in addition to the research described in the previous section, which forms the bulk of the 'science and technology for global change' programme):

- i. space science and technology

³ www.gov.za/about-SA/science-technology

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- ii. hydrogen and energy
- iii. biotechnology and health innovation
- iv. innovation planning and instruments
- v. radio astronomy advances

The Environmental Services programme and the Sector Innovation programme may also make climate-related technology investments.

These programmes articulate with the climate-related applications in several ways: renewable and more efficient energy provision; the use of biotechnology and health science to promote adaptation to climate change impacts; and the supply of information required for climate change monitoring and research. The DST Biotechnology Strategy aims to build up the biotechnology sector through agriculture, health and industrial applications to a 5% contribution of the country's gross domestic product by 2050.

DST has two technology flagship programmes with some relevance to climate change R&TD, but since climate is not their primary focus, they have been excluded from the accounting: they are the Waste flagship and the Water Innovation and Development flagship. Water technology deployment is brokered by the Water Technologies Demonstration Programme, co-developed with the WRC.

Within the specific domain of dissemination of climate change-related technologies, DST uses several instruments. One is the SARVA, an IT portal making research findings available to users. A second is the Climate Technology Centre and Network (CTCN), an international expertise network where DST is the national focal point, and in which South Africa can act as both a technology supplier and a technology requester. The CTCN helps to prepare proposals to both the GEF and the Adaptation Fund. A third is the Climate Risk Centres located at several universities. A fourth is the national and international effort around Climate Services.

In terms of TD funding support, DST operates mostly through its agency, TIA.

Technology Innovation Agency (TIA)

The Technology Innovation Agency (TIA), was created by the Technology Innovation Agency Act (No. 26 of 2008). It is a public entity focused on supporting the research, development and commercialisation of technology within South Africa. TIA invests in a host of technology sectors, including support of both products and services related to advanced manufacturing, agriculture, health, energy, and industrial biotechnology – all of which have relevance and utility within climate change-related R&TD. Through support of innovation, TIA plays a role in facilitating the development of new industries and fostering the kinds of economic development needed by the country to create sustainable jobs and improve economic competitiveness with the global economy. TIA advances technological innovation in South Africa through a number of vehicles, including Biotechnology Regional Innovation Centres and the Innovation Fund. The Innovation Fund, operated by the NRF, invests in the completion of research and development stages of innovation, the protection of intellectual property and commercialisation of technologies.

Within TIA, TD is funded via the Technology Advancement Programme (TAP) and Missions in Technology (MiTech) programme. These programmes foster involvement in technology via public venture capital and public private partnerships focused on the building of technology platforms. The TIA Commercialisation Office assists businesses with the commercialisation of technology and uses a 'Seed Fund' to assist product developers or start-ups to advance from prototypes to commercialisation. Climate change-related technology and the advancement of the green economy are both prioritised within TIA.

It should be noted that TIA is not intended to be the 'endpoint' of the technology development pipeline. It takes technologies to the proof-of-viability, pre-commercialisation stage. From there they are intended to be picked up by public or private sector financing bodies, such as the Industrial Development Corporation or venture capitalists, and by private sector corporations.

South African National Energy Development Institute (SANEDI)

SANEDI is a Schedule 3A state-owned entity established in 2011 as a successor to the previously created South African National Energy Research Institute (SANERI) and the National Energy Efficiency Agency (NEEA). The main function of SANEDI is to direct, monitor and conduct applied energy research and development, demonstration and deployment, as well to undertake specific measures to promote the uptake of Green Energy and Energy Efficiency in South Africa. Its current portfolios include: Cleaner Fossil Fuels (Clean Coal Technologies, South African Centre for Carbon Capture and Storage (SACCCS)), Renewables (Renewable Energy and Energy Efficiency Partnerships (REEEP), Renewable Energy Centre of Research and Development (RECORD), Wind Atlas of South Africa (WASA)), Energy Efficiency (Big EE, South African-German Energy Programme (SAGEN)), Green Transport, Smart Grids Energy Data and Knowledge Management (South African Smart Grids Initiative) and the Working for Energy Programme. SANEDI's vision is to serve as a catalyst for sustainable energy innovation, transformation and technology diffusion in support of sustainable development that benefits our nation. SANEDI's mission is to advance innovation of clean energy solutions and rational energy use that effectively supports South Africa's national energy objectives and the transition towards a sustainable low carbon energy future.

South African National Space Agency (SANSA)

SANSA, founded in 2010 by the amalgamation of several pre-existing elements, has the mandate to foster space science research, develop human capital in South Africa for advanced scientific engineering and to support the development of space technologies. SANSA facilitates international collaboration and cooperation in space science, and the agency provides ground-station services to a host of space missions, including some (such as NASA's Orbiting Carbon Observatory-2) which contribute to climate change research. It provides a range of operational earth observation services, and with Denel's Space Dynamics unit, is involved in satellite design and manufacture (including satellites with application in climate adaptation). SANSA also has a role in climate research, especially through its engagement with the South African National Antarctic Programme.

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Department of Environmental Affairs (DEA)

A significant part of the funding allocated by DEA in the area of climate change R&TD can be classified as technology development – the roll-out of existing knowledge at operational scale. This includes substantial support at national, provincial and local level to the climate adaptation strategies, as well as funding for mitigation experiments, and for the required reporting to the UNFCCC.

Eskom

Eskom, the state-owned utility responsible for most of the electricity supply in South Africa, has a Technology Services International group. This group consists of a multidisciplinary industrial laboratory and consulting organisation which works on the assessment of new energy-related technology in terms of its appropriateness for South Africa and the integration of energy technologies into the South African system. These include several important climate mitigation technologies, such as energy efficiency, renewable energy and low carbon fuels.

Sasol

Sasol, the large formerly state-owned, now privatised, petrochemical company which specialises in coal-to-liquid and gas-to-liquid technologies, includes Sasol Laboratories, the largest single private sector TD team in South Africa, and one with considerable relevance to shifting to a low carbon development path. It has been a significant contributor to CCS research locally and internationally. Sasol is a particularly promising candidate for CCS since the very large gaseous waste stream it generates is 98% CO₂.

Council for Scientific and Industrial Research (CSIR)

The CSIR has been discussed in Section Five as a research organisation, but its mandate also covers TD. In the realm of TD for climate change, the operational delivery of advanced climate model analyses is a key technology developed at CSIR, which is also active in energy technologies such as batteries, hydrogen as an energy store and solar power.

Water Research Commission (WRC)

The WRC, discussed as a research funder in Section Four, has a mandate which extends to funding TD as well. It is active in agricultural water-use, effluent management, membrane technology, hydraulics, and the transfer of technology related to efficient water usage.

Universities

Much of the pre-commercialisation TD work in South Africa is conducted in engineering faculties in the South African universities, which include several styled as 'Technology Universities'. Renewable energy and energy efficiency are leading topics.

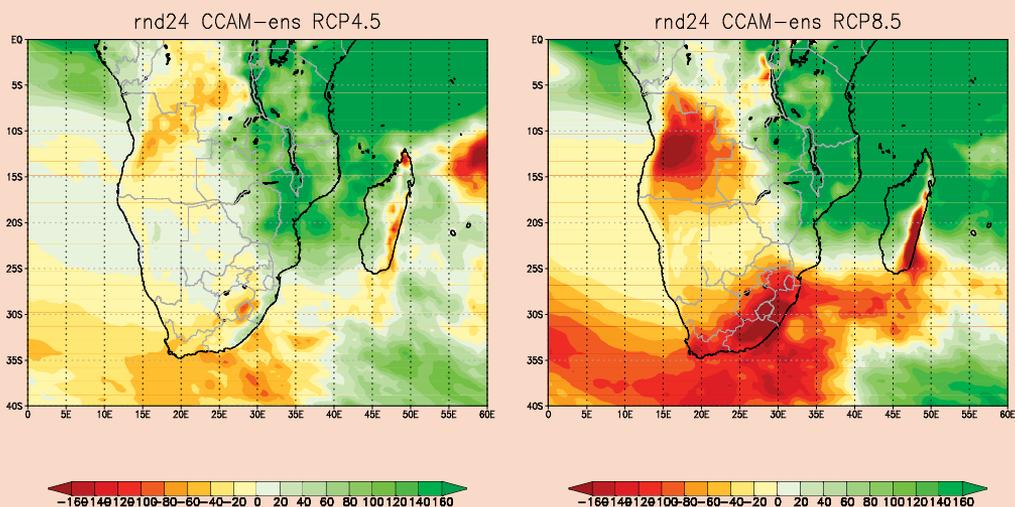
6.2 Metrics of climate-related technology development

The impact measures for technology development are less easy to establish than those for research because of the longer period required to achieve measurable impacts, difficulties of attribution of success, and disagreement on how impact should be measured. Nevertheless, it is widely perceived by those responsible for implementing adaptation and mitigation actions that the system as a whole is underperforming in terms of producing operational technologies within South Africa. Partly this may be an unrealistic expectation of what fraction of the solutions can be produced solely by the South African system (which is very small relative to the global technology performers). It is also due to poor coupling between the research and development elements of the South African system (the ideas developed in the research domain may be poorly aligned to market and societal needs, and good ideas are not identified at the appropriate stage and then nurtured and sustained through the development process). It is also likely due to underfunding of development relative to research. The latter deficiency is partly because the private sector in South Africa (with notable exceptions) is apparently almost absent from development funding, choosing rather to purchase tested technologies internationally.

One local success story is the downscaling of a global climate model to the local scale, an innovation that is critical for local climate projections (Box 3).

Box 3. Innovation success story: Downscaling of global climate to local projections

Much impact and adaptation decision-making depends on projections of the local climate in the future. The global models are too coarse for this purpose. The climate groups at CSIR and UCT (CSAG) have developed downscaling approaches to do this translation, in different ways: the only such capacity in Africa. The CSIR collaborated with CSIRO (Australia) and Japan to implement a coupled, stretched-grid approach which in successive stages can get down to 1 km resolution. UCT uses a nested model approach and statistical techniques. Both institutions are strongly linked to projects supplying climate information to governments and the private sector throughout Africa.



Downscaled (38 km) rainfall projections for the end of the 21st century, relative to the end of the 20th century, under a middle-of-road (global 2 C) and business as usual mitigation scenario, using the CSIR/CSIRO CCAM system [F. Engelbrecht]

6.3 Technology development priorities

Policy, strategy and research and technology performers argue that the priorities for technology development and transfer in South Africa include:

- Energy provision, renewable energy supply and the energy mix.
- Transport technologies, for people and goods.
- Climate-wise agriculture.
- Water-related technologies, including water harvesting.
- Waste-related technologies which reduce GHG emissions.

There is an overarching need to develop a range of generalised technology capabilities, including:

- Human capacity for technology development.
- A well-connected system for technology demonstration, piloting and then large scale roll-out.
- Technology tracking, important in the climate change space where the effectiveness and efficiency of various technologies are rapidly changing.
- Technology costing, market and economic analysis.
- An understanding of market conditions which impact the uptake of technology.
- Ability to assess the appropriateness of technology for local environmental conditions.

- The appropriateness of technology for use in the range of socio-economic contexts in South Africa, in particular in relation to rural and informal settlement communities and the uptake of climate-smart technologies.
- Willingness of potential users to adopt new or adapted technologies.

Given the coal-based history of energy supply in South Africa and the need to shift to a less carbon-intensive economy, technologies related to energy are of strong interest. Identifying barriers to the roll-out of efficient energy supply and use is a key aspect of technology transfer in the energy sector. 'Cleaner' forms of fossil fuel-based energy sources, such as improvements in scrubbers, and batteries with longer and more effective storage, particularly in relation to intermittent forms of renewable energy such as solar or wind power, are other priorities.

6.4 Gaps and barriers in the R&TD value chain

The innovation system as it applies to finding solutions to climate change challenges for South Africa is depicted in Figure 6-1. A key point is that South African research and development efforts are embedded in a much larger global effort (South African contributions are of the order of 1%), which is partly shared knowledge ('public goods') and partly proprietary knowledge ('private goods', especially technologies). Gaps and barriers can develop in many places within this system, reducing the effectiveness of South African adaptation and mitigation efforts.

The cycle begins with the problem of global climate change, which is itself evolving in response to new findings, technologies and international agreements. To drive South African innovation, the problem needs to be both well-understood and perceived to be important (barrier 1). Climate change is still perceived by many to be a distant problem, displaced by more urgent development challenge; a perception which can be addressed with reliable climate monitoring systems and good communication of the risks of climate change. The mechanisms for translating societal needs into a prioritised research programme (barrier 2) largely exist in South Africa, but the loop is not always closed to ensure that promises of alignment between need and outcomes, made at the research proposal stage, are accompanied by actual and effective execution. Figure 5-2 illustrated the mismatch between what the users of research and technology perceive as the key needs in the coming decade, and what has been published in the past decade. The solutions lie in rigorous research governance and an appropriate balance between exploratory and directed research. The bi-directional connection between the South African research community and the global research community (potential gap 3) is very good (South Africa fares much better than other African countries, and even some BRICS countries in this respect), but needs to be actively managed and supported to ensure succession within the research networks, particularly as South African science transforms.

It is widely acknowledged that one of the weaker links in the system is the 'technology chasm' which exists between promising ideas developed in the research domain and operational technologies developed by market and implementation-facing institutions (gap 4). Most innovations fail to cross this gap. The solutions include better coupling

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between the research and development elements of the system, the application of a phased and scaled funding model, with stage-gates filtering out unfeasible ideas and supporting promising ones, and the creation of a South African venture capital mechanism.

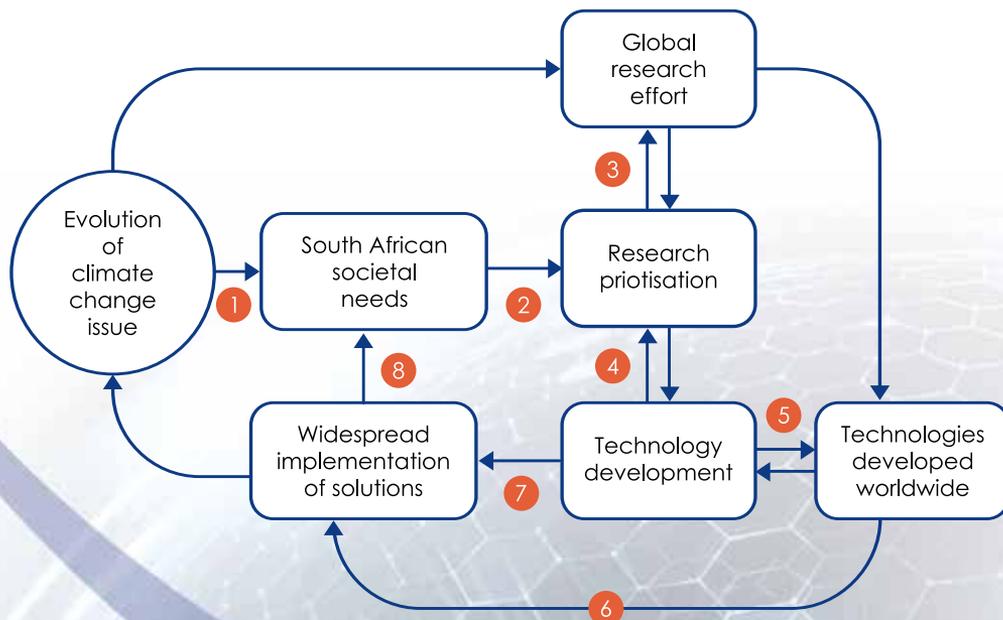


Figure 6-1: The innovation system with respect to responses to the challenge of global climate change

Note: (1) problem perception (2) alignment of research to needs (3) interaction with the global research community (4) interaction between researchers and technology developers in South Africa (5) interaction between South African technology developers and international technology developers (6) transfer of licensed and unlicensed technologies from global sources (7) technology transfer from local sources (8) maladapted technologies.

The link between South African technology developers and the world players (gap 5) can be improved. Partly its weakness is a post-colonial, post-isolationist legacy: on the one hand our development agencies tend to believe we can always do the job better ourselves; while on the other hand, the implementing entities in practice access most of their technologies abroad. Where South Africa has been most effective in technology adoption in the past is through developing effective partnerships; South African entities add local value while simultaneously gaining privileged access to world-class technologies. Link 6 is the traditional 'technology transfer' path favoured in treaties such as the UNFCCC. It is an expensive and risky dependence if South Africa does not at the same time have a competent R&TD system of its own. The alternate path, through technology co-development and implementation of the locally-adapted version through South African partners (link 5 then 7) is both more economically sound and more secure. Failure to do so increases the risk of maladapted technologies (barrier 8).





7 CONCLUSIONS AND RECOMMENDATIONS

Section Seven draws conclusions based on the prior sections.

7.1 Summary of key findings

The following key findings emerge from this investigation and analysis.

- 1 The climate change science research community in South Africa is productive, internationally well respected and growing.** This assessment is based on a bibliometric survey of peer-reviewed journal articles and book chapters over the period 2005 to 2015. Outputs have increased by 16% p.a. over this decade, from 131 p.a. in 2005 to 596 p.a. in 2015, compared with a 5% p.a. growth in all research topics. The mean citation rate, a measure of the impact of a paper, is 24.7, which is high relative to global standards in this or any field. The survey also revealed strong international research linkages, with the number of research collaborating countries increasing from 40 in 2006 to 135 by 2015. There are strong links internationally, and many South African scientists serve in leadership positions in international climate change research and assessment bodies.
- 2 Over 30 institutions are engaged in climate research in South Africa, but the budgets and outputs are concentrated in five higher education institutions.** Five research-intensive higher education institutions (UCT, SU, UKZN, Wits and UP) dominate research output and production of graduate students. Over the period 2005 to 2015, they collectively produced 63% of South Africa's publications (UCT - 23%; SU - 12%; UKZN - 10%; UP - 9%; Wits - 9%). Postgraduate student output as measured by dissertations produced over the same period is also clustered in these five universities. Seven climate-relevant research centres and six SARCHI chairs were identified, and these too are concentrated in the same five institutions. ACCESS, which is a virtual Centre of Excellence (CoE) hosted at the CSIR and is a funder, coordinator and facilitator of research rather than doing research itself, includes seven universities and six research organisations. ACCESS is currently undergoing major restructuring following its five-year review and mid-term review of the GCGC.
- 3 There are strong linkages among climate change researchers in the various higher education institutions and between the university community, science councils and local and national government, but relatively weak linkages with the private sector.** A substantial fraction of climate change research is conducted in multidisciplinary, multi-institutional teams. Many of these teams have adopted 'transdisciplinary' approaches in which they co-generate knowledge with user groups, often in national or local government, or at community level. Researcher engagement with policy processes and products is quite high. Collaboration between research institutions and the private sector, on the other hand, where much of the technology development takes place, is relatively weak and usually takes the form of contractual arrangements.
- 4 There is a degree of mismatch between South African research strengths as evidenced by published output, and the research priorities as identified by users and reflected in policy documents.** South African research strengths in the climate-related field are disproportionately in ecology and biodiversity, strongly biophysical rather than

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social, and oriented toward fundamental understanding and impact analysis rather than mitigation and (to a lesser extent) adaptation. Interviews with climate change users, accompanied by questionnaire surveys, suggest that a greater emphasis on the social, legal, institutional and human dimensions of adaptation and policy implementation is desired in future work. There is also a desire for more engagement in mitigation-related work (especially technology development). This finding must be tempered by the high uncertainties involved in the determination of both past patterns of investment and future priorities.

- 5 Climate change-related research and technology development in South Africa is currently funded at around R400 million p.a., and this funding base has grown at about 12% p.a. (nominal, 6% real) over the past decade.** This funding is split about two-thirds research and one-third technology development, with the latter mostly taking place in two market-oriented organisations: Sasol and Eskom. South African climate change R&TD spend amounts to about 1.7% of the total South African research spend, which is towards the lower end of international developed country norms, but high for a developing country. Taken with the fact that total South African R&TD spend, at 0.76% of gross domestic product (GDP) (growing at 5% p.a. in nominal terms, with inflation currently around 6% p.a.), is at the lower end of the target desired by the NDP, there is room for continued real growth in climate change R&TD.

7.2 Recommendations for the period 2017 to 2019 (and beyond)

Recommendation 1: Ensure that future biennial reports include the critical information needed to provide a comprehensive ongoing assessment of the status of climate change science and technology research in South Africa, and guide future investment.

This report represents the first assessment of climate-related R&TD in South Africa, which is intended to be produced on a regular two-yearly interval in future. The requirement of biennial reports to Cabinet signals the national importance of this thematic research area. This report has focused on the key performance areas as defined by the study brief. It turned out to be very difficult to extract robust and consistent information relating to **expenditure** and **performance** in relation to climate change research and development across the wide range of actors. Currently no formal mechanism exists to do so. Investment in climate change R&TD is a long-term strategy that is supported by national and international policy. It is imperative that South Africa is able to report in a comprehensive manner on national government and private sector funds invested, international research funds secured, and outcomes achieved. It has been difficult to amass such information for this first report as there is no central repository and many sources have been slow or reluctant to provide information. A new body or process is not proposed to do so, but enhancements to existing mechanisms, such as audited annual accounts and the annual R&D surveys, are recommended. A more comprehensive and representative process for determining R&TD investment priorities is also required.

Recommendation 2: Build on South Africa's research advantages in climate change science, using cross-sectoral, interdisciplinary, inter-institutional and international partnerships where appropriate to steer the R&TD portfolio in greater alignment with perceived needs.

South Africa has a relatively small scientific community, by world standards. It cannot be expected that it can achieve international recognition in all aspects of research, but it does remarkably well in climate change-related research. There are pockets of global excellence, mostly situated in the top five research-intensive universities and two science councils. It makes good sense to invest in these high performers, while simultaneously guiding them, through appropriately-structured funding calls and key performance metrics, into needed areas and deeper engagement with government, industry and civil society.

Annual output of graduates is high – about 50 per year, one-third at doctoral level. The challenge is to broaden the skills base so as to be more inclusive of the remaining higher education institutions and to facilitate the building of research capacity in strategic thematic areas that are inadequately covered. While it would not be wise to consider strengthening climate change science and technology at every institution, an assessment should be undertaken of current partnerships, capacity in terms of research personnel, infrastructure and students, and then a decision taken as to which institutions should be supported to become better integrated into the South African climate change research community and on what topics, thereby avoiding proliferation of relatively weak and fragmented pockets of research.

The virtual CoE, ACCESS, and other programmes, such as the Climate Risk Centres, can play a strategic role in building research links between the leading institutions and institutions currently on the margins. This role should aim towards functional though distributed integration with the current research hubs, rather than supporting isolated and uncoordinated projects.

Recommendation 3: Fully use all the opportunities for South African researchers and technology developers to access international funding sources.

South African climate change researchers have been successful at participating in competitive international collaborative research and accessing international funding streams, through for example the EU Framework Programme 7 and Horizon 2020; the Belmont Forum; and the UK DFID/NERC. It is less clear that South Africa is fully and actively using the new climate technology development funds for adaptation and mitigation made available as a result of the UNFCCC Paris Accord and its predecessors. Typically, this requires active intervention by the government departments appointed as focal points, and in the case of bilateral arrangements, through energetically pursuing the full potential of the agreements with various countries and administered by government departments, especially in this case, by DST and DEA. It also requires attention to the processes and institutions involved within South Africa proposing for and allocating such funds. The channeling of climate adaptation funding through SANBI is not appropriate for all the topics to be covered under 'adaptation' and raises issues of being both a fund administrator and potential user of the same funds.

Recommendation 4: Provide financial and diplomatic support to South African scientists involved in high-level international assessment and research bodies and committees.

This report has revealed that, considering the size of the South African climate change research community, a significant number of scientists are serving in a volunteer capacity on high-level international assessment panels, such as the IPCC and IPBES; on global research steering committees, such as IGAC, iCACGP and SPARC; and various other influential bodies. Such participation brings great prestige and benefits to the country and should be documented centrally, celebrated and supported. It is recommended that the DST maintain a register of South African scientists' participation in such international bodies and committees and that the information be communicated to the scientific community and the public through appropriate communication channels.

Consideration should be given to providing support to those scientists participating in major international commitments such as the IPCC. This could take two forms: the provision of postdoctoral and administrative support to help with the execution of their international roles (while simultaneously building capacity) and advocating for South African candidates in leadership positions.

Recommendation 5: Provide high-level, cross-departmental support for open research, including open data.

South Africa, through the DST, is a signatory to the Open Data in a Big Data World Accord (<http://www.icsu.org/science-international/accord>) and is a founder member of the Group on Earth Observation. As such, it is a proponent of the global movement towards open research, including open access and open data, and this is in accordance with existing Cabinet decisions and legislation on publicly-funded data. The climate change research field presents one of the foremost scientific communities that stands to benefit immediately from the open science, especially the open data, movement. Fundamental to much climate change research are meteorological data collected by the SAWS, the ARC and the DWS. Comprehensive data exist but they are not readily and freely accessible to the scientific community. The commercialisation pressure on these institutions encourages them to either charge a fee for data access, or make servicing of such requests a low priority. This makes little economic sense at national scale and is a serious impediment to research.

Recommendation 6: Strengthen links between research (academic) and business communities.

There is very little evidence of strong partnerships, in the climate R&TD field, between business and the research community; or between the biophysical, social sciences and engineering research communities within universities and science councils. This silo-formation is impeding the full potential of the innovation system. Deliberate construction of transdisciplinary, multi-sector research programmes will help to build these links.

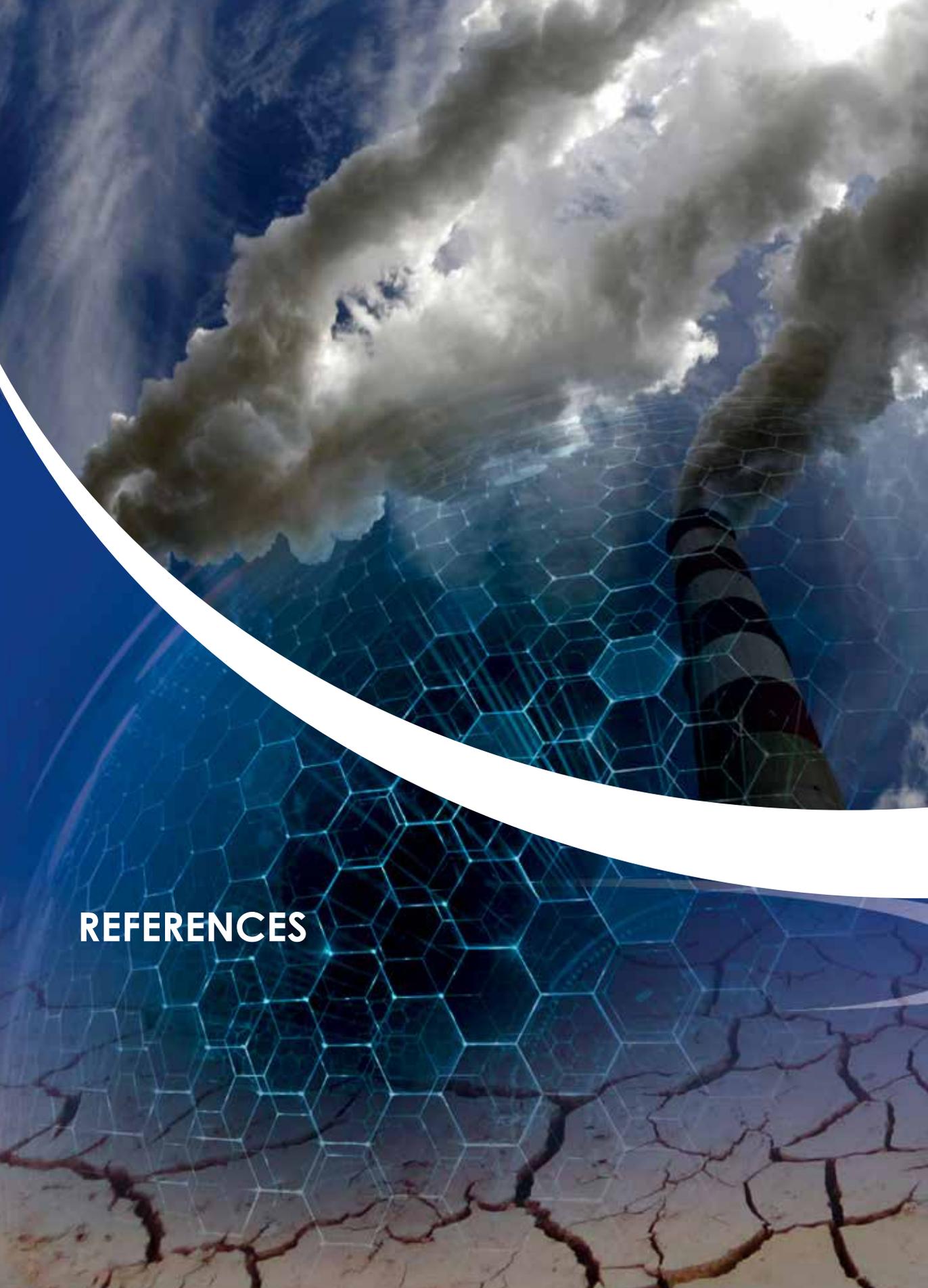
Recommendation 7: Take steps to enable more effective interdisciplinary and multidisciplinary research, in particular by more effective engagement of social sciences.

It is widely recognised that social science research is a critical component of climate change adaptation research in particular. Interdisciplinary, multidisciplinary and transdisciplinary approaches are generally increasingly adopted in this field, a trend to be encouraged, supported and built into curricula. While this approach is widely accepted, there is little evidence of successful multidisciplinary projects which are framed by social scientists, led by social scientists and which satisfy the social scientists call for non-instrumentalist research. This phenomenon is not unique to South Africa. It requires leadership from the social science community, for instance by prominent social scientists agreeing to be on the key climate change research coordination bodies, and a recognition that there are boundless opportunities to engage in societally-relevant research, to secure potentially large research funds, to build linkages with internationally connected scientists in the natural sciences and to undertake policy-relevant research. The newly established Future Earth regional office, which will be administered by the NRF presents a new opportunity to initiate a research project with the attributes described above to be established.

Recommendation 8: Strengthen research collaborations in climate change science and technology with African countries.

While there is evidence of strong international collaboration in the climate change research community, the links are overwhelmingly with traditional partner countries in the global North, viz. Europe and the US. Given that the climate system and climate change impacts are regional in nature, and the leading role of South African climate R&TD on the continent, it makes sense to strengthen research links with African countries, particularly with those in the SADC region. R&TD bilateral agreements with African countries should explicitly include collaboration in climate change science and technology where this is not already the case. They should provide opportunities for partnerships that extend beyond traditional university researchers but should include, for example, opportunities for science academy collaborations or practitioner collaborations. The African Research University Alliance may be an appropriate platform to advance this objective.

Around 2030, at a time when changes in climate will be apparent and vexing in South Africa and the commitments made in Paris in December 2015 will fall due, South Africa needs to be in a position to first, adequately understand its climate challenges, their causes and solutions, independently of experts from other regions; and second, have a suite of technology and policy solutions which are appropriate to South Africa, under our control, and competitive in the global marketplace. The biennial reports should have this end goal in mind.



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APPENDICES

APPENDIX 1: TERMS OF REFERENCE



science & technology

Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

TERMS OF REFERENCE:

PREPARATION OF THE FIRST BIENNIAL REPORT TO CABINET ON THE STATE OF CLIMATE CHANGE SCIENCE AND TECHNOLOGY IN SOUTH AFRICA

1 Background

Chapter 5 of the National Development Plan (NDP) proposes an increased public investment in research and technological innovations to support environmental sustainability and resilience actions of government, business and civil society. These actions have been translated into specific actions and performance indicators in the NDP's implementation plan for the environment sector under Outcome 10 in the Medium-Term Strategic Framework (MTSF) 2014-2019. There are three performance indicators for the Department of Science and Technology (DST) in this Outcome 10: 1) *A functional climate change research network formalised through MoUs*, 2) *Biennial reporting to Cabinet on the state of climate change science and technology in South Africa*, and 3) *Increase public-private investment into Green R&D in line with the 1.5% increase in GERD by 2019*. Specifically, the DST has an Outcome 10 MTSF target of submitting two (2) such biennial reports to Cabinet, the first by 30 March 2017 and the second by 30 March 2019.

The Department of Planning, Monitoring and Evaluation (DPME) within the Presidency remains the driver of the entire Presidency Outcome Framework, with the Department of Environmental Affairs (DEA) coordinating the environment sector (Outcome 10 MTSF), and the DST as a contributing Department to this sector. The DST Outcome 10 MTSF indicators are operationalised through the 5-Year Strategic Plans and Annual Performance Plans (APPs) of the Department, and the DST is expected to report progress on them on a quarterly basis.

The reports must provide Cabinet with a critical assessment and comparative overview of climate change scientific research and related technological innovations, identify any gaps or barriers in research and technology development value chains, and suggest ways to improve the current situation and maximise opportunities for South Africa.

2 Rationale

As the Department with a science and technology national mandate, the DST provides national policy frameworks for strategic scientific research as well as technology development and innovations to support South Africa's socio-economic development.

While the mandates and responsibilities of national Departments such as the DST and DEA, in relation to climate change, are clearly articulated, there is little or lack of coordination of efforts by different role players can be specifically improved, in order to ensure proper knowledge of these efforts and their collective impact.

The biennial reporting to Cabinet becomes a mechanism by which these efforts (climate change science/research, and technology development and innovation, programmes, projects, interventions and activities) are collated, recorded, analysed and reported.

3 Scope and extent of work

The reports will be divided into two parts – climate change science/research; and technology development, deployment and transfer. While a more in-depth assessment of current climate change science/research programmes, initiatives and activities is required, there may be a need to build on the recent study by the Academy of Science of South Africa (ASSAf) – “*The state of green technologies in South Africa*” – for the technology component of the report. A consultative and interactive approach must be taken in collecting information, data and opinions from different role players, with a view to compiling detailed reports that give an accurate state of climate change science and technology in South Africa.

Without necessarily dictating the methodology for collecting data, scientometric analysis of research outputs and the use of different human capital development instruments, consulting different role players, and eventually compiling biennial reports for consideration by DST prior to tabling to Cabinet, the service provider will be at liberty to utilise a combination of available techniques and approaches.

The overall scope of work shall include the following:

- An overview of various national legislative, policy and regulatory instruments governing climate change – climate change science; systematic observation/monitoring; impact and risks; response measures (mitigation and adaptation, inclusive of technology development); and cross-cutting issues such as financing, and monitoring and evaluation.

What various national legislative, policy, strategy and regulatory frameworks exist governing climate change-related research and technological development in South Africa?

- An overview of various international instruments available to support national climate change responses, with emphasis on scientific research and technology development and deployment.

Which international and continental initiatives and programmes is South Africa or South African institutions involved in? How does South African institutions benefit from them?

- An analysis of various climate change-related research and technology development programmes and initiatives in different areas, and key stakeholders or role players.

Who undertakes climate change research and generate various knowledge products in South Africa? What various knowledge and innovation products and services emanate from various climate change research initiatives? How are these initiatives and programmes implemented, managed and funded or supported?

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- An analysis of research needs and priorities from climate change/adaptation plans and strategies at national, provincial and municipal level.
- An analysis of the extent to which technological programmes and initiatives are informed by research needs and priorities from climate change/adaptation plans and strategies at national, provincial and municipal level.
- An analysis of the extent to which climate change/adaptation responses are informed by research outcomes/outputs.

4 Expected deliverables

The following specific deliverables are expected from this evaluation:

| Deliverable | Activities | Timeline |
|--|--|-----------------|
| a) Project plan | <ul style="list-style-type: none"> • Propose an overall evaluation design and detailed methodology • Propose sampling framework • Develop an evaluation matrix with possible questions. • Finalise the detailed activity plan aligned with deliverables, budget and timeframes • Produce/propose content structure for the reports. | 15 June 2016 |
| b) Contract finalisation | <ul style="list-style-type: none"> • Facilitate the signing of a contract with service provider | 30 June 2016 |
| c) Set up working groups or technical teams and consultations | <ul style="list-style-type: none"> • Set up various working/task/technical teams to collect info and data, review documents, and conduct interviews etc | 30 June 2016 |
| d) Data collection tools, fieldwork operational plan, fieldwork report and data analysis plan | <ul style="list-style-type: none"> • Finalise sampling strategy • Finalise fieldwork operational plan • Develop data collection instruments • Conduct fieldwork/collect data • Provide clean data sets and other evaluation documents. | 31 July 2016 |
| e) Data and info collection | <ul style="list-style-type: none"> • Interviews, meetings, working sessions etc • Data and info analysis, and report synthesis | 30 October 2016 |

| Deliverable | Activities | Timeline |
|---|--|------------------|
| f) First draft report submitted to DST | <ul style="list-style-type: none"> • Full (up to 150 pages maximum) and in 1/5/25 format, (a 2-5 page executive summary of the whole report; and 1-2 pager on policy implications) • Produce slides in hard copy and electronic format • Conduct a consultative workshop on the draft report with relevant stakeholders | 30 November 2016 |
| g) Final draft report submitted to DST | <ul style="list-style-type: none"> • Same as above (with proposed revisions) | 31 December 2016 |

5 Contract duration and management

The project shall be for a period of six (6) months (calculated from the time a contract is signed with the service provider), with the draft report due for submission to DST by 30 November 2016 and final report by 31 December 2016.

A Project Management Team (PMT) comprising representatives of the service provider, DST, Global Change Science Committee (GCSC), identified technology formations and industry associations, shall be established to oversee the execution of the project. The meetings of PMT shall be convened at a convenient venue on a monthly basis.

6 Contacts

All queries in respect of these terms of reference should be directed to:

Mr Leluma Matookane, Director: Earth Systems Science; (012) 843 6437; leluma.matookane@dst.gov.za

APPENDIX 2: REPORT BY THE ACADEMY OF SCIENCE OF SOUTH AFRICA - “THE STATE OF GREEN TECHNOLOGIES IN SOUTH AFRICA”

Chair: Prof Eugene Cloete (Stellenbosch University)

Executive summary

One of the key drivers for an increasing focus on green technologies is climate change, although other concerns, such as the global energy and financial crises, resource depletion and environmental degradation have strengthened interest in green technologies. Further, it is recognised that there can be no transition to a green economy without green technologies and technological innovation.

The overall aim of this study is to document green technologies currently being utilised in South Africa, to identify gaps and opportunities for the utilisation of these technologies and to make recommendations to promote the growth of green technologies. The key questions are as follows:

- What are the green technologies currently available and in use in South Africa and how does South Africa compare globally in terms of the uptake of green technologies?
- What are the political, economic, sociological, technological, legal & environmental (PESTLE) factors that influence and impact on the implementation of green technologies in the South African context?
- In which sectors/areas are there gaps in the availability and/or implementation of technologies and potential for future growth?
- How best can new technologies be identified for transfer to South Africa and how should this be done to ensure that skills transfer is included?
- Are there opportunities for new innovative green technologies that can be implemented sustainably?
- Is there a set of indicators that can be used to measure successful implementation of green technologies?
- What is needed to promote and increase the use and development of local green technologies in South Africa?
- What recommendations are there for policies that would assist in promoting efficient and sustainable green technologies in South Africa?

A broad definition of green technologies is favoured, with the term embracing products, services and procedures that are used in green production and consumption processes. Green technologies have as their goals, inter alia, to minimise damage to the environment, conserve the use of energy and natural resources and, in the South African context

where green technologies form an integral part of the green economy, an additional socio-economic goal that addresses job creation is considered vital.

The approach adopted in this study to assess the state of green technologies in South Africa is an Academy consensus study methodology, in which a panel of experts appointed by the ASSAf Council undertakes the task. The panel received evidence from a variety of sources and organisations and also commissioned research.

A public workshop entitled Green Technologies: Drivers, Barriers and Gatekeepers was also used as a forum to gather information. The panel compiled the report and through consensus agreed on the findings and recommendations. The report is peer reviewed and then considered by the ASSAf Council, which approves the report for publication and dissemination.

There are many factors that influence the deployment of green technologies in a country. These may include, *inter alia*, cost, geographic availability, technological readiness, job creation potential, availability of skills and government policy.

Chapter 2 addresses the critical question of how a country should prioritise green technologies, outlining various approaches. The greenhouse gas (GHG) inventory points to the energy sector as the prime contributor to GHG emissions, making this sector a key sector for interventions. A Technology Needs Assessment survey undertaken for the Department of Science and technology (DST) prioritises solar power and waste management under mitigation responses and the provision of water supply and sanitation under the adaptation responses. The McKinsey cost curve approach, which takes into account cost and potential to reduce GHGs, concludes that energy efficiency, the introduction of renewable energy, carbon capture and storage (CCS) and biofuels, offer the greatest opportunities. Technology readiness adds a further dimension and shows that of the renewable energy technologies, such as wind and solar, wind is more mature, with a technology readiness level (TRL) of 9. Solar thermal has a TRL of 6 – 8 and solar PV is some way behind with a value of 3 – 4. First generation biofuels also have a TRL of 9, with second generation biofuels scoring 5. Based on job creation potential, the natural resource management sector emerges as the most favourable, followed by energy generation, although it is cautioned against using employment potential as a single criterion as there are broader environmental, particularly climate change, benefits to be gained from activities in the other sectors. A further consideration is the number of manufacturing jobs created, with natural resource management creating none and energy generation the most at approximately 23 000.

Chapter 3 of the report focuses on the national policy context in South Africa. The growth and dissemination of green technologies is strengthened by a favourable policy environment. Policies can provide justification for the introduction of green technologies (e.g. climate change policies aimed at mitigating GHGs); promote innovation; provide incentives; alleviate barriers to implementation of green technologies; and through investment in research, foster an environment conducive to innovation and human capital development. Policies also help to guide the nature of and pace at which investment in green technologies occurs. South Africa is regarded as having a favourable

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policy environment when it comes to green technologies. A chronological account of relevant national policies is given, with the point of departure being the broad, overarching National Framework on Sustainable Development. There are a large number of overarching and sector-based policies that refer either directly or indirectly to green technologies. It was also noted that while favourable policies are a necessary driver for success in green technology development and implementation, they are not a sufficient condition. Green technology programmes require a balanced mix of technical, financial and legal professional service providers, innovative funding and interdepartmental leadership, and project championship to be successful. The need for this balance is very relevant for the South African situation, where there tends to be an over-emphasis on creating a favourable policy environment, with some neglect of other important factors.

Chapter 4 provides an international context for the analysis of the current status of, and future priorities for, green technologies in South Africa. It starts by summarising global trends in green technologies in the energy, water, sanitation and waste sectors. The chapter draws on some of the available indicators of green innovation and its impacts and then sets out some considerations for countries that are seeking to learn lessons from international experience. This focuses on technology and industry-focused 'catching up' strategies that have been pursued by some developing countries, and the role of technological capabilities and policy frameworks in these strategies.

Case studies of two countries that have had particularly strong 'green growth' strategies, viz. Germany and South Korea, are presented. Whilst the energy sector has been central to green growth strategies in both countries, there are some differences in the way green technologies are conceptualised. The differences are particularly apparent in the field of nuclear power. In South Korea, the development and deployment of nuclear power is part of the national green growth agenda and is prioritised in the country's R&D strategy. On the other hand, in Germany, the planned nuclear phase-out combined with challenging national emissions reduction targets have shifted the focus to renewable energy. Despite these differences, a common feature between the two countries is that green growth is seen as a way to develop their economy and enable a transition to a new economic model. In addition to supporting green technology diffusion in their domestic markets, a focus on exports and achieving world leader status is considered key to long-term economic growth.

The framework used in this report to assess the state of green technologies is sector-based.

Chapter 5 provides an overview of the state of green technologies in energy, water, waste and sanitation in South Africa, as well as green technologies in sectors such as industry, mining, agriculture, information and communication technology (ICT), health, transport and buildings. There is a strong emphasis on green technologies in the energy sector, as transformation in this sector is central to decoupling economic growth from negative ecological impacts and excessive resource use and shifting to a low-carbon growth path. In sectors other than energy, there has been limited progress in implementing green technologies, with the general conclusion that South Africa's record in terms of the uptake of green technologies is below average. This is borne out

by global ranking data. According to the CleanTech Group and WWF Global Cleantech Innovation Index 2012, South Africa is ranked 28 out of 38 countries and is below the ranking of other BRICS countries (e.g. Brazil (25th), India (12th) and China (13th)). South Africa has average scores for general innovation drivers, such as enabling institutions and infrastructures and commercialised cleantech innovation, but performs poorly on cleantech-specific innovation drivers and emerging cleantech innovation. The same report showed that while South Africa raised an average amount of green technology-related funds, the country has limited green technology friendly government policies (contrary to conclusions drawn in this study), and local investors.

South Africa also performed poorly in terms of venture capital investments in green technologies and the number of environmental patents attributable to South African institutions. South Africa is one of the most carbon-intensive economies globally, and national government has committed strongly to transitioning to a green economy and being a clean technology leader. However, like many developing countries, South Africa has been slow to develop and adopt green technologies despite much enabling legislation. The implicit assumption embedded in these policy documents is that the systems, such as financial, infrastructural, resources and skills, required to be a technology leader are in place and work efficiently in all respects, however, in many instances this is not the case.

Energy: Particular focus areas included energy efficient technologies, renewable energy technologies, as well as technologies aimed at reducing the environmental impacts of coal. South Africa has been slow to introduce renewable energy technologies, but the recent improved progress in this regard was noted. Given South Africa's high dependency on coal, clean coal technologies must continue to receive attention. Energy efficient technologies received relatively early attention and major investments have been made in both the public and private sectors.

The priority areas for South Africa from a renewable energy perspective, given the policy direction, are those of solar, wind and bioenergy resources. Hydropower potential is limited due to the small number of rivers suitable for generating hydroelectricity and current and projected water limitations in the country.

The country has amongst the best solar energy resources in the world – abundant sunshine, together with low precipitation and vast tracts of unused flat land. To date, very little has been exploited. Currently, concentrated solar power (CSP) is expensive compared with fossil fuel-based plants and will need a variety of incentives to make it cost-effective. However, South Africa could position itself as a leading global player in CSP in the future. To date, two large 100 MW CSP projects have been commissioned. Another opportunity is that the materials used to construct CSP plants are (mostly) readily available and many of the components can be manufactured locally. There is potential for South Africa to position itself in terms of technology development to support photovoltaic (PV) applications. The current roadmap highlights that South Africa should primarily consider crystalline silicon (wafer, cell), not only to create a knowledge base for growing the market in the country and elsewhere in Africa, but also to be able to compete in that market – in terms of establishing manufacturers across the PV value chain. Wind

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farms offer the largest immediate potential for input into the national electricity grid, and for significantly alleviating South Africa's power supply shortage. The technology is mature, and is mainstreamed globally. There is also considerable potential for biofuels, particularly when advanced second generation biofuel technologies come to fruition.

Water: Provision of potable water to all people in South Africa presents a challenge and there are millions of people without access to a potable water supply. This presents an opportunity for the development of innovative, low-cost green technologies aimed at potable water provision. Examples include solar water pasteurisation, ultraviolet disinfection and rainwater harvesting. Nanotechnology also has a role to play in improved water quality. South Africa also faces many water quality challenges linked to urban and industrial activities. These include the management of algal blooms on dams and acid mine drainage (AMD). Increasingly, green technologies are being used to solve these problems.

Waste: Green technologies within the waste space are technologies that will facilitate a move up the waste hierarchy from disposal through to recovery, recycling, reuse and waste prevention.

Sanitation: Green sanitation does not favour a particular technology, but embraces a philosophy of recycling resources. The question is whether urine and faeces can be made safe for crop production. The challenge therefore is to safely reticulate human-derived nutrients. In order to save energy, the case can be made for decentralised systems, incorporating cost-effective solutions and a holistic interdisciplinary approach. This opens up a wide range of sanitation options.

Industrial sector: The implementation of green technologies in industries aims to minimize the use of hazardous materials and increases energy efficiency during a product's lifespan, as well as improve resource efficiency and water efficiency. Many opportunities exist for new technologies that could green the manufacturing process. Examples include the use of light-weight materials, methods of marking products so that a product's life cycle can be traced and digital or additive manufacturing.

Mining sector: This sector has a reputation as a major polluting sector, yet ironically, it is the key to the introduction of green technologies in many other sectors. The mining sector is the source of raw materials used, for example, in hybrid cars, modern wind turbines, energy efficient lights and motor vehicle catalytic converters. The negative impacts will need to be managed and balanced against the benefits that the mining sector offers to the broader economy and at the same time highlight the importance of sound environmental management within the mining sector itself and the value of green mining.

Agricultural sector: This sector was one of the first to apply green technologies through recycling of waste for use as fertiliser (composting, manure application) and sound conservation management. It is also responsible for many negative environmental impacts which present good opportunities for application of modern green technologies to improve production efficiency and reduce the negative environmental impacts. Green technologies considered include conservation agriculture, biogas production, precision agriculture, biotechnology, integrated pest management and organic farming.

ICT sector: This sector has the potential to play a fundamental role in enabling system-wide benefits, primarily through efficiency improvements that bring together various systems, software, data and infrastructure.

Health sector: Green technologies can be implemented across the sector aimed at implementing energy efficiency and clean energy generation; reducing water consumption; reducing the volume and toxicity of waste and ensuring safe disposal of waste; ensuring safe disposal of pharmaceuticals; following green building design principles and procuring food locally.

Transport sector: Transport is the third largest source of GHG emissions in South Africa. Since an effective transport system is a key driver of economic growth and social development, one of the strategic focus areas outlined in the National Development Plan is the prioritisation of transport solutions that are safe, affordable and effective. Development and uptake of green technologies in the transport sector are therefore an important strategy. Road transport accounts for 87% of transport emissions and presents as the sub-sector where the use of green technologies will have the greatest impact. There are many green technologies that have been implemented or are being investigated within the transport sector internationally, some of which are in use or under investigation in South Africa, while others have the potential to be acquired through technology transfer mechanisms. Examples include the use of green fuels, various green paving systems and green materials used in the manufacture of transport systems.

Building sector: The construction industry is also a significant consumer of resources, especially materials, energy and water. In South Africa, buildings account for 23% of electricity used, and a further 5% in the manufacturing of construction products. The construction industry has traditionally been a slow adopter of new technologies in general, mainly due to the perceived associated risks. The building sector, in particular, is reluctant to adopt new technologies due to potential buyer resistance. It was concluded that major reforms are necessary to respond to the various challenges facing the sector in terms of the implementation of green technologies.

There are many barriers that inhibit innovation and stand in the way of more effective implementation of green technologies in South Africa. Those highlighted in the report (Chapter 6) include: institutional challenges, pertaining to the lack of a coherent policy framework; government bureaucracy, referring to complex and lengthy government processes, and a lack of political will, that are delaying and even preventing green investment and the implementation of green projects; skills shortages; intellectual property rights (IPR) barriers; South Africa's poor track record in adopting foreign technologies; financial barriers, particularly funding during the 'valley of death' stage to ensure commercialisation and scale-up of technologies; and finally, a lack of market information and an understanding of how to address human behaviour.

Overcoming these barriers requires interventions that support green transition. Various categories of instruments that could assist in the development and implementation of green technologies were considered. These included: regulatory instruments, with South Africa having an abundance of relevant policies and an enabling policy environment;

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economic instruments, with South Africa having a range of financial instruments such as environmental taxes, incentives and subsidies to support the growth of green enterprises; research and education instruments, which were recognised as critical to successful implementation of green technologies but acknowledging that there is a skills development lag; cooperation instruments, such as voluntary agreements and interventions that support technology transfer, with the latter not having demonstrated great success to date in South Africa (e.g. clean development mechanism (CDM)) and the latter having had some measure of success; and finally, information instruments, aimed at plugging the information gaps and of which many recent successful examples were given.

Perspectives from the business sector are considered in Chapter 7. Like many emerging industries, increased uptake of green technologies requires support from both the private and the public sectors. Business is faced with the challenge of reducing pollution, waste and resource consumption to minimise environmental impacts, while at the same time, continuing to grow and increase profitability, and acting as a stimulus for innovation in the private sector. The focus of this chapter is on the key role for the business sector in South Africa in terms of green technology development and uptake, the challenges and opportunities around diffusion of green technologies and then finally, to explore opportunities for enhancing the role of business in green technology implementation. The various roles that the private sector plays in green technology innovation and deployment are summarised as developer/innovator; manufacturer; distributor/user; and partner/collaborator.

Chapter 8 addresses social and behavioural aspects of implementing green technologies. There are many factors that determine the success or failure of a specific technology, with the most common reason often being attributed (sometimes incorrectly) to cost. While cost is an important component, it is suggested here that the adoption and use of technology is less about cost and the technical qualities of the technology, and more about being socially bound; being determined by access to education and training, the perceived application within a society and by individual ability. Adoption of green technologies is a process that takes place over a period of time, with significant interactions required between the adopter and the target technology. The logical starting point relates to two aspects of awareness: (1) awareness that a technology exists, and (2) awareness that the specific technology may have some positive impact on socio-economic or environmental upliftment for the individual or the individual's community. At this point it is vital that there is sufficient communication by government, consumer groups, and green technology innovation companies so that people are aware of the existence of the technology, as well as the potential benefits of that technology.

It is important to consider communication networks other than traditional media such as the power of early adoption by significant people (e.g. celebrities, politicians, business leaders, etc.), user-friendly websites, education at schools, and online social networking. Next, one needs to pay close attention to the socio-economic environment in order to establish a social environment conducive to technological adoption. Technology adoption can only be considered if people actually have access to the target technology. Government can assist at this point by providing incentives such as subsidies, tax relief, and eco-labelling. Similarly, government can assist by instituting barriers to non-adoption

such as taxes (e.g. carbon emissions tax for vehicles), government-regulated minimum costs, and raising disposal costs.

The development of an evaluation framework for measuring the implementation of green technologies is discussed in Chapter 9. The approach is based on the Principles, Criteria & Indicators (PC&Is) framework, from which a set of robust input and output indicators can be developed through a consultative process. Six principles, reflecting the broad goals of green technology implementation in the South African context were identified as: boosting economic growth; creating employment opportunities; facilitating the sustainable use of natural resources; reducing waste and pollution; reducing dependency on non-renewable resources; and addressing inequality and historical imbalances. In order to ensure that these goals are achieved, a set of criteria or management principles is identified. They are: increasing financial investment in research and development (R&D) to improve opportunities for the development and dissemination of green technologies; developing the necessary skills and capacity to foster innovation and provide the knowledge base and skills to facilitate uptake of green technologies; creating a business environment that is conducive to the uptake/diffusion of green technologies; ensuring that the development and deployment of green technologies contributes to ecological sustainability; ensuring that new green job opportunities are 'decent' and target previously disadvantaged and marginalised groups; and ensuring that green technologies are utilised to improve quality of life and basic service delivery. The development of a set of indicators is proposed as a follow-up consultative study.

Finally, in Chapter 10, the key findings are summarised and a consolidated set of nine recommendations aimed at promoting the implementation and development of green technologies in South Africa is provided. The recommendations are as follows:

1 Policy certainty and policy coherence

Ensure that policies play an enabling role by: setting clear targets and including mechanisms to assist in meeting those targets; instilling certainty in the market; and, ensuring that there is policy co-ordination between different government departments. Make provision for a regular review of the effectiveness of green technologies policies to allow for learning to be incorporated.

2 Implementer and developer roles

Prioritise niche areas for local development of green technologies based on existing innovation capacity and encourage transfer of green technologies that have a good socio-technical fit with the local context. It makes sense to prioritise and maximise synergies with current industrial and other capabilities in South Africa but there is also a need to think about and develop capabilities in new niche areas.

3 Creation of an 'entrepreneurial state'

Government should consider itself as more than an enabler of green technologies but should actively shape the market through sound investments in R&D, education and training, and through the implementation of market incentives.

4 Skills transfer and innovation capacity

Government should focus on strengthening the National System of Innovation (NSI), ensuring interconnectedness between role players and skills development at tertiary level.

5 Focus on the market

Ensure that market demand is not neglected in favour of a focus on the supply-side of green technologies. There is a need for a targeted communication strategy to promote uptake of green technologies by the public and a need to plan for the export market, particularly within Africa.

6 Alignment with South Africa's development needs

South Africa's development needs, particularly job creation, poverty alleviation and the need to overcome equity imbalances, should inform and direct, but not prescribe, green technology investment strategies.

7 Development of indicators

Initiate a follow-up study to identify a set of indicators for the monitoring and evaluation (M&E) framework for green technology uptake in South Africa.

8 Green technology hubs

Municipalities should consider the establishment of green technology hubs to foster the development of green technologies.

9 Systematic evaluations of failed or discontinued projects

There should be systematic reviews of projects, particularly failed or discontinued projects, so that learning can be enhanced.

APPENDIX 3: PEOPLE AND INSTITUTIONS CONSULTED IN PREPARING THIS REPORT, AND METHODS FOLLOWED

1 List

| | |
|--------------------|---|
| Balmer, M | <i>Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)</i> |
| Barnard, P | South African National Biodiversity Institute |
| Davies, H | Environmental Policy & Strategy Department, City of Cape Town |
| Engelbrecht, F | Council for Scientific and Industrial Research |
| Froneman, W | Department of Zoology and Entomology, Rhodes University |
| Germishuisen, I | Institute for Commercial Forestry Research, University of KwaZulu-Natal |
| Harrison, S | Sasol |
| Landman, W | Department of Geographical and Environmental Sciences, University of Pretoria |
| Maila, M | Agricultural Research Council |
| Mantlana, B | Department of Environmental Affairs |
| Marquard, A | Energy Research Centre, University of Cape Town |
| Midgley, G | Department of Botany and Zoology, Stellenbosch University |
| Molefe, L | Environmental Regulatory Services, City of Johannesburg |
| Rautenbach, H | South African Weather Service |
| Rennkamp, B | Energy Research Centre, University of Cape Town |
| Roman, H | Environmental Services and Technologies, Department of Science and Technology |
| Russel, A | Sasol |
| Seseng, T | International Relations, Technology Innovation Agency |
| SurrIDGE-Talbot, K | Renewable Energy Centre of Research & Development RECORD): Renewables Programme, South African National Energy Development Institute (SANEDI) |
| Sweijd, N | Applied Centre for Climate and Earth Systems Science, CSIR/NRF/DST |
| Wright, C | Medical Research Council |
| Ziervogel, G | Climate System Analysis Group, University of Cape Town |

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Additional contributions through written responses were received from:

| | |
|-------------|--|
| Hamann, R | Graduate School of Business, University of Cape Town |
| Stroebel, A | National Research Foundation |
| Taviv, R | Climate Change, Information and Research, Gauteng Department of Agriculture & Rural Development |

2 Methodology

2.1 Synthesis of climate change research finance

In order to develop a synthesis of the financing of climate change science research and technology, data were collected for the period 2006-2015. Data sources which provide information on funding for research and development related to climate change have included published annual reports, annual reporting on project funding, in-house budgets and funding records within government departments and the National Research Foundation. Further data were collected from international funding instruments via the internet and through direct engagement with representatives of these instruments within South Africa.

Hard data points for climate research funding have been difficult to ascertain as often reporting is descriptive or annual R&D budgets are provided for overall expenditure rather than being broken down in a manner that highlights which sectors or themes have been researched. As such, estimations have at times been used as extrapolations from the existing data.

Analysis of funding data has involved the collation of many and varied data points into an excel spreadsheet. Subsequently, data were analysed to determine trends in R&D spend over time and the range of spend within and across institutions which have reported annual budget allocations and spend.

2.2 Stakeholder engagement

The focus of stakeholder engagement was to ascertain the current research foci within the country, priorities for future research and the nature of the research-policy interface. Stakeholder engagement took the form of semi-structured interviews and a short questionnaire.

Interviews

The interview sample was purposively determined. An initial list of prospective interview respondents was compiled through inputs from the study panel members and by reviewing the websites of research organisations, centres and institutions within the country. All 30 prospective participants were formally requested to be interviewed. Of these requests, most participants either agreed to be interviewed or requested that a colleague be interviewed. Thus, between 18 September and 10 November 2016, 20

interviews were completed. The majority of interviews were conducted face-to-face while a small number took place telephonically or via Skype.

Interview schedule

For all participants

- 1 What should the South African climate change-related research and technological development priorities be in the next 5-10 years?
- 2 Why should these be the priorities?
- 3 Which South African organisations are best positioned to deliver these priorities?
- 4 Who are your key (national or international) partners, or who would you like them to be, in order to deliver these priorities?
 - a. Do you work with these partners already? And if so, in what ways?

Additional questions for government/policy-supporting representatives

- 5 From where do you get your inputs when producing policy/strategy regulations related to climate change?
- 6 Do you have any specific examples of instances where policy/strategy/regulations have been informed by research?

The interviews were semi-structured, with conversation being initiated through a list of questions which were asked of all respondents. Initial discussion then allowed for further probing of these topics. Interviews generally lasted 60 minutes and were conducted in the workplaces of the participants. The majority of interviews were recorded.

Analysis of the interview data was interpretative, with themes being drawn from the main points raised within interviews. Similar points raised repeatedly across the sample became the dominant themes reported on in regard to future research priorities, research-policy interface, research collaboration and the main challenges in undertaking climate change R&D.

Questionnaire

Following the interview process, a short questionnaire (Table 3-1) was submitted to all 30 individuals included on the initial interview sample list, as well as to a further 15 individuals from across the private sector, NGO and research organisations. This sample was intended to be representative of all sectors which would have an interest in undertaking or using climate change-related R&TD. The questionnaire was sent via email

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to the sample, with a number of follow up reminders also sent. The response rate was low, with only ten responses received, however, these were representative of the local and national government sector, business, environmental NGOs, research councils and higher education institutions

The questionnaire focused on the allocation of future funding priorities into the various foci of climate change research and technology development (insert). The responses were captured on a spread sheet and were analysed through the use of basic descriptive statistics. Analysis focused on establishing where the greatest priorities for future research funding lie.

Table 3-1: Questionnaire on preferred future funding allocation of climate change Science research and technology development

| Please fill in the %of funding that you would like to see allocated tot he following areas or research and technology development. | | | | | |
|--|---|---|---|--|---|
| You simply need to type the number of % in the boxes. | | | | | |
| For each question you have 100% of funding to allocate. | | | | | |
| | % | | % | | % |
| Of 100% of research funds, how much would you like to see allocated to the following: | | | | | |
| Fundamental research (e.g. Earth System Science) | | Applied research and technology development (e.g. adapation and mitigation approaches). | | | |
| Of 100% of the FUNDAMENTAL research funds, how much would you like to see allocated to the following: | | | | | |
| Atmospheric (including climate models, greenhouse gas measurements etc.) | | Ecological (terrestrial cycle, traits, physiological processes) | | Oceanic and polar research (physical and biological oceanography, ice studies) | |
| Of 100% of the FUNDAMENTAL research funds, how much would you like to see allocated to the following: | | | | | |
| Biophysical fundmantale research | | Social fundamental research (attitides, behaviour change, governance systems, economics, environmental history, legal structures) | | | |

Please fill in the % of funding that you would like to see allocated to the following areas or research and technology development.

You simply need to type the number of % in the boxes.

For each question you have 100% of funding to allocate.

| | % | | % | | % |
|---|---|--|---|--|---|
| Of 100% of the APPLIED research funds, how much would you like to see allocated to the following: | | | | | |
| Impacts and adaptation research | | Mitigation research | | | |
| Of 100% of the APPLIED research funds, how much would you like to see allocated to the following: | | | | | |
| Biophysical (including engineering) | | Human systems research (policies, governance, barriers to uptake, education) | | | |
| Of 100% of the IMPACTS AND ADAPTATION research funds, how much would you like to see allocated to the following: | | | | | |
| Biophysical protection | | Agriculture (crop and livestock), forestry and fisheries | | | |
| Human Health | | Water security and floods | | | |
| Cities | | | | | |
| Of 100% of the MITIGATION research funds, how much would you like to see allocated to the following: | | | | | |
| Transport | | Improving the carbon intensity of primary energy sources | | | |
| Construction | | Mining and industry emission reduction (excluding energy processes) | | | |

Thank you for our input

2.3 Policy and instrument review

A wide range of documents was gathered as the basis of a comprehensive synthesis and assessment of the regulatory framework enabling climate change research in South Africa. Furthermore, information available on the internet and in organisational reports were gathered, synthesised and evaluated in order to provide an overview of the international and national instruments which facilitate climate change research and to which a host of South African actors in the climate change arena contribute.

APPENDIX 4: BRIEF BIOGRAPHIES OF PANEL MEMBERS

RJ (Bob) Scholes

Prof Bob Scholes is a systems ecologist with a particular interest in the savannas of Africa. He is among the top 1% of environmental scientists worldwide based on citation. He has led several high-profile studies (e.g. the Assessment of Elephant Management, Commission on Sustainable Agriculture and Climate Change, Strategic Assessment of Shale Gas Development) and large research campaigns (e.g. SAFARI 2000, Southern African Millennium Assessment). He was an author of the Intergovernmental Panel on Climate Change 3rd, 4th and 5th assessments. He has been on the boards of the International Centre for Research in Agroforestry, the South African National Parks and South African National Space Agency. He is a Foreign Associate of the US National Academy of Sciences, Fellow of the CSIR, Fellow of the Royal Society of South Africa, Member of the Academy of Science of South Africa, a Research Associate of the CSIR, an NRF A-rated scientist, and a winner of the National Science and Technology Forum Lifetime Contribution to Science Award.

Roseanne Diab

Prof Roseanne Diab is Executive Officer of the Academy of Science of South Africa (ASSAf) and Emeritus Professor in Environmental Sciences at the University of KwaZulu-Natal. She is a Fellow of the university, the South African Geographical Society, The World Academy of Sciences (TWAS), the African Academy of Sciences (AAS) and a Member of ASSAf. Her research interests are in atmospheric science, with a focus on climate change and air quality. She has over 100 publications in peer-reviewed journals and has supervised approximately 50 PhD and Masters students. Prof Diab has served on numerous international committees such as the International Ozone Commission (IOC), the Commission on Atmospheric Chemistry and Global Pollution (CACGP) and the SPARC (Stratospheric Processes and their Role in Climate) Steering Group. She is active in the Organisation for Women Scientists in the Developing World (OWSD) and serves on the Gender Advisory Board to TWAS.

Jane Olwoch

Dr Olwoch is a climate change impacts specialist with a background in biology and vector ecology. She holds a PhD from the University of Pretoria, an MSc from the Medical University of Southern Africa (University of Limpopo, MEDUNSA campus), a BSc from Makerere University, as well as an MBA from the Netherlands Business School. She is a C2-rated scientist from the NRF. She is the former Managing Director of Earth Observation at the South Africa National Space Agency (SANSA) and is currently the Executive Director of the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL). Prior to this, Dr Olwoch was at the University of Pretoria (UP) where she supervised over 30 postgraduate students. Through her research work on climate change, Dr Olwoch has published in several peer review journals. She serves on a number of national and international committees. She was a Lead Author of Chapter 11, Human Health, of the Working Group 2 to the IPCC, Fifth Assessment Report (2010-2014).

APPENDIX 5: PROCEDURE AND KEYWORDS USED FOR THE BIBLIOMETRIC SURVEY OF CLIMATE CHANGE RESEARCH AND SUMMARY OF INTERVIEW RESULTS

Procedure for survey of journal and book publications

The following procedure was undertaken in order to conduct a bibliometric survey of climate change research from 2006 to 2015:

- 1 The Web of Science was used as the database from which to extract publications. The Web of Science was selected as it has expansive functionality, a rich underlying database, includes the 'gold standard' outputs, and can export to Excel for processing of data and graphical representation.
- 2 Publications were extracted on a year-by-year basis (publication year) for all years 2006 to 2015. The 2016 publications were not yet all in the system and hence were not included in this survey.
- 3 Keywords used in the search are listed below. Search terms included overarching topics such as 'climate change', 'global change', 'climate adaptation', 'climate mitigation', 'climate impacts', 'climate system' and a long list of sector and sub-discipline-based search terms. The list of search terms was derived by the panel based on the search terms used in the Norwegian Report on climate change research. These were adapted to suit the South African context. All search terms used in the survey are listed below.
- 4 The author address was used to filter the potential results to include only those with at least one author based in South Africa.
- 5 Only journal articles and chapters in books were included in the survey as these are peer-reviewed, substantive publications.
- 6 Using the results yielded from Web of Science, data were analysed by producing a graph of publication units, per year for the period 2006-2015, and determining the trend line for productivity.
- 7 Outputs were also sorted by institution, to establish which are the most productive institutions overall, and to evaluate whether this ranking had changed between 2006-2010 vs 2011-2015.

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- 8 Rates for the distribution of citations were evaluated to determine whether the overall (mean) citation rate for South African authored papers is higher or lower than the average for these journals for all authors. Furthermore, the rates for distribution were assessed to determine to what degree the citation rate is concentrated in a few top-end papers.
- 9 Co-authorships were examined to determine which countries/institutions South African researchers collaborate with and to establish which South Africa institutions work together on climate-change research.

Procedure for survey of Masters and Doctoral dissertations

- 1 The National Electronic Thesis and Dissertation Portal was used as the database from which to extract South African theses and dissertations. Although this is a challenging database from which to extract large amounts of data and much cleaning of the data was required, it provides the largest repository of dissertation records in South Africa.
- 2 Dissertations were extracted on a year-by-year basis (publication year) for all years 2006 to 2015. The 2016 dissertations were not yet in the system and hence were not included in this survey.
- 3 Only Masters and Doctoral level dissertations were included in the survey.
- 4 The search was undertaken using keyword search terms extracted from the list used for journal and book chapter publications. Terms used in a search of dissertation titles were: climate change and (adaptation/mitigation/impact); climate and change/adaptation/mitigation/impact/system); climate and (change/global change/adaptation/mitigation/impact/system); climate system; biosphere; hydrosphere; atmosphere; land surface; temperature; biota; carbon sequestration (and all the derivatives as indicated in the list below).
- 5 The search produced a widely varying list which resulted in the necessity to check every output for validity.
- 6 Any missing data, particularly in terms of the institution or degree level, was searched for online within institutional libraries and databases and then added to the dataset.
- 7 Dissertations were assessed in terms of the year of their completion and the institution from which they were produced.

South African topic search terms

Climate system

Biosphere

biosphere climat*
biome* climat*
forests climat*
forest climat*
biodiversity climat*
coral reef* climat*
ecosystem* climat*
biological species* climat*
phenolog*
biological system* climat*
climat* AND (plankton* OR phytoplankton
OR zooplankton)
vegetation climat*

Hydrosphere

hydrosphere climat*
river* climat*
wetland* climat*
catchment climat*
ocean* climat*
seas* climat*
aquifer AND climat*
sea level climat*
sea level AND (change* OR rise)
ocean acidification
"tide gauge*" AND climat*
(streamflow OR river discharge) AND
climat*
"saltwater intrusion" AND "sea-level ris*"
arid region* AND climat*
desert* AND climat*
drought AND climat*
flooding AND climat*
erosion AND climat*
groundwater AND climat*
hydrographic events AND climat*
isohyet AND climat*
landslide* AND climat*
"saltwater intrusion" AND climat*
runoff AND climat*
semi-arid region* AND climat*
streamflow AND climat*
storm surge AND climat*

upwelling region AND climat*
cryosphere climat*
Antarctica AND climat*
Southern Ocean AND climat*
Sub-Antarctic island* and climat*
"Ice cap" AND climat*
"sea ice" AND climat*
(ice shelf*) AND climat*

Atmosphere

atmospher* AND climat*
cloud* climat*
meteorological drought*
(Extreme weather event*) AND climat*
monsoon* AND climat*
"radiative forcing" AND climat*
weather AND climat*
(storm* OR cyclon*) AND climat*
tropospher* AND climat*
stratospher* AND climat*
tropopause AND climat*
meteorolog* AND climat*

Land surface temperature

land surface* AND climat*
borehole temperature* climat*
surface temperature* climat*
"soil temperature" climat*
global surface temperature

Biota

benthic communit* AND climat*
biota AND climat*
coccolithophores AND climat*
Coral* AND climat* NOT Reef*
ecological communit* AND climat*
ecological corridor* AND climat*
ecophysiological process* AND climat*
ecotone AND climat*
food chain* AND climat*
extinction AND climat*
extirpation AND climat*
habitat AND climat*
"keystone species" AND climat*
limnolog* AND climat*

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(peat OR peatland) AND climat*
pelagic communit* AND climat*
(phytoplankton OR plankton) AND climat*
("population system" OR "ecological system*") AND climat*
pteropods AND climat*
succulent* AND climat*
savann* AND climat*
karoo AND climat*
grassland AND climat*
rangeland AND climat*
shrubland AND climat*
fynbos AND climat*
trophic AND climat*

Carbon sequestration

Sout* Africa AND climate
topograph* AND climate
land-use AND climate
carbon sequestration

Climate system patterns

"climate system"
"climate feedback*"
Climate-carbon cycle coupling
"Climate sensitivity"
"Climate shift" OR "climate regime*" OR
(Patterns of climate variability)
"El Nino-Southern Oscillation"
Climat* variability
erosion climat*
Evapotranspiration OR "water evaporation" OR transpiration
"Southern Annular Mode" OR "Antarctic Oscillation"
albedo NOT Subject Areas=(ASTRONOMY & ASTROPHYSICS)
albedo feedback*
"solar activity" AND climat*
"energy balance" AND climate
climat* history
palaeoclimat*
paleoclimat*
interglacial*
last glacial maximum
dendroclimatolog*
climat* AND (precambrian* OR

phanerozoic*OR quaternary* OR
proterozoic* OR holocene* OR "hockey stick*" OR "temperature record*" OR
"lithologic indicators" OR "Dansgaard-Oeschger*" OR
"pollen analys*" OR pleistocene OR
"warm period*" OR "tree ring)
"ice core*" OR "ice-core*" OR "icecore*"
Climate change*
Abrupt climate change*
Rapid climate change*
thermohaline circulation
soil respiration
carbon cycle
aerosol* climate
aerosol* AND cloud*
algal bloom
desertification
coral bleaching
deforestation climate
land-use change climate
forestry climate
plantation climate
human-induced degradation of forest*
impact* AND ("climate change*" OR
"climate shift*" OR "climate variab*")
aggregate impacts AND "climate change*"
impact assessment AND ("climate change*" OR "climate shift*")
integrated assessment AND ("climate change*" OR "climate shift*")
market impact* AND climate change
market potential* AND climate change
net market benefit* AND climate change

Adaptation

resilience AND climat*
Vulnerability AND "climate change"
acclimatisation AND "climate change*"
climate change* adaptation*
climate change* adaptive capacit*
adaptability AND climate change*

Coasts

mangrove* AND climate change*
mud AND sand flats AND climate

change*
Diseases
disease* AND climate change*
“dengue fever” AND climate change*
cholera AND climate change*
virus AND climate change*
hantavirus AND climate change*
malaria AND climate change*
meningitis AND climate change*
morbidity AND climate change*
zoonoses AND climate change*

Global warming

(“carbon dioxide” OR CO₂) AND
fertilisation
(“food security” OR “food insecurity”)
AND climat*
“global warming”
“greenhouse effect*”
Emissions
Anthropogenic emission*
greenhouse gas*
Carbon dioxide emission*
Carbon dioxide equivalent*
CO₂ equivalent*
CO₂ emission*
methane emission*
nitrous oxide emission*
hydrofluorocarbon* emission*
perfluorocarbon* emission*
sulphur hexafluoride* emission*
CH₄ emission*
N₂O emission*
PFCs emission*
SF₆ emission*
“carbon leakage”
“carbon intensity”
climate threshold

Climate models

Climate model*
Coupled Atmosphere-Ocean General
Circulation Model*
GCM
AOGCM*
climate prediction*
climate forecast*

climate projection*
climate scenario*
emission* scenario*
SRES scenario*
RCP
“dynamic global vegetation model” OR
DVGM

Mitigation

Mitigation climate change
United Nations Framework Convention on
Climate Change OR UNFCCC
Joint Implementation climat*
Kyoto Mechanism*
Kyoto Protocol*
Clean Development Mechanism* OR
CDM
Certified Emission Reduction Unit* climat*
mitigation climate change
mitigation climate change potential*
mitigation climate change capacit*
mitigative climate change capacit*

Economic policy measures

emission* trading
tradable permit*
Taxes AND climat*
carbon tax*
energy tax*
eco tax*

Policy

climate policy
climate politic*
energy policy
(technology transfer OR “technological
change”) AND climate
voluntary AND (action* OR agreement*)
AND climate
afforestation
reforestation
“renewable energy”
(fuel cell*) OR hydrogen
methane recovery
retrofitting AND climat*
biofuel* AND climate

Summary of interview data

The data accumulated through conducting face-to-face, Skype and telephonic interviews have been summarised in accordance with key themes that emerged from the data. The information is arranged such that the key theme is presented along with the main features raised within the theme. The number of interview respondents who raised these matters are shown in the brackets alongside the bullet points. The interview data focus on three areas: research outputs, priorities for future research, and the science-policy-practice interface.

1 Characteristics of research outputs

Theme 1: Research products are varied

The characteristics of these research outputs include:

- published journal articles in accredited journals (11)
- books (2)
- book chapters (11)
- participation in international conferences (10)
- climate models (6)
- computerised forecasting applications (2)
- systems for the support of decision-making (5)
- reports to users in the public and private sectors (18)
- strategies, implementation plans and policy inputs (12)
- newsletters which inform and educate stakeholders and actors within the economy (2)
- development of new cultivars and their testing and licensing (1)

Theme 2: A variety of forms of research output are needed to respond to the diversity of climate change stakeholders

- Variety of outputs occurs in response to the diverse needs of those engaged with climate change science (11)
- Much climate change research is designed as academic endeavour (3)
- Research can emerge from a need raised by a stakeholder organisation for application in planning or implementing a mitigation or adaptation intervention (7)
- Implementation of climate change mitigation and adaptation indicates what the research needs are and the related appropriate form of outputs (3)
- University-affiliated research groups or centres conduct research that is driven by stakeholder need as they require this work as a form of income (4)
- The production of 'grey literature' is a significant component of work (1)
- Specific sectors need specific kinds of information (1)
- It is necessary to present at least some climate change-related research in the popular science and media domain as this is important for sharing information and generating understanding of climate change impacts within society (3)

2 Priorities for future research

In considering priorities for climate change research in South Africa in the next 5-10 years, interviewees raised a concern regarding prioritising climate change adaptation responses over mitigation responses. They further called for research funding and activities to be focused in ten thematic areas. Two additional themes emerged from the interview data in relation to future priorities, namely data constraints and challenges which need to be overcome; and consideration of the need for increased research capacity within the country.

Theme 1: A focus on adaptation is now needed

- A good understanding of why the climate is changing has been established (10)
- Much is known at a global and regional scale about how the climate will change in the next few decades (10)
- Much attention has been paid to mitigation already (10)
- Adaptation to climate change is a much more complex set of responses to consider because adaptation requires different responses at different scales and in different localities (12)
- The complexity of systems is a challenge for adaptation and needs to be prioritised in research programmes (4)
- The success of currently utilised adaptation strategies and techniques needs to be assessed (1)
- There is a need for developing responses that effectively address both chronic changes/risks, such as a general heating up of summers in certain parts of the country, and acute risks, such as flood events. This requires integrated research across multiple disciplines and within the context of spatially-related biophysical and socio-economic characteristics (5)

Theme 2: Thematic research areas

1 **Observation and monitoring**

- Basic meteorological, oceanographic and ecosystems variables need ongoing and increased monitoring and observation (4)
- Extreme weather observation and monitoring as well as accurate, timeous forecasting of these events (4)
- Monitoring needs to be introduced at many more sites across the country (5)
- The role of climate observation and monitoring as a public good (1)
- Civic science as a useful method for monitoring of some flora and fauna populations (1)

2 **Modelling capabilities and alignment of models**

- Scale is a significant concern in relation to the development and testing of climate change models (11)
- Most models have been focused on low resolution or large-scale predictions. A much more fine-grained outcome of the models is needed (5)

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- Downscaling of models is currently an important challenge and it is likely to be an area of focused activity in the near future. The validity of modelling at a smaller scale needs to be tested (4)
- Need for strong climate models developed from an African perspective (1)
- With current model development, there is an ongoing need to test the model and to analyse the results of the modelling and their implications as per climate change effects. Accuracy of models need to be improved through this testing process (1)
- The models that scientists currently utilise in South Africa are not compatible with each other. Researchers need to remain cognisant of the differences between what each of these models predicts and should engage with these differences (3)
- Medium-term climate forecasting models need development as this is a particularly difficult time scale to predict but it plays a role in shorter term adaptation planning and response as well as preparedness for the impacts of changing local conditions and extreme weather events (3)

3 Shift to a low carbon economy

- Devising carbon tax (3)
- Carbon taxation impacts (1)
- Implications for businesses of reaching the end of their capabilities for mitigating their climate change impacts (1)
- Carbon trading (3)
- New forms of generating energy, especially renewable forms of energy (5)
- The integration of energy generated by renewables with the existing energy system in South Africa (3)
- The uptake of new technology and techniques by users in various sectors (2)

4 Linkages between land, air and ocean systems

- The inter-relatedness of the impacts of climate change causes changes in one system to affect change in other systems. A more holistic and integrated understanding of these systemic relationships are needed (4)
- Ecosystem changes, with shifts in temperature and rainfall, needs deepened understanding (3)
- Biodiversity threats and changes due to changing climate (2)
- Research on plant genetics in order to better understand species which adapt well to water scarcity and to the increase drought and temperature resistance in species (2)
- Resilience of ecosystems when these changes occurs needs to be further assessed (4)
- Shifts in the spatial reach of species within terrestrial and aquatic systems (2)
- Impacts of changing marine ecosystems on fisheries (4)
- Vulnerability of the poor to reduced availability of ecosystem services and food sources such as marine species (4)

5 Impacts of climate change on water resources

- The nature of current and future water scarcity in South Africa (13)

- Increased understanding of the inter-relationship between climate change, water resources and water security is needed. This serves as a basis for adaptation strategy development and practice (12)
- Impacts of water scarcity and drought on ecosystems (13)
- Impacts of water scarcity and drought on economic sectors, particularly agricultural production (2)
- Flooding risk and adaptation responses are viewed as a critical area of research (5)

6 Sustainable urban development and urban resilience

- Vulnerability of coastal cities and towns (3)
- Socio-economic impacts of climate change on urban communities (5)
- Urban resilience (3)
- Green economy as a means of addressing economic development needs (2)
- Uptake of new energy systems (3)
- Consideration of the quality of life of the urban poor who are most vulnerable to the impacts of extreme weather, higher temperatures, water scarcity and flooding (4)

7 Energy and renewable energy systems

- Implications for increasing summer temperatures on energy supply and demand (3)
- Increasing ability to produce energy through a mix of renewable energy sources (4)
- The optimum mix of energy sources for a low carbon economy that meets energy needs (2)
- Optimum roll out of new energy technologies (3)
- Social factors in the uptake of renewable and alternative energy resources (3)
- Baseline information and longitudinal studies on costs of the production of renewable energy. This is noted as especially important for supporting development of the green economy and the transition to a low carbon economy (2)

8 Agriculture and food security

- The implementation of 'climate-smart' agriculture across South Africa (2)
- Implications of water scarcity and drought on agricultural production (3)
- Crop resistance to heat (2)
- Establishing the changed characteristics of growing seasons and patterns as well as responses to these (3)
- Shifts in the spatial economy of farming due to changed temperature and rainfall patterns limiting productivity (3)
- Genetic modification of plants to allow for adaptation of farming (2)
- Water harvesting and improving the efficiency of water use in the agricultural sector (2)

9 **Human health implications of climate change**

- Improved understanding and verification of the relationship between disease prevalence and increased temperature (4)
- Improved understanding and verification of the relationship between disease prevalence and wetter local climates (2)
- Changing spatial patterns of disease occurrence and of disease vectors (4)
- Increasing health impacts due to climate change (2)
- Public health preparedness and responses to disease outbreaks (3)
- Increased data collection and adaptation that is specific to questions of climate change and health inter-relatedness; and formatted for such research (1)

10 **Climate science relevance to the needs of South African society**

- Concern for employment and poverty alleviation through the green economy (3)
- The need for a balance between policy driven science and 'pure' science is of concern (2)
- The importance of good and accurate scientific research as a resource for sound policy content and implementation (5)

Theme 3: Data

Data availability is of concern to scientists and research administrators and funders. The issues raised by interview respondents are as follows:

- Currently there are insufficient data to answer the multitude and complexity of climate change-related research questions (4)
- Local level data from multiple systems and socio-economic contexts required for adaptation-oriented research are typically not included within wider observation systems (3)
- High resolution data are needed to facilitate more accurate analysis of satellite imagery (3)
- Difficulty in accessing data even when they do exist (11)
- The expense of data is prohibitive (11)
- The difficulty of obtaining weather observation data from the South African Weather Service and the cost involved is of critical concern (11)
- The quality of data can be problematic (4)
- The format of data can make it difficult to use within the context of research (2)
- There is a need to adapt data captured for one purpose to be able to use it for research (2)
- Storage and sharing of the massive (and growing) data sets needed to undertake climate modelling is challenging (5)
- The integration of big data sets needed for climate modelling is a concern (1)
- There are problematic gaps in the data sets available for use by pure and applied scientists (2)
- Very little capacity for data patching within the country (1)

Theme 4: Building research capacity

As with many fields, there is a need to build adequate capacity for climate change science research. The main topics raised by interview respondents are as follows:

- Retention of skilled researchers in universities is a challenge (3)
- Increasing demand for climate change research (2)
- Need for multidisciplinary and interdisciplinary research capacity (7)

3 The science-policy-practice interface

Theme 1: There is a strong linkage between the policymakers and implementers and the researcher community

- Many people are working together across research and government institutions (21)
- This work is focused on policy support and development (18)
- Research outcomes are fed into the policy development process as a basis for policy directives, strategies, and the content-related to permitting processes (16)
- There is a strong relationship between the national research councils and national and provincial government departments (4)
 - Reporting from research councils on relevant research outcomes and progress to standing committees at the provincial and national scale (2)
 - Research programmes within the councils are designed in consideration of the national development priorities and ministerial mandates (4)
- University-affiliated research centres and national departments cooperate in staff exchanges to build research capacity, foster knowledge sharing and integrate science and governance processes (2)
- Researchers have input into global reporting required by South Africa's commitments to the United Nations and other multinational organisations (3)
- South African researchers and government officials are active members of committees within multiple multi-national climate change-related organisations and networks and thus contribute to the development of the research agenda and climate change response in the international sphere (3)
- The natural sciences have traditionally dominated the inputs of climate change knowledge from science to policy (2)
- Co-production is increasingly important as a form of collaborative research between academics and government officials (3)
- The value of co-production as a research process remains debated within the research community (5)

Theme 2: Challenges related to science-policy relationships

- Not all relationships between government and the research community are equal or smooth (3)

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- Differences in the mandates of national departments create challenges for researchers (3)
- Engaging multiple departments in cross-sectoral research is difficult because government departments are inward looking and not cross-sectoral in focus (2)
- Research that is driven by government or the private sector tends to be conducted over the shorter term. This limits opportunities for research projects that have a medium or longer terms timeframe or which build baseline information that services multiple research foci rather than a very specific and directed agenda (5)
- The receiving environment within the state, the economy and civil society needs consideration because it is vital that the users of research outputs are able to understand, interpret and apply climate science. This plays a significant role in the effectiveness of climate change research to render appropriate and successful responses on the ground (2)

Theme 3: Need for an increased role of scientific engagement in regulation

- Researcher input into policy should move beyond policy development (1)
- A further step in the science-policy engagement needs to take place in the area of regulation as a means of policy implementation (1)

APPENDIX 6: POLICIES AND REGULATIONS PERTINENT TO CLIMATE RESEARCH

The following section provides an overview of the various national legislative, policy and regulatory instruments governing climate-related R&TD in South Africa, including those that govern climate change science in terms of systematic observation; impact and risks; response measures (mitigation and adaptation, inclusive of technology development); and cross-cutting issues such as financing, and monitoring and evaluation. Table 6-1 lists the policies that have been included in this overview.

Collectively, this legislative framework governs climate change science-related research and technological development in South Africa through identifying climate change as a national and global priority, outlining overarching and sector-specific responses to climate change and addressing barriers to climate change mitigation and adaptation. These laws, policies, strategies and plans highlight the need for climate change science research and technology development in a broad range of sectors; and provide mechanisms to facilitate research and technology development and initiate increased investment into these activities. In addition, they promote innovation, technology uptake and the furthering of human development and economic goals through scientific research and technology-based responses to climate change.

Table 6-1: List of national policies relevant to climate change R&TD

| Policy type | Policy |
|--------------|--|
| White Papers | <ul style="list-style-type: none"> • Science and Technology White Paper, 1996 • Energy Policy White Paper, 1998 • Renewable Energy White Paper, 2003 • National Climate Change Response White Paper, 2011 |
| Acts | <ul style="list-style-type: none"> • National Environmental Management Act, 1998 and Amendments • National Skills Development Act, 1998 and Amendments • National Water Act, 1998 • National Environmental Management: Air Quality Act, 2004 • National Environmental Management: Biodiversity Act, 2004 • National Energy Act, 2008 • National Environmental Management: Waste Act, 2008 and Regulations |

| Policy type | Policy |
|----------------------------------|---|
| Strategies, Plans and Frameworks | <ul style="list-style-type: none"> • National Industrial Policy Framework and the Industrial Policy Action Plans (IPAP) • National Waste Management Strategy, Water and Waste Roadmaps • National Building Regulation and Building Standards Act, 1977 • National Research and Development Strategy, 2004 • National Energy Efficiency Strategy (2005, 2008, 2012) • Information and Communication Technology (ICT) R&D and Innovation Strategy, 2007 • DST-Ten Year Innovation Plan, 2008 • Framework for South Africa's Response to the International Economic Crisis, 2008 • National Framework for Sustainable Development, 2008 • Global Change Grand Challenge Research Plan, 2009 • New Growth Path, 2010 • National Development Plan, 2011 • National Framework for Green Buildings, 2011 • National Strategy for Sustainable Development and Action Plan (NSSD1), 2011-2014 • Industrial Policy Action Plan, 2012/2013-2014/15 • Carbon Tax Policy Paper, 2013 • ICT Research, Development and Innovation Roadmap, 2013 • Innovative Building Technology Implementation Plan, 2013 • National Water Resources Strategy 2 (NWRS 2), 2013 • Integrated Resource Plan for Electricity (IRP) 2010-2030, Update Reports produced 2013 and 2016 • Medium Term Strategic Framework, 2014-2019 • Draft Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors, 2015 |

1. Overview of national policies governing climate change science and technology

The discussion in this section addresses the legislative and policy framework in South Africa in four parts. Section 1.1 provides an overview of the broader South African development frameworks and strategies which provide an overarching frame for climate science research and technology. Section 1.2 describes the legislation, policy and strategies which directly address the environment and climate change in South Africa, including climate change science research and technology. The third part of the discussion (Section 1.3) engages with sector-based policies related to climate

change science research and technology. This is followed by a brief discussion of national economic policies and plans that have implications for climate change science research and technology. The final section (Section 1.4) addresses policy which has implications for climate change-related technological development.

1.1 Broad South African policy frameworks and strategies

National Development Plan 2030 (2011)

Released in 2011, the National Development Plan 2030 (NDP) provides a comprehensive plan for the development of South Africa as a whole, addressing socio-economic, political and environmental challenges that the country faces. Climate change, the quality of the natural environment, and the ability to use science and technology are among the development challenges raised in the plan, and are highlighted as areas in which development activities should be prioritised.

The NDP addresses environmental management and education as key priorities. In terms of the environment, the transition to a low-carbon economy is covered in a full chapter that emphasises investment in skills development and technology. The energy sector is noted as a priority base infrastructure for economic development as well as the availability of water resources (NPC, 2011). The introduction of a carbon price within the national economy is raised. The development of green products and services is viewed as an important contributor to much needed job creation in sectors where competitive advantage exists or can be leveraged in future (NPC, 2011).

Chapter 9 of the NDP focuses on education, raising the need for “higher levels of education, skills, research and innovation capacity” to facilitate the transition to a low-carbon economy and other climate change mitigation measures (NPC, 2011: 296). In particular, higher education is significant for the furthering of climate change science research and technology progress. The National Planning Commission (NPC) notes the current shortage of academics in natural science and engineering as well as other disciplines and states the intention of increasing the number of Doctoral and Masters degrees within the country, especially within science and technology. The NDP calls for a strengthened and better co-ordinated science, technology and innovation (STI) system.

New Growth Path (2010)

As a framework for directing the growth of jobs within South Africa, the New Growth Path (NGP) identifies six areas in which investment with the purpose of driving job creation needs to be focused: infrastructure, energy, transport, communication, water and housing. As such, the creation of 300 000 jobs within the green economy over the next decade is identified as a critical target that supports growth within climate change-related technological development and entrepreneurship. The green economy, agriculture, mining, manufacturing, tourism and high level services are prioritised sectors for job growth. The NGP calls for an increase in South Africa's

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research and development investment to 2% of gross domestic product between 2010 and 2018. The NGP promotes the use of public private partnerships as a mechanism to foster job creation and facilitate economic development.

Medium-Term Strategic Framework 2014-2019 (2014)

The Medium-Term Strategic Framework (MTSF) sets out the Presidency's key overarching policy objectives and planned actions for the period 2014 to 2019. This is the first MTSF to be undertaken after the adoption of the NDP and therefore supports the NDP goals, particularly for South Africa's transition to a sustainable, climate change resilient, low-carbon economy, and for the creation of decent work. The 2014-2019 MTSF follows on from the former strategy (2009-2014) in which climate change was identified as a key strategic priority. The current MTSF acknowledges the realities of water scarcity; the need to reverse environmental degradation; the significance of South Africa's greenhouse gas emissions and the vulnerability of the country to negative impacts of climate change on the economy, natural resources, water supply, food security, and public health. The strategy states that market-based instruments such as a carbon tax, carbon budgets and support for low-carbon technologies will be employed in order to address climate change. Support for the strengthening of the green economy and for research and technology development are noteworthy aspects of economic development plans in the MTSF.

Lack of data as well as capacity constraints in compliance monitoring and enforcement and the inadequacy of information management systems are noted as a weakness within the country's environmental governance system. Sufficient reliable data, good systems of data management and sharing, as well as expansion of the national pool of researchers are thus raised as a priority. Furthermore, the coordination between research institutions and the national science and innovation system is needed, along with greater collaboration between these actors in order to enhance research and technology outputs. These directives of the MTSF create an enabling environment for climate change science-related research and technology in order to facilitate meeting climate change response targets.

1.2 Environmental and climate change specific policy, legislation and strategies

National Environmental Management Act and Amendments (1998, 2002, 2003, 2004, 2008)

NEMA (No. 107 of 1998) and its amendments are focused on providing an overarching legal framework and principles for environmental management across sectors within South Africa. It concentrates on providing an overarching structure for sound and co-operative environmental governance. Climate change is not specifically mentioned.

NEMA includes a section (Chapter Six) which governs South African international agreements and obligations in regard to the environment. This chapter also cites

the ability of the state to join and participate in research programmes and protocols through international agreements and international environmental instruments. NEMA also allows for the introduction of legislation or changes to existing legislation in South Africa in response to becoming a signatory to an agreement/instrument. These certainly include agreements and instruments in relation to climate change mitigation which facilitates the active inclusion of South Africa within climate change science research and development programmes.

Importantly, NEMA operates as the overarching legislation for environmental management within the country, while facilitating the more specific regulation on a sectoral basis through an associated cluster of policies and guidelines. These include:

- The National Environmental Management Air Quality Act (NEMA:AQA)
- The National Environmental Management Environmental Impact Assessment Regulations (NEMA:EIA)
- National Biodiversity Framework (NBF), mandated by the Biodiversity Act (NEMA:BA)
- Guidelines Regarding the Determination of Bioregions and the Preparation of and Publication of Bioregional Plans (Guidelines, mandated by NEMA: BA).
- National Environmental Management Act: Environmental Management Framework Regulations

Collectively, these additional policies support climate change responses more directly than the umbrella Act of NEMA. A number of these laws are discussed further below.

National Environmental Management Act: Air Quality Act (2004)

The core purpose of the Air Quality Act is to update and reform the legislation pertaining to air quality in South Africa. The Act is concerned with pollution prevention, ecologically sustainable development, the regulation of air quality and standardised monitoring of air quality. The Act makes no direct mention of climate change but it does have a stated concern with GHG emissions, the negative effects of these emissions and the need for their management in order to protect environmental quality. As such the Act provides an enabling context for climate change science research and technology development.

National Environmental Management Act: Biodiversity Act (2004)

As with the Air Quality Act, the Biodiversity Act does not specifically address climate change. The intention of the Act is to “provide for the management and conservation of biological diversity within the Republic and of the components of such biological diversity.” Most importantly for climate change science research, the Act makes provision for the establishment of the South African National Biodiversity Institute (SANBI). SANBI has expanded its activities to become an instrument for facilitating climate change research in South Africa, a role discussed elsewhere in the report.

The National Framework for Sustainable Development (2008) and the National Strategy for Sustainable Development (2011)

The National Framework for Sustainable Development (2008) and its accompanying strategy provide a vision for sustainable development in South Africa as well as direction for the re-orientation of the country's development path to one that is more sustainable. The need for balance between environmental management and the addressing of poverty and economic growth is raised as an important sustainability concern. The overall strength of South African environmental policy and legislation is acknowledged within the Framework.

The framework provides the platform for the national climate change response strategy. It identifies climate change as 'a cross-cutting global trend' and prioritises climate change as one of the five priority areas of sustainable development in South Africa which require immediate attention through specific and coordinated strategies and action plans. One of the sectoral strategies needed to assist in the national climate change response is a National Science and Technology for Development Strategy in order to make more efficient use of resources through technological innovation, including through cleaner technology and green energy technology.

The framework lists a number of challenges which need to be addressed to further climate change mitigation and adaptation, including the improvement of climate models and scenarios at detailed regional level and the building of experience and understanding of adaptation measures. Concerns for the effects of climate change on biodiversity are also noted as substantive, particularly in relation to marine and fresh water systems, and the need to offer support for research into biological system changes and early indicators of change is raised. Advances in research and technology development on energy efficiency are called for. These challenges and highlighted concerns indicate the kinds of issues that need to be addressed and supported through climate change science research and technology.

National Climate Change Response Policy (White Paper) (2011)

The National Climate Change Response Policy was gazetted as a White Paper in 2011 in order to formalise the South African stance on climate change and to state the vision and plan for transition to climate resilience and a lower-carbon society and economy. The response policy states two objectives for climate change in South Africa, namely, to:

- "Effectively manage inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity.
- Make a fair contribution to the global effort to stabilise greenhouse gas (GHG) concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner."

In line with the transformation agenda in South Africa, there is a focus in the policy of prioritising adaptation and mitigation measures that address developmental priorities of South Africa such as job creation and poverty relief. The key sectors of water, agriculture and forestry, health, biodiversity and human settlements are emphasised in the policy, as well as concern for resilience of many systems to climate variability and extreme weather events that are likely to affect the country. Envisioned responses are laid out in a five-year and a twenty-year response plan as well as goals for climate responses to be achieved by 2050.

The National Response Plan lists Parliament, the Forum of South African Directors-General, the National Disaster Management Council, and provincial and local governments as important actors in the implementation of climate policy. In order to facilitate a coordinated response to the priorities of the response plan and related legislation, the plan lists the required institutional arrangements at a national level, namely, an inter-governmental Committee on Climate Change; a National Committee on Climate Change; a Monitoring and Evaluation Task Team; a Technical Working Group on Adaptation and a Technical Working Group on Mitigation.

According to the plan, policy actions are required to be evidence-based and therefore rely on research, monitoring and new technology that does not damage the environment. In accordance with South Africa's signatory of international climate change agreements, such as the UNFCCC and the Kyoto Protocol, prior to 2011, the policy states the country's intention to foster a robust research agenda and systematic observation of climate change to generate knowledge, manage information and to support the organisations which undertake these activities. In terms of mitigation and systematic observation goals, the 2011 Plan gives priority to a Greenhouse Gas Inventory to be initiated by 2014, and which is required to provide current and comprehensive data to support mitigation efforts and impact analysis. Informed decision-making and planning in relation to addressing climate change are reliant on the outcomes of these research-based activities and the generation of a useful knowledge-sharing system.

At a sectoral level, the response plan highlights the need for climate change science research in relation to the following:

- Water vulnerability and water resource uses such as desalination and groundwater extraction
- Agricultural and commercial forestry adaptation strategies
- Health implications of climate change and particularly the relationship between changing climate variables and disease at temporal and spatial scales
- Marine and terrestrial ecosystems and biodiversity
- Ecosystem services
- Water, nutrient and soil conservation technologies and techniques
- Climate-resistant crops and livestock
- 'Climate-smart' agriculture that lowers carbon emissions
- Monitoring of climate change implications in order to inform understanding

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of current and future risks as well as the design and refinement of adaptation responses

- Monitoring and observation of the outcomes of adaptation activities
- Rescaling of climate modelling to the urban and municipal scale to assist with decision-making and action in regard to adaptation – especially for urban settlements.
- Impacts of climate change on artisanal fishing communities and livelihoods in coastal areas as well as appropriate responses
- Defining carbon budgets for key emitting sectors of the economy
- Observation and analysis of the impact of mitigation measures

Two flagship programmes in relation to climate change science research and technology are listed in the plan. These are the Carbon Capture and Storage Flagship Programme and the Adaptation Research Flagship Programme. These are respectively intended to facilitate the building of knowledge and technical skill in relation to the energy sector, carbon emissions control, and biodiversity.

In terms of technological development related to climate change science, the response plan has a strategic priority for technology research, development and innovation as well as the building of capacity for technology transfer. The plan highlights the need to promote and invest in technology-related research and development and to acquire technologies that will facilitate climate change adaptation through energy efficiency and lower-carbon processes and practices. The development of climate change responsive technology for both urban and rural communities is given importance, but there is particular emphasis on rural areas in relation to water resources and agricultural productivity. Climate change adaptation is seen as having a much stronger local focus for green technology development and utilisation than climate change mitigation and thereby creates possibilities for green jobs. This priority is thus viewed as encompassing the dual needs of climate change response and employment creation in South Africa.

The response plan acknowledges that research co-ordination and financing are required in order to strengthen the utility of scientific research and technology development in relation to climate change. To this end, academics and scientists are considered a key stakeholder group to facilitate the national climate change response plan by conducting research, ensuring that data and findings are shared and that other stakeholder groups are enabled to make informed decisions. Coordination between stakeholder government departments and organisations are required to facilitate strong support platform for climate change science research and technology. This platform is envisaged as including Climate Change Research Chairs in the family of the DST/NRF South African Research Chairs Initiative; research and innovation partnerships in the area of climate change resilience and a Climate Change component within the existing NRF-administered Technology and Human Resources and Innovation Programme sponsored by the dti. In addition, climate change response programmes are to include grants for research and development, incentives to study and research climate change such as centres of excellence

for climate change research, support for PhDs and postdoctoral fellowships and additional education bursaries for studies related to climate change science research and technology.

Section 11.3 of the plan deals directly with mobilising science and technology development resources for addressing climate change in South Africa and with a view to the country becoming a more capable and competitive global player in the green economy. Informed decision-making through a specialist scientific advisory council based in the Department of Science and Technology is established through the response plan. Investigation of, and planning for, additional institutional and funding mechanisms to support climate change responses are also laid out in this section, with a particular focus on science and technology capabilities.

Given this multi-pronged focus and significant support and facilitation for climate change science research and technology development, the 2011 national climate change response plan provides a significant policy stance in prioritising research and technology development in relation to climate change science and supporting the transition to a green economy.

1.3 Sector-based policies related to climate science research and technology

Sector-based national policies which drive climate science research and technology are important for generating research and technology development agendas and practices which are focused on the needs of specific sectors. The following section gives a brief overview of the relevant policy in the energy, water, agriculture, buildings and skills development sectors.

Energy

The White Paper on Energy Policy (1998)

This early energy policy for South Africa recognised climate change as a factor in the development of energy. The white paper did not go so far as to set targets for renewable energy even though it set the precedent for the inclusion of alternative energy sources within the energy production mix. The white paper does not speak directly to research and technology development in relation to climate change but did establish the pathway to later legislation and policy which are more defined in this sector, for example, the Renewable Energy White Paper, which is discussed below.

Renewable Energy White Paper (2003)

The White Paper on Renewable Energy promotes the use of renewable energy sources as approximately 4% of the projected energy demand of South Africa. To facilitate this, the white paper commits the country to developing a practical implementation strategy for renewable energy and sets targets for increased energy production by 2013 through a variety of sources, including biomass, wind, solar and small-scale hydro generation of power.

National Energy Efficiency Strategy (2005, 2008, 2012)

The National Energy Efficiency Strategy (NEES) of 2005 builds on the 1998 White Paper on Energy Policy published in 1998. This strategy has been reviewed twice with the most recent approval of the revised strategy being granted in 2012. It sets a national target for improved energy efficiency with specific sector-based improvements required. The responsibility for implementing recommendations made in 2008 lies within the ambit of the National Energy Efficiency Action Plan. Meeting of targets and implementation of recommendations is further supported by regulations such as the Income Tax Allowance on Energy Efficiency Savings regulations for large companies, national building codes and specifications for Minimum Energy Performance of household electrical appliances.

National Energy Act (2008)

The Energy Act governs the South African energy economy. The overall purpose of the Act is to provide for energy planning and increased energy generation through a mix of energy sources that includes increasing reliance on renewable energy. The Act also seeks to ensure that energy supply in South Africa is sustainable, cost effective and supportive of economic growth. One of the stated aims of the act is to establish a South African National Energy Development Institute (SANEDI). This Institute is required by the Act to promote energy research and technology development through conducting, supporting and monitoring energy-related research. This also includes research in relation to the development of greener technology and clean energy production, all of which relate to climate change responses. Through the establishment of the Institute, the Act promotes the commercialisation of clean energy technologies resulting from energy-focused research and development programmes; and states the national intention to make provisions for registration of patents and intellectual property related to this research, the issuing of relevant licences for use of patents and intellectual property, the funding of research and the building of energy related research skills, particularly in relation to innovation.

Integrated Resource Plan for Electricity (IRP) 2010-2030 (2010, 2013, 2016)

Following the original 2010-2030 resource plan produced in 2010, the 2013 updated plan for meeting of energy resource needs in South Africa addresses changing factors within the national energy sector. The 2013 plan highlights the need for diversity within the mix of energy sources for the country and a flexible approach to future planning. Possibilities are considered for meeting energy requirements in the context of a number of challenges. The plan includes a section on long-term planning that is needed to reduce South African carbon emissions post-2030. Three alternatives are provided in terms of energy planning that address future carbon mitigation as well as cost estimates of these scenarios and further discussion of a carbon tax and carbon budget. Technology needs and costs associated with these scenarios are addressed. One aspect that is further considered is embedded generation and this further frames the possibility for alternative energy generation capacities and their grid connections. These concerns form an energy-related planning framework for research and science and technology development, usage options and provide

direction as to which aspects researchers will need to test, address, etc. During 2016, a further update of the IRP was published. The 2016 IRP update is focused on presenting the assumptions on which future energy planning is reliant and the base case from which the policy directs future energy sector configurations and actions. Along with the Integrated Energy Plan, the 2016 IRP assumptions and base case for the energy future of South Africa will be scrutinised through public consultation in early 2017.

The Integrated Energy Plan (IEP) (2013)

Building on earlier Integrated Resource Plans developed for South Africa, the IEP takes cognisance of existing energy policy and regulations while aiming to guide the future energy landscape in the country. The plan thus focuses on providing direction for future energy infrastructure investments, and further policy development to effectively manage the energy sector in the medium to long term. The IEP incorporates national goals of creating energy efficiency, job creation, improved energy access, and the diversification of energy sources. The IEP presents a number of scenarios to provide an analysis of current energy consumption trends across a variety of economic sectors in order to project future energy needs in South Africa and to consider these in relation to the need for a low carbon economy.

Carbon Tax Policy Paper (2013)

Produced by the National Treasury, the policy paper discusses the introduction of a tax on carbon emissions as part of the combination of market-based and regulatory measures needed to facilitate climate change mitigation. This policy paper supports taking a carbon budgeting approach to assessing the implementation of climate change response policy implementation. The policy paper suggests rates of taxation and the time frames for the introduction of a carbon tax. During the announcement of the medium-term budget strategy in October 2016, the Minister of Finance noted that the carbon tax is planned to go ahead in 2017.

Water

National Water Act (1998)

The National Water Act regulates water resources in South Africa in terms of their equitable use and fair management, development, conservation and protection and their long term sustainability. As such, although it does not specifically address climate change, it provides an overarching framework for all activities in relation to water resources, including climate change science research and technology.

National Water Resources Strategy 2 (NWRS 2) (2013)

Following a first National Water Resource Strategy (NWRS) in 2004, the 2013 second National Water Resource Strategy (NWRS2) is focused on implementation of the requirements for management, protection and use of water resources. Of significance is an emphasis on the connection between water and energy generation

such that one of the objectives of the strategy is to promote the development of hydroelectricity generation.

Agriculture

Draft Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors (2015)

Gazetted in May 2015 for public comment, the Draft Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors stems from the larger framework of the climate change national response plan. This sectoral plan includes consideration of the full range of farming and forestry from subsistence to large-scale commercial activity and addresses the impacts of climate change on agriculture and forestry; the kinds of adaptation measures that can be used in each sector and those issues that cut across both agriculture and forestry. Challenges to taking on adaptation and mitigation in these sectors and the possible responses to these, as well as an implementation plan for the climate change response in these sectors are put forward in the draft plan.

Research and technology for climate change science are prioritised within the adaptation and mitigation plan. Climate change science research is addressed primarily in Section 7.3 of the draft plan through the comprehensive identification of the research needs in relation to climate change impacts and responses with the agricultural and forestry sectors. It is acknowledged that there is a need to build knowledge through research as a response to the need for greater understanding of climate change implications, modelling and monitoring of impacts as well as adaptation and mitigation. The development of “an improved understanding of the links between atmosphere, land and ocean and how they impact on terrestrial climates over South Africa, and reducing uncertainties by improving model projections at different scales, particularly local scales that matter” (2015, 50) are key areas for research. Research that contributes to the preparation for rapid change in environmental conditions and extreme weather events is also noted as critical to research that is needed to bring about greater climate resilience in the agricultural and forestry sectors. Research in these areas is seen to support biodiversity, ecosystem services, food security for people and animals and the ongoing production of fibre supplies for industry (p 50). Scientific studies are required to be timeous and action-oriented with the research effort as a whole being better co-ordinated, integrative and collaborative across stakeholder groups and institutions. Because of the diffuse nature of existing data and knowledge, the plan recommends an audit of relevant research data and the development of a knowledge management system to improve data access, identify gaps in data, and to facilitate information sharing and research collaboration.

There is a further requirement for the promotion and cooperative development, use and diffusion of technologies that reduce greenhouse gas emissions which are related to agriculture and forestry practices or which might harness the outputs of the sectors to produce greener energy, for example, through the development of

biofuel and alternative uses of biomass. One of the other priorities that focuses on building resilience in agriculture, notes the need for research into technology which promotes the conservation of water, nutrients and soil.

The need for long-term funding commitments to support the research agenda is raised as a challenge with mention of the capabilities articulated in the National Agricultural Research and Development Strategy and within the national Department of Agriculture, Forestry and Fisheries (DAFF) being of particular importance to facilitating research progress. Furthermore, garnering of international funding for scientific research and technology development is important. For example, in relation to research focused on monitoring and reducing greenhouse gas emission, the draft plan strongly promotes that DAFF should “vigorously pursue the latent opportunities in becoming part of the existing Global Research Alliances and that the Alliances and new international partnerships should be used as a vehicle to maximise the benefits for the sector to carry out tasks required in meeting climate change obligations under the UNFCCC” (p51).

The draft plan notes a number of existing research documents and research-related initiatives being undertaken in relation to climate change and agriculture, for example, the Atlas of Climate Change and the South African Agriculture Sector: A 2010 Perspective (Schulze, 2011). As noted in sector 1.6.5 of the draft plan, there is also the availability of the Climate Change Sector Plan for Agriculture, Forestry and Fisheries (2013) which acts as a guide to climate change response that includes consideration of research.

Buildings

National Building Regulation and Building Standards Act (1978)

As noted above in relation to energy regulation, the regulation of building standards supports energy efficiency requirements for buildings and requires all new buildings and building extensions to meet national energy efficiency standards.

National Framework for Green Buildings (2011)

This National Framework articulates a national vision for sustainable building and construction and indicates strategic interventions to ensure that construction and buildings are more resource efficient.

Innovative Building Technology Implementation Plan (2013)

Further support for the greening of buildings in South Africa comes through the Innovative Building Technology (IBT) Implementation Plan of 2013. The plan aims to facilitate increased use of innovative building technologies and provides mechanisms for this.

Waste

White Paper on Integrated Pollution and Waste Management Act (2000)

The White Paper on Integrated Pollution and Waste Management for South Africa written in 1998 (RSA, 2000) provides a broad framework for integrated waste management. It introduced the principles of 'cradle-to-grave' and 'polluter pays'.

National Environmental Management: Waste Act (2008)

The National Environmental Management: Waste Act (NEM: WA) of 2008 is the primary piece of legislation governing waste management in South Africa. It introduced the concept of the 3Rs: reduce, recycle and re-use for the first time.

National Environmental Management: Waste Amendment Act (2014)

The National Environmental Management: Waste Amendment Act (NEM: WAA) of 2014 sets out amendments to the Waste Act, particularly relating to certain definitions, including the definition of "waste"; the drafting of a pricing strategy to guide the implementation of economic instruments in the waste sector; establishment of the Waste Management Bureau; and transitional provisions in respect of existing industry waste management plans.

National Waste Management Strategy (2011)

The National Waste Management Strategy specifies eight goals to be achieved by 2016, many of which provide an enabling framework for the development and implementation of green technologies. Examples include Goal 1 – Promote waste minimisation, re-use, recycling and recovery of waste; Goal 3 – Grow the contribution of the waste sector to the green economy; Goal 5 – Achieve integrated waste management planning; and Goal 7 – Provide measures to remediate contaminated land.

Skills Development

Skills development is an important component of climate change science research and technology. Although not specifically focused on climate change science research and technology, a suite of skills development legislation and action plans support the development of new skills, advancement of existing skills and facilitation of education that supports research and technology development within the sphere of climate change science.

National Skills Development Act with Amendments (1998, 2003, 2009, 2013)

The purpose of the Act and its amendments are to develop the skills of the South African workforce, make provisions for the increasing levels of investment within education and training in the labour market and to improve the return on investment

of that input, to encourage and provide opportunities for skills development within and associated with the workplace. In addition, the Act serves to improve the work prospects of people within South Africa through establishing a whole variety of skills development engagements and practices such as sector education and training authorities (SETAs), national skills development funding, learnerships, and encouragement of public private partnerships.

Following on from the National Skills Development Act and in response to the objectives of the New Growth Path, the National Skills Accord (2011) states commitments by national stakeholders to support and advance training and skills development in the country, particularly for artisanal skills and technical vocations. One of these commitments encompasses the focus of training on the goals of the New Growth Path. This encourages skills development in sectors that relate to climate change science and technology.

Furthermore, the National Skills Development Strategy (NSDS III) was introduced in 2011 as a national strategy to guide skills development between 2011 and 2016. There is no mention of skills development directly related to climate change science research and technology but there is an inclusion regarding the need to further develop skills which support the green economy, education and health. There is furthermore a call for increased university research collaboration with industry and the importance of the knowledge economy is noted as a critical support which facilitates introduction of innovation and new knowledge into the workplace.

National economic policy that frames climate change science research and technology

Framework for South Africa's Response to the International Economic Crisis (2008)

While focused on the economy at large, the national response to the global economic crisis includes a number of acknowledgements of the possibilities for economic activity which stems from engagement with climate change. There is recognition of economic opportunity for industry in tackling the impacts of climate change, particularly through the development and uptake of green technologies. The Framework announces a willingness to develop a programme of incentives for investment that builds on existing initiatives to focus on the creation of 'green jobs' within the sectors that are primarily responsible for climate change responses. Furthermore, the Framework notes the use of a public investment programme across a variety of sectors, including energy generation capacity, water infrastructure, information technology and health care. These are sectors in which scientific research and technology development for climate change could be included and utilised.

The National Industrial Policy Framework and the Industrial Policy Action Plans (IPAP) (2007)

The National Industrial Policy Framework, adopted in January 2007, sets out the broad policy on industrialisation for South Africa. This framework is being implemented

through a series of Industrial Policy Action Plans (IPAPs). IPAP 1 in 2007 focused on solar water heating, while the second IPAP for 2010/11-2012/13 included a focus on the spectrum of wind, solar and biomass energy, as well as water and energy efficient appliances and materials, waste management and energy and material recovery. IPAP 2 for the period 2013/14-2015/16 is focused on job creation. A key contributor to employment creation within the IPAP 2 is the advancement of the green economy and the local manufacturing of green technology.

1.4 Policy for climate change-related technological development

This section considers a set of national legislative, policy, strategy and regulatory frameworks which specifically relate to the governing of climate change-related technological development.

Information and Communication Technology (ICT) R&D and Innovation Strategy (2007)

The strategy does not specifically raise the topic of climate change response and green technology but it does provide an overarching support for innovation and research and development for ICT. This creates an enabling environment into which climate change responsive technological development can be inserted.

ICT Research, Development and Innovation Roadmap (2013)

Approved in 2013, this roadmap was developed by the DST in order to support research and development within the ICT sector. Although the roadmap addresses a number of sectors, one specific cluster is that of sustainability and the environment which includes the fostering of green ICT and thereby supports technological development in relation to climate change science.

Ten-Year Innovation Plan – National Department of Science and Technology (2008)

The DST published its ten-year plan for fostering innovation in the country in 2008. The plan enables innovation primarily through five Grand Challenges, one of which deals specifically with global change science with a focus on climate change. The Plan highlights the opportunities for South Africa to be a leader in climate change science, with science and technology innovation playing a significant role in addressing climate change impacts as well as leveraging economy opportunities for the country. The plan advances the opportunities for, and the need to, research climate change in relation to a number of fields, including, oceanography as a means to understanding earth systems related to climate change, flood and drought patterns, agriculture, biodiversity, and health.

In terms of technological development, the plan calls for innovation to be a national competence in order to address development needs and facilitate the growth of a competitive economy. In this regard, there is acknowledgement of an 'innovation chasm' which needs to be overcome. Further obstacles are noted as being the

commercialisation of technological innovations and the lack of appropriate research and development skills within the country. Amongst a number of planned responses, the plan introduces the establishment of a Technology Innovation Agency (TIA). TIA is institutionalised as a national public entity with the primary role of promoting the development and exploitation of discoveries, new technology and innovations within the country.

There is also a strong focus in the plan on human capital development, building the knowledge economy and raising the number of PhDs per 1 000 population. This agenda has implications for climate change research and technology as funding mechanisms, institutional programmes and research support prioritised within the plan can be utilised within the field of climate change science research and technology development and offers opportunities for support and growth of the intellectual, human and knowledge capacity of South Africa in this regard.

1.5 Discussion

Overall, the legislative and policy framework reiterates the prioritisation of climate change R&TD as important for alleviating the negative impacts of climate change in the country and for leveraging opportunities for economic development and job creation. With the technology focus on 'green technology' there is no highlighted trade-off between economic development and climate change mitigation and adaptation. The lack of human capital to support and accomplish such an advancement of research and technological development is well noted and actions to change this circumstance are prioritised. Little is mentioned in these documents about specific alignment across policies and across the legislative framework of different spheres of government.

As well as the frameworks which govern climate change science research and technology development, an international arena of supporting instruments work to facilitate research and development. These international instruments are outlined below.

APPENDIX 7: CLIMATE CHANGE R&TD INSTRUMENTS

Actors within the South African climate R&TD arena are well integrated with the international community of researchers and the instruments and networks which foster further research, knowledge sharing and applications of research findings in regard to mitigation and adaptation efforts. The following section provides an overview of various international instruments available to support national climate change responses, with emphasis on scientific research and technology development and deployment. A number of South African instruments are also considered, either as facilitators of international instruments or as locally-originating supporters of climate change science research and technology development. For the purposes of this report, 'Instruments' for climate change science research and technology include those organisations, networks and structures that provide support in terms of funding, technical support, data sharing, skills transfer and sharing, and which foster engagement through communities of practice.

When considering instruments, there is a strong emphasis on funding sources for climate change science research and development since this is a regular feature of the role of international instruments in the South African climate change arena. As evident in the discussion below, there are significant flows of international funds into the South African climate change research community. However, because of the variety of sources and the disparate nature of projects and outputs, it is difficult to reliably quantify these flows. In addition, international funding is not simply focused on research and technology development but can be used to support actual change through projects rather than through research (Green Fund Report, no date).

The overview considers only those international and continental initiatives and programmes in which South Africa or its institutions are actively involved or from which they directly benefit. The discussion outlines the specific agendas of these instruments, the form of South African linkages to these instruments and the benefits gained by South African institutions from these instruments, with specific attention paid to research and development projects supported by these instruments.

1. International instruments

International instruments can be multilateral or arranged in a direct country-to-country basis. The South African climate change research landscape includes engagements with both forms of instruments. Multilateral Instruments include the Global Environmental Facility, the UNFCCC Adaptation Fund, the Global Climate Observation System of Systems and Future Earth. These multilateral organisations tend to have a structure in which a South African state agency works as the contact point between South Africa and the instrument, providing co-ordination and management for activities and funding flows within South Africa.

Global Environment Facility (GEF)

The GEF is an operating entity of the financial mechanism for the United Nations Framework Convention on Climate Change (UNFCCC) which is involved in financially supporting developing countries' projects in relation to mitigation and adaptation. The GEF has a long history of 25 years activity and has provided funding for more than 1 000 projects globally, amounting to support in excess of USD 2 billion. The GEF states that their resources work as "a catalyst for large-scale investments in the low-carbon economy and building greater resilience" and therefore financial support is typically granted for initiatives involving energy efficiency and renewable energy, sustainable transport and climate-smart agriculture, which collectively contribute to the global efforts for climate change mitigation.

The Development Bank of South Africa (DBSA) was appointed as the national project agency for the GEF in 2014 (Green Fund Report, no date). Through the mechanism of the DBSA, South Africa receives GEF funding for projects within various national government departments and the funds are monitored by National Treasury in compliance with the Medium-Term Expenditure Framework (MTEF).

The Adaptation Fund

The Adaptation Fund is a multilateral source of funding established under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. The fund was made active in 2009 and receives its financial resources from Certified Emission Reductions (CER) income and individual country grants from a number of states in the developed world. The Adaptation Fund is used to support climate change adaptation projects particularly for countries in the developing world.

In 2011, investment of up to USD 10 million in climate change adaptation within South Africa was allocated by the fund. The South African National Implementing Entity (NIE) for the Adaptation Fund is the South African National Biodiversity Institute (SANBI) with the NIE Secretariat housed within SANBI's Climate Change Adaptation Directorate. SANBI is thus responsible for assessing and approving proposals for funding. SANBI is also responsible for the overall management of funding and the monitoring of funded projects and programmes⁴. As of 2014, two South African proposals for funding had been approved by the Adaptation Fund for support over a five-year period. It is anticipated that, as these projects begin to produce results, it will be possible for further applications for climate change research and development to be submitted by the NIE to the Fund.

Currently, the two approved projects are the Community Adaptation Small Grants Facility (USD 2.44 million) and the uMngeni Resilience Project (USD 7.5 million). According to SANBI, the Small Grants Facility project "will develop and implement a small grant finance mechanism in the context of climate finance, to deliver direct and tangible adaptation benefits with a view to scaling up and replicating this model. This project will be led by SouthSouthNorth and will be implemented in the Namakwa and Mopani Districts in the

4 (<http://www.adaptationnetwork.org.za/climate-finance/sanbi-nie/>)

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Northern Cape" in order to address community needs for accessing adaptation funds in areas of high vulnerability to climate change impacts⁵. The uMngeni Resilience Project focuses on building resilience in the Greater uMngeni Catchment area within KwaZulu-Natal through the introduction of "early warning systems, climate-smart agriculture and climate proofing" in both urban and rural settlements that are vulnerable to the impacts of extreme weather events⁶.

The Group on Earth Observations (GEO)

The GEO is a voluntary partnership of 102 member states, the European Union and a further 103 organisations that have a focus on earth systems observations. The purpose of the GEO is to create and maintain a comprehensive repository of Earth observation data and information (a Global Earth Observation System of Systems – GEOSS) to be used for the purposes of informing decision-making and actions across the world.

As a member state of the GEO, South Africa participates in the GEO communities of practice for biodiversity, carbon, forests, global agricultural monitoring, and water monitoring⁷. Their role in these communities is information sharing, engagement with global stakeholders in the specific area of focus, reliance on shared data and shared knowledge production. Furthermore, via the DST, South African researchers are members of the AfriGEOSS which draws the Earth observation initiatives into a specific focus on enhancing access to local and international bilateral and multilateral initiatives across Africa and thereby facilitating improved synergy, information sharing and greater leverage within wider partnerships. The key linkage to GEO and GEOSS is via the Director-General, DST, South Africa.

South Africa contributes to the following Task Components within AfriGEOSS through the projects listed per category below (www.earthobservations.org/afrigeoss.php, 11/9/2016):

- Global Agricultural Monitoring: A Global Operational Monitoring System of Systems for Agricultural Production, Famine Early-warning, Food Security and Land-use Change
- Global Biodiversity Observation (GEO BON): Global Biodiversity Observation Network (GEO BON)
- Climate Information for Adaptation: Extension and Improvement of the Climate Record
- Informing Risk Management and Disaster Reduction: Global Wildfire Information System
- Global Ecosystem Monitoring: Global Standardised Ecosystem Classification, Map and Inventory (incl. characterisations of ecosystems in protected areas)
- Energy and Geo-Resources Management: Tools and Information for the Resource Assessment, Monitoring and Forecasting of Energy Sources (including solar, wind,

5 (<http://www.sanbi.org/biodiversity-science/state-biodiversity/climate-change-and-bioadaptation-division/national-impleme-2>)

6 (<http://www.sanbi.org/biodiversity-science/state-biodiversity/climate-change-and-bioadaptation-division/national-impleme-1>)

7 (www.earthobservations.org, 11/9/2016)

ocean, hydropower, and biomass) and Geological Resources (including mineral and fossil resources, raw material and groundwater

- Tracking Pollutants: Global Mercury Observation System
- Advancing GEOSS Data Sharing Principles: Developing Institutional and Individual Capacity; Institutional and Individual Development: Building a User-Driven GEOSS; GEOSS-Wide Activities for a User-Driven GEOSS
- Building a User-Driven GEOSS: Outreach and Awareness Raising
- Earth Observing Systems: Radio-Frequency Protection
- GEOSS Communication Networks: Utilisation of Communication Networks
- GEOSS Design and Interoperability: GEOSS Design and Interoperability
- Oceans and Society: Blue Planet: Sustained Ocean Observations and Information, Sustained Ecosystems and Food Security; Ocean Forecasting and Services
- Global Land Cover: Land Cover for Africa
- Global Urban Observation and Information: Global Urban Observation and Information
- Integrated Water Information (incl. Floods and Droughts): Global Water Quality Products and Services

Future Earth

Future Earth is a multilateral initiative established with the main purpose of advancing global sustainability science by building capacity and providing an international agenda that can guide research in this arena. A further key agenda within Future Earth is the networking of researchers and the building of interactions between researchers and users of research within broader society⁸. This network purposefully draws together the natural and social sciences, engineering and the humanities to address cross-cutting issues and the need for new knowledge in relation to the complexities of global environmental change and its implications for society. Amongst its various networking and information sharing activities, Future Earth fosters access to research funding, funds some research itself and contributes to building the capacity of young scientists. Overall, Future Earth engages with research that is framed within three broad themes: the dynamic planet; global sustainable development; and transformations towards sustainability. The current agenda for Future Earth is established through a ten-year plan that was initiated in 2015 and which draws on cooperation and alignment with the UNFCCC, the UN Sustainable Development Goals and the UN Convention on Biological Diversity.

Although Future Earth has its main operations centered within five hubs in the Global North, there are increasing centres of activity developing within regional offices and national structures that work to realise the goals of Future Earth⁹. There is an African Regional Forum of Future Earth, namely, the African Future Earth Committee (AFEC), which held its first physical meeting in August 2015 in Pretoria, partly supported by the NRF. The current AFEC committee includes representation by South Africa as one of the two vice-chairs is Professor Coleen Vogel from the University of the Witwatersrand, Johannesburg.

8 (www.futureearth.org/get-involved-future-earth)

9 (<http://www.futureearth.org/who-we-are>).

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South Africa has also been named as one of the two regional offices of Future Earth in Africa. The office will be hosted at the NRF.

The Belmont Forum

The Belmont Forum is a particularly important group for the support of climate change research. The forum groups together many of the key funders of all aspects of global environmental change research with the purpose of accelerating research that is required to tackle the critical concerns for global sustainability, particularly through interdisciplinary and transdisciplinary research. The Belmont Forum is particularly focused on fostering research partnerships that bring together natural scientists, social scientists, and users – these are typically multi-country partnerships involving multiple institutions which are typically derived from the national scale of each country.

Members of the forum must be legally mandated to mobilise research funds from national or international sources. These can be public or private sector funds or 'in-kind' contributions to a project. South Africa is active in the programmes of the Belmont Forum through the NRF. Multi-country research projects, called collaborative research actions (CRAs), involving South Africa have been undertaken since the mid-2010s. South African research is supported by the Belmont Forum through the NRF which makes direct funding contributions to projects involving South African researchers.

Projects in South Africa that have been funded by the Belmont Forum include those accepted by the NRF within the Belmont Forum's CRA Biodiversity Scenarios. Here, the NRF contributes co-funding of up to R500 000 for networking and development projects that bring diverse researchers together to address biodiversity concerns linked to climate change. A 2014 call by the NRF to support biodiversity related research via the Belmont Forum yielded research projects involving collaborative teams across multiple countries such studies addressing climate change impacts through examining various aspects of food security, agriculture, land use, water security and vulnerability of coastal communities (Table 7-1).

Table 7-1: South African projects funded in collaboration with the Belmont Forum, of which South Africa is a member, and undertakes to find the South African partners in competitively-selected international projects

| Project title | Countries involved | South African institutions involved | Timeframe |
|---|---|--|--|
| Food System Governance, Food Security and Land Use in Southern Africa | | University of Pretoria | Medium to Long-term Integrated Project |
| Hydro-social and environmental impacts of sugarcane production on land use and food security' across Brazil, India and South Africa | | University of KwaZulu-Natal's Centre for Water Resources | Medium to Long-term Integrated Project |
| Short-term Community Building Project | South Africa, UK, USA, Netherlands | Stellenbosch University, University of Cape Town | Medium to Long-term Integrated Project |
| Southern Africa's hydro-economy and water security | | CSIR | Medium to Long-term Integrated Project |
| Multi-scale adaptations to global change and their impacts on vulnerability in coastal areas | | Nelson Mandela Metropolitan University | Medium to Long-term Integrated Project |
| Global learning for local solutions: Reducing vulnerability of marine-dependent coastal communities | | Rhodes University | Medium to Long-term Integrated Project |
| Food Security Impacts of Industrial Crop Expansion in Sub-Saharan Africa | Ghana, Malawi, Mozambique, Sierra Leone and Swaziland | CSIR | Medium to Long-term Integrated Project |
| Hydro-social and environmental impacts of sugarcane production on land use and food security | | UKZN | Medium to Long-term Integrated Project |

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| Project title | Countries involved | South African institutions involved | Timeframe |
|--|--------------------|-------------------------------------|--|
| African Food, Agriculture, Land and Natural Resource Dynamics | | University of Pretoria | Medium to Long-term Integrated Project |
| Delivering Food Security on Limited Land | | University of the Witwatersrand | Medium to Long-term Integrated Project |
| IHDBS: South African component of: Savannah Biodiversity project | | SAEON/UCT | Medium to Long-term Integrated Project |
| SEAVIEW: Scenario, fishery ecological-economic modelling & viability network | | UCT | Medium to Long-term Integrated Project |
| ScenNet: South African component of: Scenarios Network for Biodiversity | | Stellenbosch University | Medium to Long-term Integrated Project |

Climate Technology Centre and Network

The UNFCCC includes a mechanism for supporting climate change-related technology development and transfer, particularly for the purposes of fostering clean and more efficient energy supply, the reduction of carbon emissions, climate resilient development and additional mitigation efforts serving specific sectors. An important aspect of this mechanism is the Climate Technology Centre and Network (CTCN) which is hosted by the UN Environment Programme (UNEP) and the UN Industrial Development Organisation (UNIDO). The CTCN does not provide funding but provides in-kind technical assistance in the range of \$50 000 - \$250 000 USD per initiative. The CTCN responds to the requests of developing countries to assist with the transfer of suitable technology to these countries as well as developing capacity for technology uptake; the establishment of a sound policy basis for fostering technology uptake, and catalysing investment in climate smart technologies¹⁰. The National Designated Entity (NDE) for South Africa is the DST.

Green Climate Fund (GCF)

Originally called the Copenhagen Green Fund after the Copenhagen Accord in 2009, the Green Climate Fund was adopted at COP 17 in December 2012. From 2010-2012, the Copenhagen Green Fund accounted for approximately USD30 million spent on research in regard to climate change mitigation and adaptation efforts. Since 2013, the GCF has been involved in driving and supporting projects related to lowering emissions and fostering development which is climate-resilient (GCF, 2016). These initiatives are undertaken with the overall GCF agenda of limiting the global temperature increase to

¹⁰ (<http://www.futureearth.org/who-we-are>).

below 2°C. GCF membership consists of 194 states from across the globe but concentrates on the reduction of greenhouse gas emissions in developing countries with its particular focus on vulnerable societies. National partners engage with the GCF through national designated authorities (NDAs) which have the responsibility of managing the national relationship with the GCF and coordinating GCF support with national programmes that are engaging in meeting a country's strategic goals (www.greenclimate.fund/home). Funding proposals are submitted to the GCF through NDAs. In South Africa, the national designated authority is the national Department of Environmental Affairs, coordinated through the office of the Director-General. In addition, the current the co-chair of the GCF Board is a South African. Zaheer Fakir, who, as head of International Relations and Governance at the Department of Environmental Affairs was selected as co-chair by developing country members and continues his term until mid-2018.

Although not without its critics and its own internal challenges, GCF activities and funding ability has been bolstered through the COP17 outcomes in Paris 2015 (King, 2016). The GCF is now under pressure to assess proposed projects and allocate funds for climate-focused initiatives to a host of countries (King, 2016). Projects are submitted to the GCF in two categories. First, as applications for readiness support in order to prepare a large funding application or, secondly, as applications for a specific project to be implemented. Readiness support funding encompasses relatively smaller grants while project grants to countries involve funding of USD 200-300 million.

Global Green Growth Institute (GGGI)

The Global Green Growth Institute (GGGI) was established in 2012 as an outcome of the Rio+20 United Nations Conference on Sustainable Development. The GGGI is made up of a group of international members which foster an interdisciplinary approach to economic development in its member countries. This approach is focused on the integration of economic growth, social inclusion, environmental sustainability and poverty alleviation, particularly in poorer and emerging economies¹¹. The particular programmatic emphasis of the GGGI is that of Green Growth Planning and Implementation and Knowledge Solutions which provide capacity building and tools for transition to a greener economy. The GGGI prioritises energy, water, land-use, and green city development solutions which can be integrated into economies as needed to foster resilience in the economy and society. Furthermore, the institute works to build capacity and dialogue between senior decision-makers on green economies across countries so that shared learning and improved policy development and implementation can take place. GGGI experts partner with government bodies, universities and business and are often embedded within partner governments to assist with investigating and implementing green growth opportunities.

As of 2013 the GGGI has been operational in South Africa with the Economic Development Department (EDD), the Department of Trade and Industry (the dti) and the Treasury's Trade and Industrial Policy Strategies (TIPS) unit playing the role of leading local agencies in the country. Projects undertaken in partnership with South African agencies include an

¹¹ (<http://gggi.org/about-gggi/background/organizational-overview/>, accessed 18 September 2016)

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assessment of the economic impacts of electricity price increases on the mining sector with the possibility that electricity pricing can incentivise mining-related companies to invest in renewable energy and energy efficiency. The GGGI also contributed to the preparation of a case study on South Africa's efforts to align the financial system with green economy principles and processes for use by UNEP and the GGGI.

Climate and Development Knowledge Network (CDKN)

The Climate and Development Knowledge Network (CDKN) is a network of actors which support the adoption of development which is climate responsive. The network works in partnership with actors in the public, private and NGO sectors to inform, support and participate in planning and research into the design and implementation of climate compatible development. The CDKN also works to improve funding support for climate sensitive development within countries of the Global South, and fosters improved strength of advocacy on the international stage.

CDKN has prioritised four themes within the framework of climate compatible development:

- 1 Climate compatible development strategies and plans
- 2 Improving developing countries' access to climate finance
- 3 Strengthening resilience through climate-related disaster risk management
- 4 Supporting climate negotiators from the least developed and most vulnerable countries.

From its outset, the CDKN has been funded through the UK Department for International Development (DfID) and the Dutch Ministry of Foreign Affairs (DGIS). Currently, funding support is being expanded to provide a more sustainable model to support the work of the network in a more sustainable manner. Funding now comes from 12 donors, including the governments of Norway and Sweden, the US Department of State and the International Development Research Centre (IDRC).

The CDKN operates in Africa, Asia and Latin America. The African programme is based in Cape Town and hosted by SouthSouthNorth, a non-profit company and trust which participates in international collaboration to facilitate climate change response predominantly in Africa. Since 2012, the CDKN has funded a number of projects in southern Africa. Some of these projects utilised research capacity from South Africa or were undertaken within South Africa. For example, the 2012-2013 "Climate change and upstream development impacts on new hydropower projects in the Zambezi" study was led by the Energy Research Centre at UCT with project funding of £200 000. A current study supported by CDKN with a grant of £500 000 is being led by the Energy Research Centre at UCT. The project is focused on "developing cutting-edge methodologies to link sectoral (e.g. energy, agriculture, land use) and economy-wide models" in order to support climate compatible policies. The project incorporates partners from Brazil, Chile, Colombia, Peru and South Africa with a view to supporting Mitigation Action Plans and Scenarios (MAPS) in each country and with learning taking place across the partners for the benefit of all countries involved and potentially for countries undertaking MAPS in future. Further to these projects, the CDKN is funding (£400 500 between 2014-2017) the

collaboration of a consortium of seven Southern African universities, including Rhodes University and UCT to develop core and elective modules for a Masters curriculum in climate change and sustainable development. Expected to be designed by the end of 2018, the degree will be offered through a common curriculum allows for a flexible region-wide learning process designed to equip future practitioners and decision-makers with the capacity to tackle the dual challenges of development and climate change in southern Africa. As the new curriculum is for a Masters level, research forms part of the degree with the potential of fostering climate change research focused on the SADC through the programme.

International Institute for Applied Systems Analysis (IIASA)

IIASA is a long established international scientific institute for research that addresses the large-scale, complex problems that extend beyond individual countries to the global community. Its work thus includes policy-orientated research on climate change. The 24 National Member Organisations (NMOs), representing the scholarly community of their country of origin, fund the institute, contribute to IIASA governance, and support relevant research activities within the member countries. South African affiliation to the IIASA is through the NRF, which became a member organisation in 2007¹². Collaborations with South Africa through IIASA extend beyond a focus on climate change, however, climate-specific research undertakings have addressed the transition to a low-carbon economy and climate smart agriculture, for example. Scientific exchanges between more than 120 South African and international scientists have also been facilitated through the IIASA with possibilities for additional collaborative research emerging from initial projects.

¹² http://www.iiasa.ac.at/web/home/about/nationalmembers/countryprofiles/south_africa.html

Table 7-2: Highlights of the interactions between IIASA and South Africa between 2008 and 2015

| | |
|--|---|
| National member organisation | National Research Foundation |
| Membership start date | 2007 |
| Key research partners | 26 South African organisations collaborate with IIASA including: <ul style="list-style-type: none"> • Central University of Technology (CUT) • Council for Scientific and Industrial Research (CSIR) • Department of Science and Technology (DST) • Nelson Mandela Metropolitan university (NMMU) • North-West University (NWU) • Stellenbosch University (SU) • University of Cape Town (UCT) • University of Johannesburg (UJ) • University of KwaZulu-Natal (UKZN) • University of the Free State (UFS) • University of the Witwatersrand (Wits) • Water Research Commission (WRC) |
| Areas of research collaboration | <ul style="list-style-type: none"> • Toward a sustainable energy system for all in South Africa • Projecting demographic change in South Africa • Improving food security in South Africa • Advancing the methods of system analysis |
| Capacity building | <ul style="list-style-type: none"> • 35 doctoral students from or studying in South Africa and 14 doctoral students from other African nations have taken part in the Southern African Young Scientists Summer Programme • 9 South African doctoral students have also developed research skills and networks by taking part in IIASA's Young Scientists Summer Programme |
| Publication output | 34 publications have resulted from IIASA-South Africa collaborations |
| Other interactions | Researchers, advisors, and diplomats from South Africa have visited IIASA 42 times, while IIASA scientists have visited South Africa over 80 times |

2 South African funding instruments

National Departments

Funding of climate change science and technology through national channels is typically through the programmes implemented by the relevant national ministries, the NRF and sector specific entities which are state owned or operated. These include the DST, DEA

and DAFF. The programmes undertaken through these ministries foster climate change science-related research and technology development in alignment with national development priorities.

The Green Fund

The Green Fund is a recently established national fund managed by the Development of Bank of South Africa (DBSA) on behalf of DEA¹³. The Fund supports green initiatives that will contribute to South Africa's transition to a low carbon economy, and an overall development path that is climate resilient. The stated objectives of the Green Fund are to:

- promote innovative high impact projects and programmes;
- reinforce climate policy and seek to achieve South Africa's sustainable development objectives;
- build an evidence base for the green economy;
- attract additional financial resources to support green economy initiatives.

Funding has been allocated within three main areas: low carbon economy, green cities and town, environmental and natural resource management. In terms of the portfolio of projects which have been funded, the Green Fund has allocated 75% of the funding to green initiatives which incorporate innovation and technology development and utilization. Research and policy development accounts for 5% of the funding allocation of the Green Fund. The final 20% of the fund is directed towards spending on capacity building. Since the Green Fund is intended to support the advancement of the green economy in South Africa, there has been a concerted effort to fund projects which incorporate innovation and action-oriented outputs for research and development activities (Green Fund Report, no date). At times, these projects would fall between the gap of donor or start-up funding and full commercialisation and the Green Fund plays a role in filling this gap. The funding instruments used by the Green Fund cover are recoverable grants, non-recoverable grants, concessional loans and equity (Green Fund Report, no date). To date, the R1.1.billion allocated to the Green Fund for disbursing has been fully utilised and new proposals for funding will not be considered until further funding is secured. Funding through loans and equity is expected to produce outcomes that generate a return of funds into the Fund for use in future projects.

Funded projects are classified by the Green Fund as investment projects, research projects, and capacity development projects. Research projects include a suite of projects at national and provincial scales. Table 7-3 provides a summary of the research projects funded by the Green Fund.

13 (www.sagreenfund.org.za/wordpress)

Table 7-3: Research projects funded by the Green Fund

| Applicant | Project name | Type | Project description | Project footprint |
|---|---|---------|---|-------------------|
| Asset Research | Sustainable farming as a viable option for enhanced food and nutritional security and a sustainable productive resource base. | Private | The objective of the research project is to translate the emerging knowledge on sustainable farming systems and food security in South Africa into a viable large-scale option in support of a greener, low carbon economy. | National |
| Endangered Wildlife Trust | An assessment of the economic, social and conservation value of the wildlife ranching industry in South Africa, and its potential to support the green economy. | NGO | The research will involve a detailed national assessment of the economic, social and environmental value and conservation contribution of the wildlife ranching industry and its potential to support the green economy in South Africa. | National |
| South African National Biodiversity Institute (SANBI) | Investing in ecological infrastructure to enhance water security in the uMngeni River catchment. | Public | The overall aim of the research is to develop a framework and strategy to guide investments in ecological infrastructure in the greater uMngeni River catchment to support water security and climate change resilience, and to advance the inclusion of the concept of ecological infrastructure in decision-making and policy development nationally. | KwaZulu-Natal |

| Applicant | Project name | Type | Project description | Project footprint |
|--|---|---------|---|-------------------|
| World Wide Fund for Nature (WWF South Africa) | Enhancing ecological infrastructure in the uMngeni catchment through collective private sector action: The role of private finance and markets. | NGO | The research will adopt an applied research and action learning approach in the uMngeni catchment to improve understanding of how collective environmental action within the private sector can be leveraged within geographically confined ecosystems. | KwaZulu-Natal |
| CM Solutions | Lithium battery recycling process | Private | The aim of this study is to develop and test a locally possible process to recycle lithium batteries that can be taken to the feasibility stage of design. The possibility of mass-scale implementation will be also be investigated. | National |
| CSIR (Natural Resources and the Environment and Enterprise Creation for Development) | Evaluation of cooperatives as a developmental vehicle to support job creation and SME development in the waste sector (case studies): A means to achieve the goals of the National Waste Management Strategy. | Public | This project will investigate the potential of waste cooperatives as a local resource-based, labour-intensive, developmental vehicle by evaluating numerous case studies of waste cooperatives in the country, and capturing this learning in practical outputs which could support future successful implementation of waste cooperatives. | National |

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| Applicant | Project name | Type | Project description | Project footprint |
|--------------------------------|--|---------|---|-------------------|
| Rust Geo-technical Consultants | The use of dormant urban mine sites to achieve greener South African cities. | Private | This research project will investigate renewable energy solutions to the problems that dormant mine sites pose to many South African towns and cities. Particular in depth focus will be given to the possibility of exploiting geothermal energy resources within dormant mine shafts in the Johannesburg area. | Gauteng |
| South African Cities Network | South African cities green transport programme. | NGO | The programme seeks to work with the metros to develop a coordinated approach across the cities for transitioning to greener and ultimately cheaper modes for public transport. This will include developing programmatic strategies around accessing finance and managing procurement that will save cities the costs of negotiating this transition on their own. The research will seek to develop a modular, phased approach for cities/stakeholders in implementing green transport solutions. | National |

| Applicant | Project name | Type | Project description | Project footprint |
|--|---|--------|---|-------------------|
| CSIR (Built Environment) | Potential for reducing greenhouse gas emissions in the construction sector. | Public | The proposal aims to identify the potential for reducing greenhouse gas (GHG) emissions in the construction sector by constructing a GHG Inventory for current conventional building materials to use as a baseline for measuring alternative building materials, products, systems and components. | National |
| CSIR (Polymers and Composites Competence Area) | Development of bio-based composite products from agricultural wastes/ crops residues for applications in automotive sector and green buildings in South Africa. | Public | The research involves the development of bio-based nano-composite products reinforced with agricultural wastes and will test its application in the green buildings and automotive industries. | National |
| Mapungubwe Institute for Strategic Reflection | Earth, Wind and Fire: Unpacking the political, economic and security implications of discourse on the green economy. | NGO | The research will provide a framework of process guidelines to aid policymakers to develop a more integrated mix of policy instruments to promote sustainable innovation in South Africa. | National |
| National Business Initiative | Proposal to conduct a research study on the design of policy frameworks and financial instruments to enhance investment in the green economy in South Africa. | NGO | This research projects aims to provide recommendations for the design of policy and financial instruments that would accelerate investment in the green economy in South Africa. | National |

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| Applicant | Project name | Type | Project description | Project footprint |
|---|---|---------|---|-------------------|
| Stellenbosch University (Process Engineering) | Repositioning South Africa in a low carbon world through the integration of chemicals and biofuels production with combined heat and power generation into existing bio-based industries. | Public | The proposal will provide an insight into the potential of utilising lignocellulose biomass (second generation biomass) in SA through the integration of a modern bio-refinery concept into an existing bio-based facility, with emphasis on advanced technologies. | National |
| Stellenbosch University (Biochemistry) | Natural Antimicrobial Peptides as Green Microbicides in Agriculture. | Public | This project entails a proof of concept study to utilise natural bio-control/microbicide agents, namely antimicrobial peptides, as green microbicides to (1) prevent latent fungal pathogen carry-over into plant cultures/nursery propagated plants and (2) afford protection against post-harvest fungal pathogens infecting harvested produce. | National |
| Camco Clean Energy | Voluntary Carbon Offset Trading Platform Proposal. | Private | The research will assess the viability of establishing a carbon offsets trading platform at the Johannesburg Stock Exchange (JSE), as an important input to the development of the offsets component under the proposed South African carbon tax. | National |

| Applicant | Project name | Type | Project description | Project footprint |
|--|--|--------|---|-------------------|
| Stellenbosch University (Mechanical and Mechatronic Engineering) | Research and Development of a Novel Direct-Drive Permanent Magnet Generator for Renewable Energy Conversion Systems. | Public | This proposal aims to develop a realisable generator technology that may improve the modern wind turbine drive-train. Specifically, the project involves the construction and testing of a 50 kW generator prototype. | National |

Source: *The Green Fund*, www.sagreenfund.org.za, accessed 28 September 2016

2.3 Bilateral agreements

The NRF has funded a number of international research projects including research teams across a range of countries through bilateral agreements with research institutions across the world. Through these projects international researchers have been hosted with South African universities to undertake collaborative climate change-related research or South African researchers have been overseas to work with foreign researchers. Projects can be comparative across countries or simply involve multi-country teams working on a joint research project. These projects are typically funded in a three-year funding cycle with the majority of bilateral research funding being awarded to collaborative projects between South Africa and the African countries of Namibia, Kenya, Mozambique and Angola.

Bilateral research funding through the NRF between 2003-2015 has included researchers from the following countries:

- China
- Flanders-Belgium
- Germany
- Japan
- Norway
- Algeria
- Angola
- Egypt
- Kenya
- Malawi
- Mozambique
- Namibia
- Tanzania
- Tunisia
- Zambia

2.4 Discussion/Conclusion

Building on a general understanding of the above-mentioned instruments, it is worth considering the role of South African actors in shaping the various instruments. Active participation within these instruments as well as the nature of the relationship between instrument mechanisms and interfacing organisations in South Africa plays a role in determining the effectiveness of these instruments in addressing South African-specific climate change challenges and the extent of access to resources and support available through these mechanisms.

Actors within the research and technology landscape in South Africa are not overtly integrated into the formulation and initiation of international instruments. However, there are a number of scientists who play a role in international committees, who work with the international bodies and funding instruments in order to direct the agenda, coordinate activities and enact the work of these instruments – including the implementation of research and technology development agendas as relevant. In many cases there is strong input at an African or regional level as South African researchers sit on regional committees or steering bodies of international instruments and therefore have a role to play in determining how the broad strategic framework of multilateral organisations get interpreted and applied in relation to the South Africa and African context.

The original question within the terms of reference regarded the involvement of government in shaping these instruments – there is much more evidence of scientists themselves playing a bigger role on committees but that government departments and entities operate as the interface between the country's researchers and tech developers and the funding instrument.

There is an emphasis on funding through these instruments. This is the primary form of support. This is followed by intellectual support and team work on various projects and technical support on programmes/projects for the shifting of government policy and the economy to mitigate against climate change and facilitate adaptation.

With the focus here on climate change instruments there is much less focus on technology in these instruments and their funding focus which is instead research and policy-orientated.

APPENDIX 8: REVIEW OF THE DST-NRF APPLIED CENTRE FOR CLIMATE AND EARTH SYSTEMS SCIENCE (ACCESS) – 2014

EXECUTIVE SUMMARY

The South African National Research Foundation (NRF) convened an external Review Panel of experts to:

- Review the alignment of the Applied Centre for Climate and Earth System Science (ACCESS) with the objectives of a Centre of Excellence (CoE).
- Assess the performance of ACCESS against the Department of Science and Technology (DST) Global Change Grand Challenge (GCGC) goals.
- Assess the performance of ACCESS in key focus areas (i.e. five initially and seven currently) from inception to 31 December 2013.
- Review the governance and funding instrument for ACCESS as a CoE.
- Make recommendations for the future of ACCESS in the context of the national science priorities in GCGC.

The Review Panel received a wide range of comments and feedback on all aspects of ACCESS. They found that ACCESS education, capacity development, interdisciplinary research networking, and community building activities to be most successful. Some of ACCESS affiliate projects cut across disciplines and institutions that otherwise would not have collaborated. In this context, lessons learnt from ACCESS can benefit national and international efforts in the rapidly changing Global Change research landscape in South Africa.

The Review Panel finds the current ACCESS disciplinary scope to be too broad, and recommends a greater scientific focus and integration on the theme of Earth-Human System Science. The current seven ACCESS themes follow the traditional disciplinary lines, and lack this holistic approach/integration. There are little or no resources dedicated to identifying and addressing trans-disciplinary research opportunities that are key to the solution of climate and global change issues. In the absence of a science strategy, ACCESS has tried to seek opportunities in national and international developments in climate/global change and as a result its research mandate has broadened with time instead of gaining greater focus. There is an urgent need to develop a bold, innovative, integrative research strategy for ACCESS that captures the imagination and interest of South African researchers and sponsors, with the commensurate expected outcome and impacts that benefit the society. There still remains the opportunity/challenge of defining a small set of compelling scientific questions that require inter/trans-disciplines collaboration, in the spirit that no single group or organisation within South Africa can accomplish them. Such a strategy may not meet all expectations of some of the current participants in ACCESS, but would create new opportunities to engage both science

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and society in preparing and responding to the challenges at the interface of climate/environment, society, and development. According to the majority of those interviewed and consulted during the review process, "ACCESS needs urgently a visionary science leader" to develop such a plan.

There is a wide recognition among ACCESS actors and stakeholders about the value of ACCESS' training and capacity development efforts. The Review Panel received inspiring and convincing testimonies from students and early career scientists on the value of such investments, and the true impact of ACCESS support, mentoring and networking on their personal and professional life. Some ACCESS affiliate projects also cut across some disciplines and institutions that otherwise would not have collaborated, including international partnerships. ACCESS networking has been a rewarding experience for some participants by bringing various players together resulting in complementary research collaborations, new research cooperation, and funding opportunities. Most of these efforts have been opportunity-based, and ACCESS needs to align its education, capacity development and networking with its strategic research objectives to ensure strongest possible support for its objectives.

The progress on Information Brokering and Service Rendering aspects of ACCESS has been very limited. These are truly unique and innovative aspects of national and international initiatives such as GCGC, Future Earth: Research for Global Development, Global Framework for Climate Services, etc. Information Brokering and Service Rendering are inherently related, therefore they can be combined together and developed/managed as one theme. ACCESS should pay greater attention to this theme in the planning and implementation of its research, education and capacity development activities, from inception to completion of these activities.

The Review Panel realises that declaring ACCESS as a Centre of Excellence by DST and NRF, at the time of establishment, may have been the best available means for its funding and governance. However, given the unique mandate of ACCESS and its approach to coordinating and facilitating inter-/trans-disciplines research requires a different management and governance framework. The Review Panel deliberated extensively on this aspect of ACCESS, taking into account feedback from some South African Science leaders as well as the DST and NRF leadership. The Panel suggests several possible models, and illustrates one such model in detail in the report for consideration by ACCESS sponsors and stakeholders.

The plan and priorities envisioned for ACCESS requires long-term commitment to adequate and stable funding. Some of the ACCESS teams/members have been very resourceful in leveraging funding from other sources. However, there is considerable frustration on the part of the recipients of ACCESS funds, especially students and early career scientists, regarding the stability and timeliness of funding through current organisational arrangements. The NRF and DST should consider revisiting the funding mechanism(s) for ACCESS activities, especially those residing within the universities, to overcome some of the current limitations and shortcomings.

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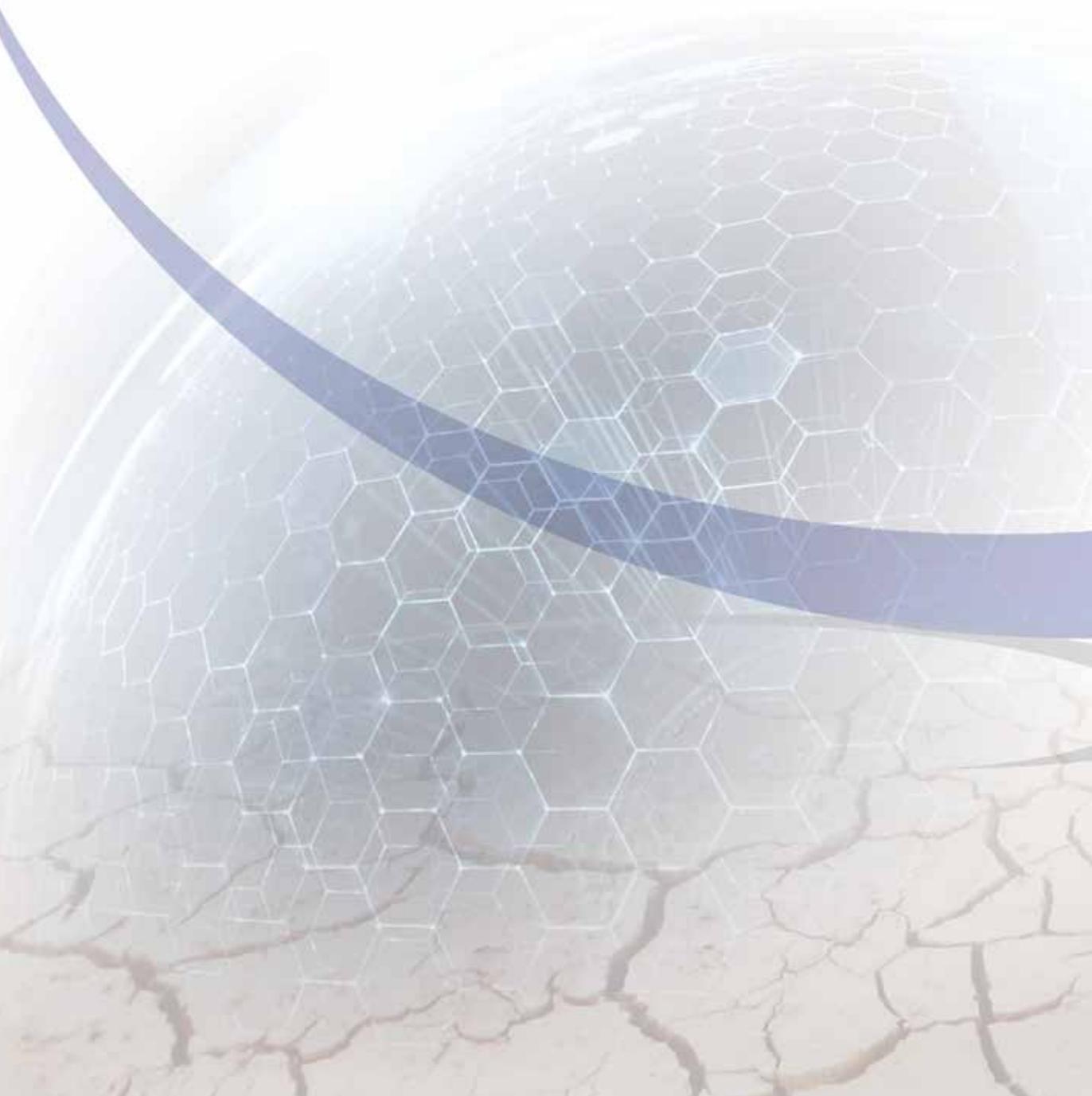
Review of the DST-NRF Applied Centre for Climate and Earth Systems Science (ACCESS)
– 2014

Review Panel

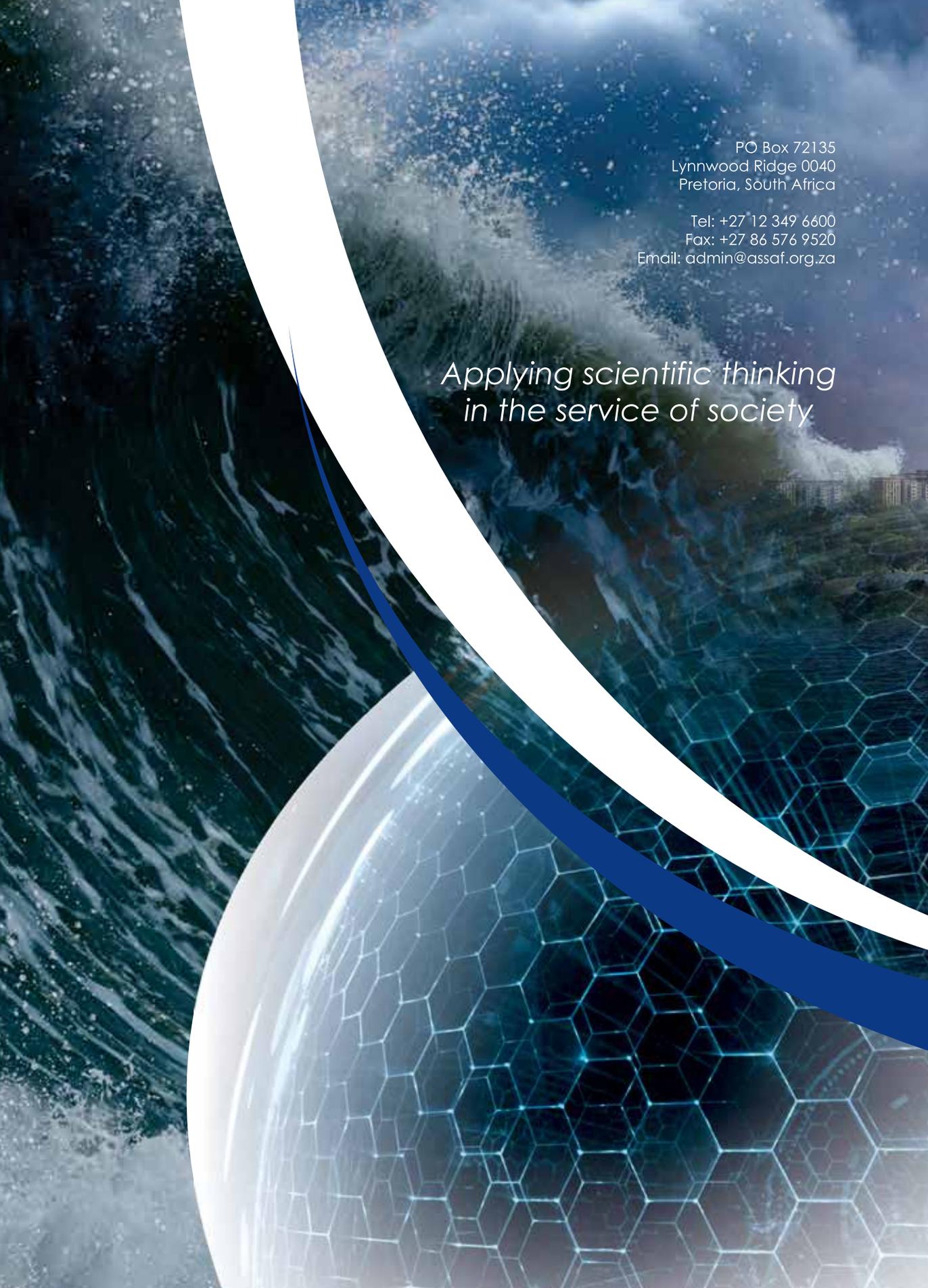
Dr Ghassem Asrar, Director, Joint Global Change Research Institute of the Pacific Northwest National Laboratory, University of Maryland, College Park, MD, USA

Dr Michel Verstraete, Chief Scientist, Earth Observation Directorate, South African National Space Agency, Pretoria, South Africa assisted by

Dr Gerhard von Gruenewaldt, Advisor on strategies and reviews within the South African National System of Innovation, Pretoria, South Africa







PO Box 72135
Lynnwood Ridge 0040
Pretoria, South Africa

Tel: +27 12 349 6600
Fax: +27 86 576 9520
Email: admin@assaf.org.za

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