ENVIRONMENTAL RESEARCH AND TECHNOLOGIES IN SOUTH AFRICA

environmental affairs

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Environmental Research and Technologies in South Africa

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Foreword

From 3 to 6 March 2009, South Africans from all spheres of life came together for the national Climate Change Summit 2009 in Midrand to initiate a consultative process to develop the South African Climate Change Response Policy. Although the Summit yielded wide-ranging consensus on a number of proposed climate change responses, it also identified various areas of divergence that required further discussion. With this, the Summit agreed, amongst others, that the National Climate Change Response Policy will be developed through a participatory, multi-stakeholder, consultative and iterative process and that issues raised during the Climate Change Summit 2009 must be addressed in a transparent manner and fed into the policy development process.

During the participatory, multi-stakeholder, consultative and iterative policy development process initiated at the Summit, certain specific issues appeared to be raised again and again in various policy development stakeholder engagements. These recurring areas of concern and/or uncertainty included: Climate Finance; Human Resources and Technology; Adaptation; Mitigation; and Governance.

In keeping with the Summit decisions and with a view to informing and enriching the debates around these issues, the Department of Environmental Affairs commissioned focussed research into these focus areas and used the findings of this research to focus and inform discussions in key stakeholder workshops on each of the topics in February and March 2011.

Although the independent research and findings contained in this publication do not necessarily represent the views, opinions and/or position of Government, the department believes that this research is an important addition to the evolving climate change discourse. Hence, the department is happy to make this work publicly available and accessible.

With this, I would like to thank everyone who contributed to the research papers presented in this book as well as everyone who contributed to the various stakeholder workshops on the topics covered by this research.

Finally, I would also like to thank our German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) partners and their local agent, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), for their generous support for this research and its publication.

Peter Lukey

Acting deputy Director-General: Climate Change

Department of Environmental Affairs

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Abbreviations

AsgiSA	Accelerated and Shared Growth Initiative for South Africa
BIGCC	Biomass integrated gasification combined cycle
CCS	Carbon capture and storage
CCTHRIP	Climate Change Technology and Human Resources and Innovation Programme
CHP	combined heat and power
CIPC	Companies and Intellectual Property Commission
CIPRO	Companies and Intellectual Properties Registration Office
COP	Conference of the Parties
CSIR	Council for Scientific and Industrial Research
CSP	Concentrating solar power
DACST	Department of Arts, Culture, Science and Technology
DEA	Department of Environmental Affairs
DME	Di-methyl ether
DOA	Department of Agriculture
DOE	Department of Education
DST	Department of Science and Technology
DTI	Department of Trade and Industry
EJ	Exajoule
EPO	European Patent Offic
ETBE	Ethyl tert-butyl ether
GHG	Greenhouse Gas
GWe	Gigawatt electrical
HDR	Hot dry rock
ICMIT	International Conference on Management of Innovation and Technology
IP	Intellectual Property
IPAP	Industrial Policy Action Plan
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
kW	Kilowatt
MWe	Megawatt electrical
NBER	National Bureau of Economic Research
NIPF	National Industry Policy Framework
NRF	National Research Foundation
NRTF	National Research and Technology Foresight
NSSD	National Strategy and Action Plan on Sustainable Development
OCIPE	Office of Companies and Intellectual Property Enforcement
OECD	Organization for Economic Cooperation and Development
ORC	organic Rankine cycle
OTEC	Ocean thermal energy conversion
PBMR	Pebble Bed Modula Reactor
PV	Photovoltaic
R&D	research and development
RDS	Research and Development Strategy
RE	Renewable energy
S&T	Science and technology
SARChI	South African Research Chairs Initiative
UNFCCC	United Nations Framework Convention on Climate Change
USD	US Dollars
USPTO	United States Patent and Trademark Office
WIPO	World Intelleectual Property Organization
WRC	Water Research Commission
ZAR	South African Rand

Summary

This report was prepared by Business Enterprises (Pty) Ltd at the University of Pretoria. It argues that South Africa will need significant human capital and a sound science and technology base to develop and implement robust adaptation and mitigation strategies that will militate against the negative impacts of climate change, while simultaneously providing the possibility of an internationally competitive economic trajectory. According to the report, both the state of relevant science and technology and the "favourability of the implementation environment"[1] will affect South Africa's ability to respond effectively to climate change as well as its international competitiveness. To this end, the report examines the current state of research and technology in South Africa related to environmental issues in general, and climate change mitigation in particular. This is achieved by analysing South Africa's relative contribution to environmentally related scientific knowledge (through an analysis of South African authored scientific papers) and South Africa's level of innovation (measured through the analysis of numbers of South African patents registered). The report also reviews current policy priorities and their degree of harmonisation as a means of understanding the current implementation environment. Based on the findings, the report provides recommendations to be considered in the drafting of the National Climate Change Response White Paper.

The sections below provide an overview of what is contained in the main report.

Current state of science and technology

Analysis of the Thomson Reuters ISI Scientific databases indicates that while South Africa's knowledge generation in environmentally related fields is increasing steadily, its relative contribution to world literature is very limited and, in some cases, is declining. Furthermore, South Africa produces three to four times fewer publications when compared to four other leading countries, namely Australia, Brazil, Canada and China. The patent analysis indicates a very low South African presence in the climate change domain, apart from carbon capture and storage technologies. For example, in the environmental engineering category, South Africa produced 0.58% of the global output between the years 2004 – 2008, 5% of China's output. This has negative implications for South Africa's technological ambition in this field.

Current policy environment

South Africa has a justifiable reputation as a leading player in the global climate change dialogue. The various official South African delegations to the United Nations Framework Convention on Climate Change (UNFCCC) Conferences of the Parties (COPs) and summits have demonstrated leadership on a number of fronts, including in the rescue and implementation of the Kyoto protocol, and more recently in the push for a new global deal on climate change. While there are numerous policies housed in different South African institutions supporting and directing climate change science and technology, the policy environment informing climate change science and technology is currently uncoordinated and highly fragmented.

Recommendations

The National Climate Change Response White Paper represents an important opportunity to strengthen South Africa's ability to build a science and technology base that will enable the roll-out of a robust climate change response strategy, as well as organise for an innovative green economy. A number of recommendations are presented for consideration in drafting the White Paper. These relate to four domains, namely governance, planning tools, science and technology funding and instruments, and partnerships.

The specific recommendations include:

- Institutionalising highly informed decision-making through a governance arrangement that includes the appointment of a chief scientific advisor to the Minister of Environmental Affairs. The Minister, with the advice of the chief scientific advisor, should establish and constitute a scientific advisory council, which includes a wide range of expertise. This council could be chaired by the chief scientific advisor;

- Ensuring medium and long-term planning for South Africa's climate change science and technology landscape. It is recommended that a rigorous planning exercise be engaged in the form of a climate change foresight exercise and a climate change technology road-map for the country in partnership with the relevant role-players; and

- Developing funding instruments to enable the development of science and technology capacity, new knowledge, intellectual property and technology to enable the implementation of a robust climate change response strategy. This may include a specialised funding agency in the form of an environmental science council or the development of specialist environmental funds in existing agencies.

1 *This is determined by the level of political will, the soundness and congruency of national climate change policy with the national economic growth path, adequate funding and capacity for implementation.*

1 Introduction

South Africa is a leading voice in the negotiations toward a binding global deal on Global Climate Change. The country is also a significant scientific contributor to the global dialogue under the auspices of the Intergovernmental Panel on Climate Change (IPCC). Furthermore, South Africa demonstrates a unique convergence between the government team and civil society in these positions.

In spite of this high international profile, South Africa continues to have among the highest per capita emissions in the world, especially when compared with other developing countries. This is largely due to the historical industrial trajectory of South Africa resulting from its investments in extractive industries as well as its coal based energy generation, which enabled the country to offer a very low direct cost energy option. This cheap energy has been associated with many important competitive advantages, including South Africa's dominance of the Fisher-Tropsch process internationally (spearheaded by Sasol) and its ability to attract investments to the region. Within the context of climate change, the main disadvantage is that South Africa has developed its primary technological competence with the associated scientific research and development (R&D) capacity to support fossil fuel dependent technologies. This has become very apparent in the recent decisions associated with South Africa's new energy investment to expand its generation capacity with a continued dominance of coal-based solutions.

In order for South Africa to develop and implement robust adaptation and mitigation strategies that provide the possibility of an internationally competitive economic trajectory in the context of a climate change, the country will require significant human capital and a sound science and technology base.

In this light, the objectives for this report are as follows:

1) Review the current state of affairs related to various environmental and climate mitigation related technologies;
2) Review policy priorities in South Africa related to the field;
3) Identify the state of environmental research in South Africa; and
4) Elaborate on possible future policy directions in the country and prerequisites that support knowledge generation and technology development.

2 Methodology

The objectives of this investigation (see Section 1) to a large extent determined the methodology that was followed in this report. The review of the state of environmental research (see Section 6) and of the relevant policies in South Africa (see Section 5) was based on a comprehensive literature review.

Following international best practice, the authors used evaluative scientometrics for the identification of the state of environmental research in South Africa. Scientometrics is a tool by which the state of science and technology can be observed through the overall production of scientific literature and patents at a given level of specialization. It provides an approach for situating a country in relation to the world, an institution in relation to a country and even individual scientists in relation to their peers. Scientometric indicators are equally suitable for macro-analysis (e.g. a given country's share in global output of scientific literature over a specified period) and micro-studies (e.g. a given institute's role in producing articles in a particular field).

Environmental research is a multidisciplinary endeavour. The variety of scientific fields affected by and contributing to environmental research dictate that the information platform to be used for the identification of the relevant South African research articles should be multidisciplinary, multi-publisher and geographically diverse. These requirements further permit comparisons of South African performance with the performance of a number of comparator countries. An additional requirement is that the databases should include the addresses of all co-authors (and not only of the first author). This is in order to permit identification of collaborative patterns and to identify all articles with a South African co-author and not only those with a South African first author.

The Thomson Reuters ISI Scientific databases (Science Citation Index Expanded, Social Sciences Citation Index and Arts and Humanities Citation Index) were identified as the most appropriate for the objectives of the investigation. The combined databases comprehensively cover the most prestigious journals in the world in all fields of research and constitute a unique information platform for the objectives of this effort. The main advantage of the ISI journals is that they constitute the highest impact journals in the world.

In South Africa, the Department of Education (DOE) has identified the ISI indexed journals for subsidy purposes: universities receive just less than ZAR100,000 (US$10,000) for each article they produce and universities give incentives to their researchers to publish in ISI indexed journals. Consequently, it is expected that the databases will cover the majority of the most important South African environmental research.

The ISI databases were used to identify South African authors that had published in the fields of environmental research between 2004 and 2008 and to compare this with environmental research that was undertaken in a number of different developed and developing countries and research centres during the same time period.

The same way that research publications indicate the state of research in a country, the number of patents issued, are used to indicate the technological status of a country. Preliminary investigation indicates that South Africa inventors receive approximately 100 patents per annum from the United States Patent and Trademark Office (USPTO) (the largest patent office in the world), 50 patents per annum from the European Patent Office (EPO) and less than 10 triadic patents per annum (patents providing protection in Japan, USA and European Union). Interpretation of patents issued by the Companies and Intellectual Properties Registration Office (CIPRO)[2] for South Africa present difficulties as CIPRO is a non-examining authority (i.e. applications are not examined for novelty and usefulness but they are just registered). This has substantial shortcomings and repercussions for the national innovation system (Pouris, 2010).

For the patent analysis presented in this report the databases of the USPTO were utilised. The USA has the largest technological market in the world and hence all inventors aim to protect their inventions there.

Patent analysis at country and institutional level can be undertaken according to different methodologies, depending on the objectives and the subject matter of analysis. The most frequently used approaches are "technology code classification" and "keyword classification". All patents are allocated multiple technology codes from the patent authorities that issue them. Provided that the patents

2 *Since the completion of this report, CIPRO and the Office of Companies and Intellectual PropertY Enforcement (OCIPE) have been merged into the Companies and Intellectual PropertY Commission (CIPC).*

required for analysis can be classified by relevant technology codes, a new dataset can be created. Keyword classification searches the abstracts or titles of issued patents for relevant keywords. Irrespective of which classification is used, the patents identified still have to be screened to ensure their relevance to the field and sector being investigated. Depending on the certainty that the patent in question is relevant to the investigation, this screening could include either a cursory or more detailed review. Another approach that can be employed is "institutional patent analysis", where all patents belonging to the institutions under examination are identified.

3 The Planning Context

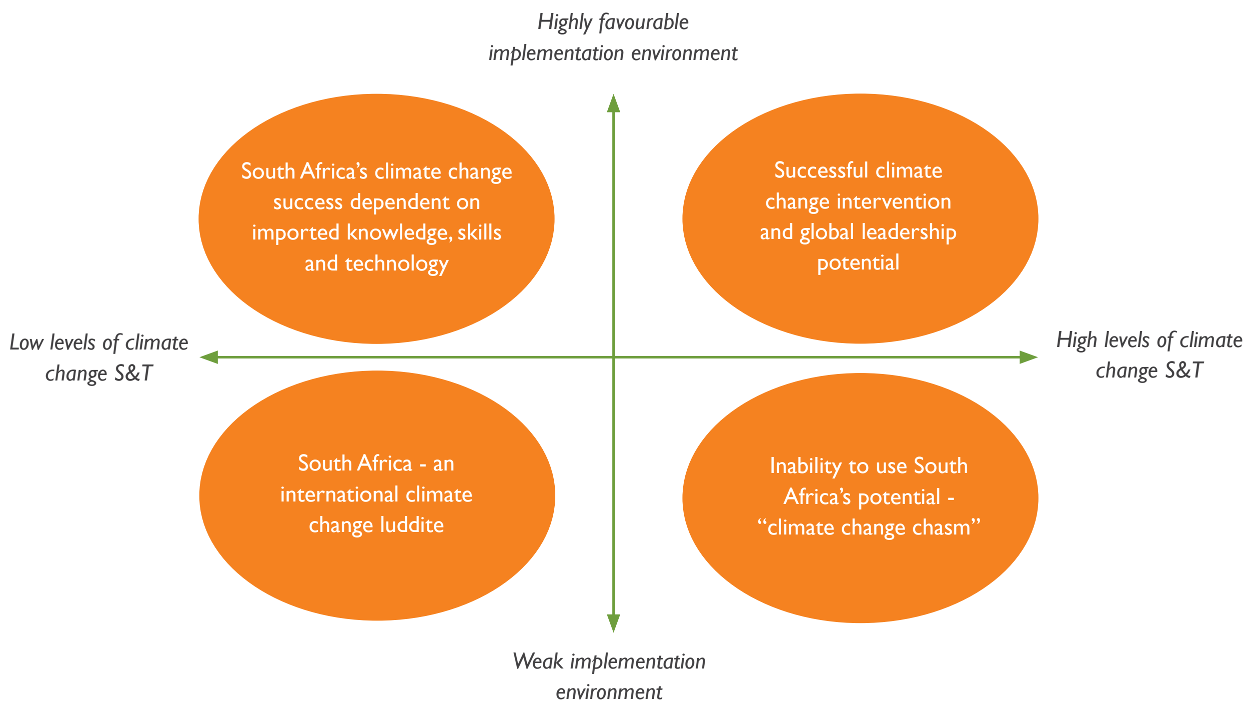
The ability of South Africa to be successful in managing climate change through adaptation and mitigation depends on the choices the country makes with respect to both the implementation and the science and technology environment. These choices will also determine the international role South Africa is able to play. Using the two axes of "the favourability of the implementation environment" and "the state of climate change science and technology (S&T)", four scenarios were developed, as illustrated in Figure 1.

The favourability of the implementation environment is determined by the level of political will, the soundness and congruency of national climate change policy within the context of the national economic growth path, adequate funding and capacity for implementation. The state of climate change science and technology is determined by the robustness of research and development, the skills and capacities of human resources (i.e. the level of human capital), and the ability to bring new technologies and scientific solutions to market.

According to Figure 1, in an enabling implementation environment that is combined with high levels of climate change research, technology development and human capital, South Africa has a good chance of being a regional and global leader. This is in both the policy arena as well as in the areas of knowledge production, capacity development, and the provision of technological and other solutions. In a favourable political environment that has a high priority placed on climate change responses but with low science and technology capacity, the responses will require imported knowledge and know-how, using technological solutions from abroad, implemented and managed by foreign expertise. An unfavourable implementation environment generates two challenging scenarios. In both cases, the country will not be able to implement effective adaptation and mitigation measures. In addition, South Africa may become an international outcast, having initially demonstrated strong leadership in the context of the United Nations Framework Convention on Climate Change (UNFCCC), and then failing to replicate that leadership in the implementation of national climate change response strategies. Strong science in an unfavourable political environment would mean that the knowledge generated would primarily be expressed in academic publications. This knowledge would be harvested abroad and converted into valuable technologies and products that South Africa would then import. This would further exacerbate the innovation chasm with the outflow of both intellectual capital and hard currency.

Keeping these possibilities of the future in mind the paper examines the current state of climate change related science and technology in South Africa.

Figure 1: Scenarios for South Africa's climate change response



4 The State of Climate Mitigation Technologies

Identification of technologies with the potential to make a contribution on energy demand patterns in the future is of importance for planning and research purposes. Such projections take place either through expert opinion or through quantitative techniques such as identifying patent activity.

While there are numerous climate mitigation technologies available, ranging from bio-sequestration and ocean iron fertilisation to stratospheric sulphur aerosols and space mirrors, renewable energy (RE) technologies promise not only to reduce greenhouse gas (GHG) emissions but also to develop into mainstream technologies for developed and developing countries. TechCast (2009) predicts that alternative energy will provide 30% of the World's energy by 2022.

The state of currently utilised renewable energy resources is provided in Table 1, below.

Table 1: The state of currently utilised renewable energy resources (Source: IPCC, 2007)

Renewable energy resource	Stage of development and deployment
Concentrating solar power (CSP) or solar thermal power:	has been around for about 25 years, with a current combined capacity of approximately 400MWe and is now gathering momentum as a "new" RE technology. Another 400MWe are under construction and 6GWe are in the planning stages. Two other technologies, namely the solar dish (based on the Stirling engine) and Fresnel-lens based CSP, are less mature but are advancing fast, facilitated by the favourable financial incentives for CSP plants in countries such as Spain and the USA.
Solar heating and cooling:	solar water heating for dwellings and offices has become a mainstream technology.
Photovoltaic power (PV):	is used for grid-connected systems and off-grid systems, the latter predominantly in developing countries.
Wind energy:	is now a mainstream technology. In 2007, investments in on- and offshore wind amounted to an estimated €27.5bn. There are several multinational wind turbine manufacturers, but also a number of wind turbine manufacturers that have a more regional scope.
Ocean energy:	wave power and tidal stream power technologies are entering the commercial stage.
Geothermal energy:	there are three main applications, namely power generation, direct heat, and ground source heat pumps. "Direct use of heat" for buildings and industry is a commercial technology. Commercial geothermal power plants range from those based on dry steam to Organic Rankine Cycle (ORC) technology.
Hydro power:	has been commercialised, although there is still significant development potential for micro hydro (i.e. less than 1MWe).
Biomass:	is currently the most important renewable energy source in terms of primary energy supply on a global scale. Commercial medium- and large-scale biomass-based combustion systems that produce power, heat or a combination of both, are well-established technologies. Medium-scale gasification systems for power and combined heat and power (CHP) are currently being commercialised. Anaerobic digestion of wet biomass streams is also commercially available. In addition to the current renewable energy technologies based on utilising biomass, the production of first-generation biofuels, mainly for transportation, is gaining momentum in several countries. Some technologies offer prospects to become main second-generation technologies for biofuels, making use of ligno-cellulosic biomass, though these remain mainly at the R&D stage, with some pilot-plant and pre-commercial scale demonstrations in place or under development.

There are several RE (and other) technologies currently in the R&D stage that have strong prospects for short to medium term deployment (i.e. within the next 5 - 10years). These include:

- Solar heating with seasonal storage and solar cooling;
- PV systems based on modules with nanotechnology-based PV cells;
- Floating offshore wind;
- Ocean thermal energy conversion (OTEC);
- Salinity gradient based power;
- Small-scale geothermal power;
- Hot dry rock (HDR) geothermal power;
- Biomass integrated gasification combined cycle (BIGCC);
- Pyrolysis of biomass;
- Torrefaction of biomass;
- Cellulosic ethanol;
- Second generation biodiesel and algae;
- Di-methyl ether (DME) from biomass; and
- Bio-refinery.

Figure 2: Stages of renewable technologies (Source: EPRI, 2007)

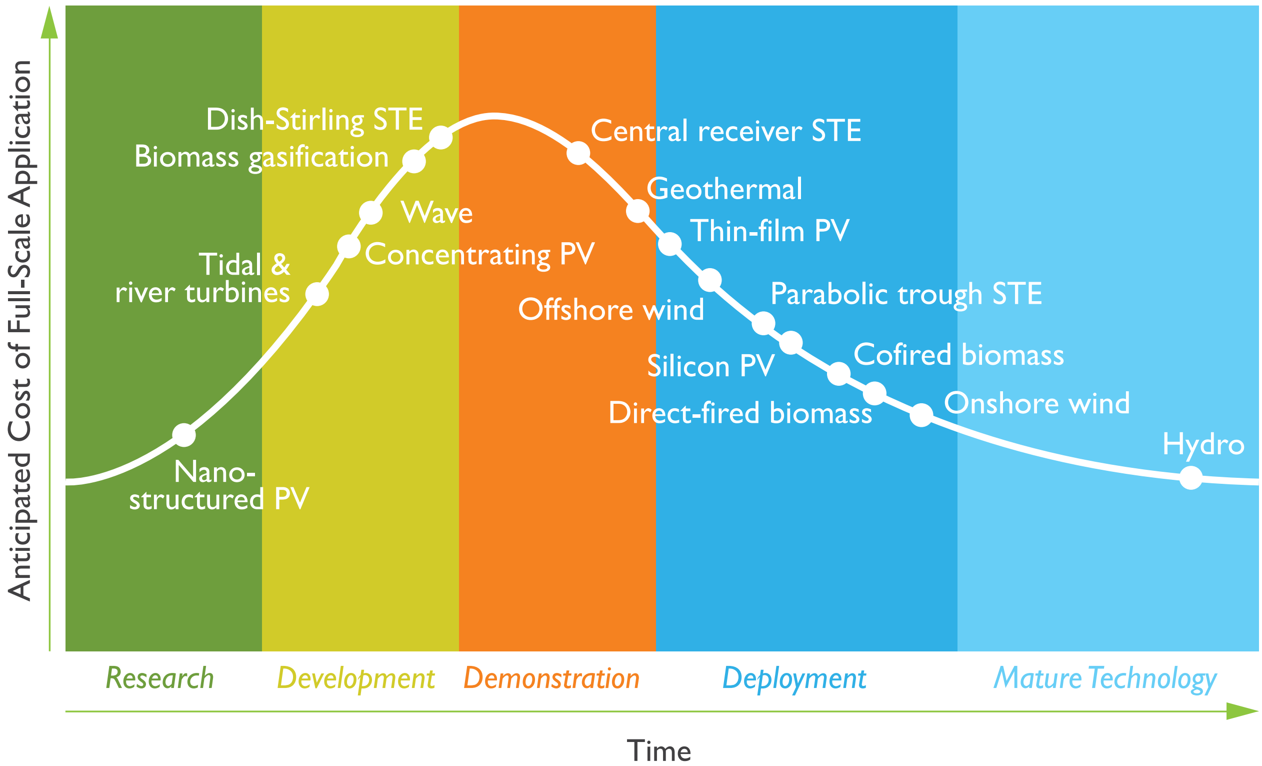


Figure 2 shows the stage of development of various renewable technologies and their relative costs. For example nano-structured PV is at the research stage and has to face all the costs related to development, demonstration and deployment. On the other hand, hydro is a mature technology.

Table 2: Generalized data for global renewable energy resources (Source: IPCC, 2007)

Renewable energy source	Estimated energy resource	Rate of use in 2005	% of primary energy supply 2005	Comments on environmental impacts
[EJ/year]	[EJ/year]		[%]	
Hydro (>10MW)	60	25	5.1	Land-use impacts
Hydro (< 10MW)	2	0.8	0.2	
Wind	600	0.95	0.2	
Biomass (modern)	250	9	1.8	Land-use for crops
Biomass (traditional)	37		7.6	Air pollution
Geothermal	5,000	2	0.4	Waterway contamination
Solar PV	1,600	0.2	<0.1	Toxics in manufacturing
Concentrating solar power (CSP)	50	0.03	0.1	Small
Ocean (all sources)	7	<1	0	Land and coastal issues

Table 2 shows the commercially available global renewable energy sources available and used during 2005. Based on this table, it is apparent that only a fraction of the potential primary energy supply available is currently being utilised.

Figure 3: Patent applications at the USPTO by technology (Source: WIPO, 2009)
Abbreviations used in this figure: SOL: Solar energy; WIN: Wind energy; BIO: Bio-energy; HYD: Hydropower; OCN: Wave and tidal power; H&FC: Hydrogen and fuel cells; CCS: Carbon capture and storage; and WST: Waste to energy.

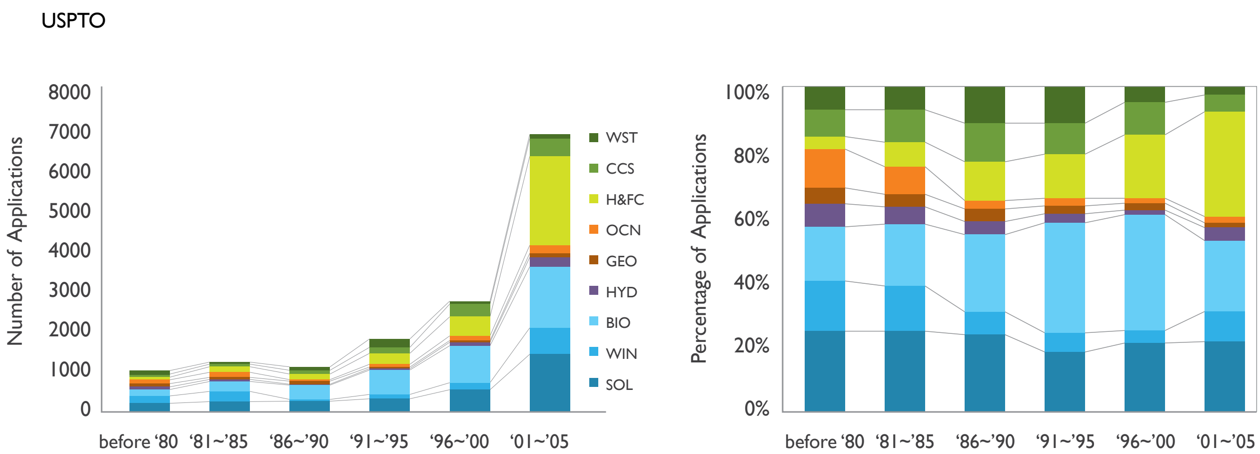
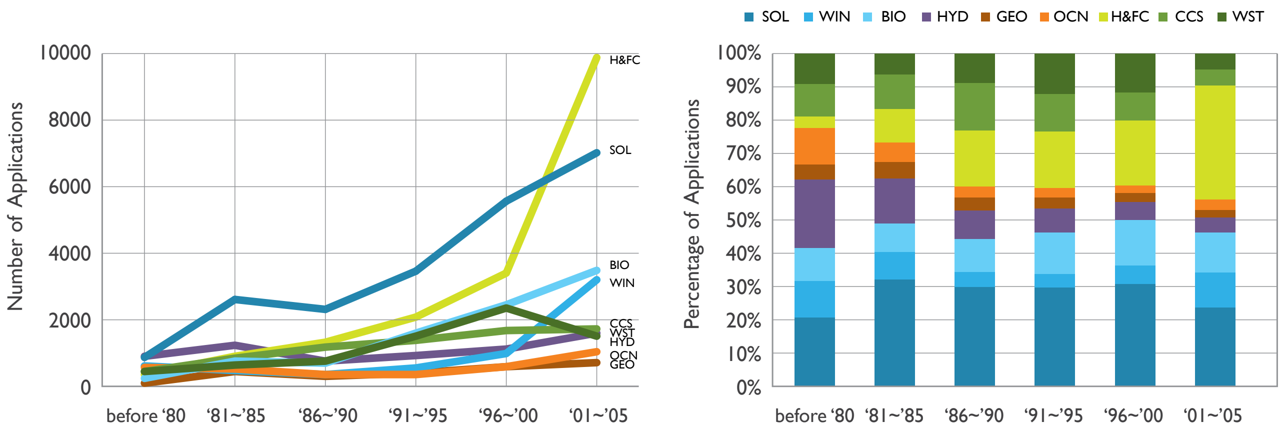


Figure 3 shows the results of a recent patent investigation by the World Intellectual Property Organization (WIPO, 2009). The investigation identified the growth of patents applications in the USPTO.

Figure 4: Patent applications by technology (Source:WIPO, 2009)



Hydrogen and fuel cell technologies have seen increasing numbers of applications at USPTO since the mid-1990s. Fuel cells were initially designed for use in spacecraft but in the 1990s further civilian uses were identified. In 2002, the US government, together with major automotive and refinery companies laid out a "National Hydrogen Energy Roadmap" to foster research and development of hydrogen-related technologies.

Bio-energy is the second most active technology. It has received increasing attention since 1991, with applications rapidly increasing until 2000. Substantial support has been provided for the use of biomass in power generation and for biofuels, for example in the form of ethyl tert-butyl ether (ETBE), a common gasoline additive.

Under US energy tax regulation passed in 1998, domestic ethanol producers received a subsidy of 51cents per gallon of ethanol in the form of tax exemptions. This tax exemption was transformed into an ethanol blender tax credit of 51cents per gallon in 2004.

In the early 1970s, the primary focus of solar energy technologies primarily focused of was on heating. Since then, development has focused increasingly on photovoltaic technologies.

Figure 4 shows the patent applications by technology in all patent offices internationally. Hydrogen and fuel cells appears to be the technology with the most patent activity, followed up by solar applications. Wind energy appears to be in the process of bypassing bio-energy in terms of the number of relevant patents.

Table 3 shows the investment requirements for a number of renewable technologies. The table reveals that certain renewable technologies (e.g. PV) are substantially more expensive than the pulverised coal fired power without carbon capture and storage (CCS) (US$1500 per kWe – see note b in the table on the next page).

Table 3: Current (2007) and future (2020) specific investment cost and generation cost of renewable energy options and selected CCS options (Source: Laco, 2008)

	Specific investment cost ($\$_{2007}/\text{kW}_e$)			Generation cost ($\$_{2007}/\text{MWh}$)			Source[a]
		2007	2020		2007	2020	
Concentrating Solar Power[b]	($\$/\text{kW}_e$)	4,100	2,500-3000	($\$/\text{MWh}$)	150-170	100-125	IS 96
Photovoltaic	($\$/\text{kW}_e$)	8,000	2,850-3,250	($\$/\text{MWh}$)	450-550	175-225	Borenstein, 2008
Onshore wind	($\$/\text{kW}_e$)	1,900	1,200-1,300	($\$/\text{MWh}$)	80-110	50-80	Lako et al, 2008
Offshore wind	($\$/\text{kW}_e$)	3,250	2,000-2,400	($\$/\text{MWh}$)	160-180	100-125	Lako et al, 2008
Wave	($\$/\text{kW}_e$)	4,875	2,000-2,500	($\$/\text{MWh}$)	275-325	125-150	IS 97-99
Tidal range	($\$/\text{kW}_e$)	3,750	2,400-2,800	($\$/\text{MWh}$)	175-225	125-150	IS 100
Tidal stream	($\$/\text{kW}_e$)	3,250-5,750	2,000-2,500	($\$/\text{MWh}$)	225-275	100-125	DTI, 2004; Davidson 2007
Conventional geothermal	($\$/\text{kW}_e$)	1,750-2,750	1,500-2,250	($\$/\text{MWh}$)	60-90	50-75	Lundin et al, 2006
Hot Dry Rock	($\$/\text{kW}_e$)	-	2,250-3,250	($\$/\text{MWh}$)	-	75-100	Lundin et al, 2006
Micro hydro (< 1 MW_e)	($\$/\text{kW}_e$)	2,250-2,750	2,000-3000	($\$/\text{MWh}$)	54-84	48-72	Lako et al, 2003
Small hydro (1-10 MW_e)	($\$/\text{kW}_e$)	2,000-3,000	1,750-2,750	($\$/\text{MWh}$)	48-72	42-66	Lako et al, 2003
Large hydro(> 10 MW_e)	($\$/\text{kW}_e$)	1,500-2,500	1,500-2,500	($\$/\text{MWh}$)	35-60	35-60	Lako et al, 2003
Biomass combustion				($\$/\text{MWh}$)			
Medium scale (5-20 MW_e)	($\$/\text{kW}_e$)	3,500-4,250	2,750-3,750	($\$/\text{MWh}$)	65-95	55-85	Mozaffarian and Lako et al, 2008
Large scale (> 20 MW_e)	($\$/\text{kW}_e$)	2,500-3,250	2,250-2,750	($\$/\text{MWh}$)	45-75	40-70	Mozaffarian and Lako et al, 2008
Biomass gasification							
Medium scale (5-20 MW_e)	($\$/\text{kW}_e$)	3,750-6,500	3,000-3,700	($\$/\text{MWh}$)	70-115	55-85	Mozaffarian and Lako et al, 2008
Large scale (> 20 MW_e)	($\$/\text{kW}_e$)		2,700-3,500	($\$/\text{MWh}$)		40-70	Mozaffarian and Lako et al, 2008
Coal-fired power with CCS[c]							
Post combustion	($\$/\text{kW}_e$)		2,100-2,400	($\$/\text{MWh}$)		60-80	Lako et al, 2004
Pre-combustion (IGCC)	($\$/\text{kW}_e$)		2,100-2,400	($\$/\text{MWh}$)		55-80	Lako et al, 2004
Oxy-fuel	($\$/\text{kW}_e$)		2,000-2,500	($\$/\text{MWh}$)		60-80	Black, 2008

a IS=Internet Source

b Under solar conditions prevailing in southern California and Nevada.

c Investment cost of pulverised coal-fired power without CCS typically $\$1{,}500/\text{kW}_e$ (Dalton, 2004). According to (Davis, 2007) a CCS-ready IGCC plant would cost at least 16.9% more than a supercritical pulverised coal plant, which is therefore approximately $\$1{,}700/\text{kW}_e$.

Sources: Internet Source 96 (CSP); Borenstein 2008 (PV); Lako et al, 2008 (wind); Internet Sources 97-100; DTI, 2004; Davidson, 2007 (wave and tidal); Lundin et al, 2006 (geothe Lako et al, 2003 (hydro); Mazaffarian and Lako, 2008 (biomass power); Dalton, 2004; Lako, 2004; Davis, 2007; Black, 2008 (coal-fired power)

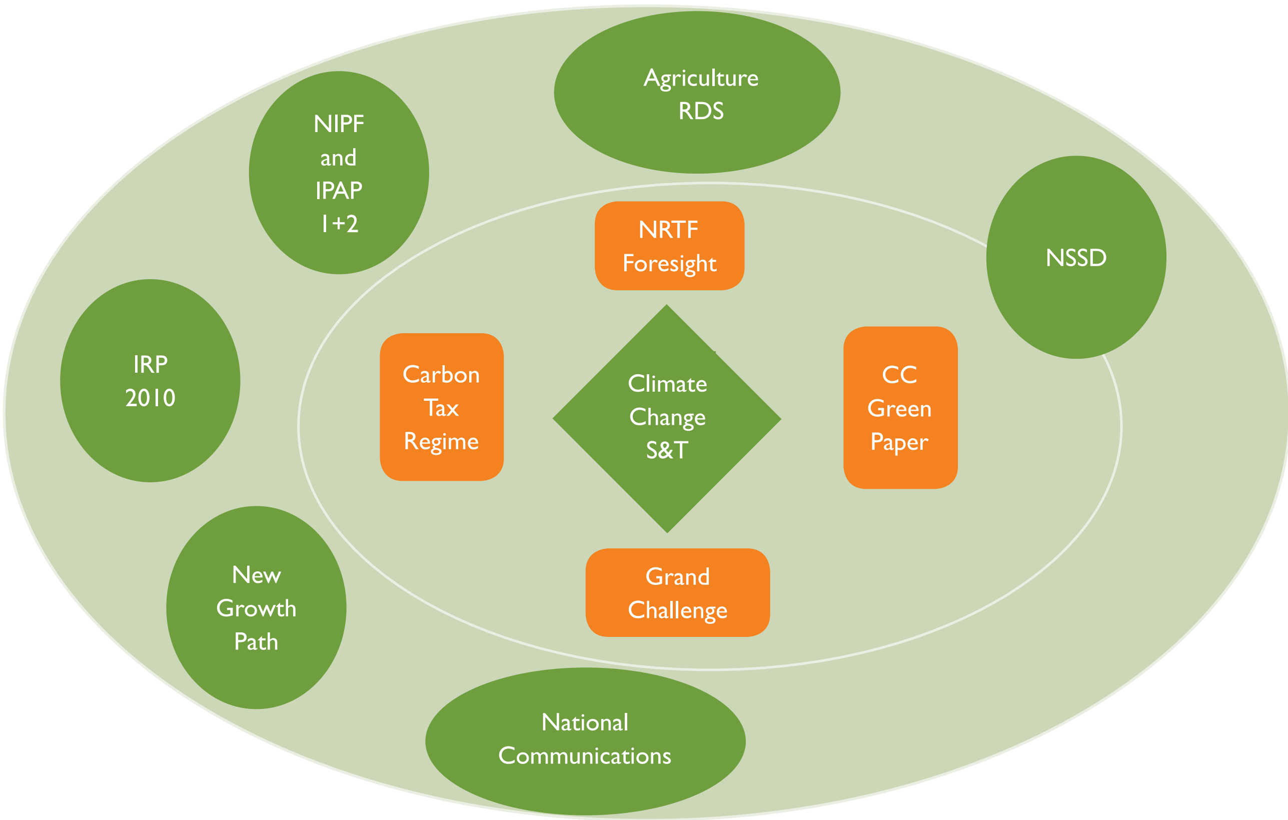
5 The Policy Environment Related to Climate Change Science and Technology in South Africa

There are numerous policies housed in different South African institutions that support and direct climate change science and technology. However, they are currently very poorly coordinated. The country's macro-policy direction comes from South Africa's macro-planning tools such as the New Growth Path (Ministry of Economic Development, 2010), the National Industry Policy Framework (NIPF) (Department of Trade and Industry (DTI), 2010) and its associated action plans (e.g. the Industrial Policy Action Plan (IPAP)), the National Strategy and Action Plan on Sustainable Development (NSSD)(Department of Environmental Affairs (DEA), 2010), the Agriculture Research and Development Strategy (RDS) (Department of Agriculture (DOA), 2009) and the Integrated Resource Plan (IRP) (Department of Energy, 2010). Summaries of these key policies are found in Box 1.

Policies specific to climate change science and technology include the Climate Change Green Paper (DEA, 2010), the Carbon Tax Regime (National Treasury, 2010), the National Research and Technology Foresight (NRTF) for the Environment Sector (Department of Arts, Culture, Science and Technology (DACST), 1999) and the more recent Science Plan for the Global Change Grand Challenge (Department of Science and Technology (DST), 2007).

Figure 5 below illustrates macro-economic and climate change specific policies and strategies that influence the climate change science and technology landscape in South Africa. The inner sphere represents those instruments that have a more direct influence on the development of climate change related science and technology. The NSSD straddles both the macro-policy context and the more climate-specific policies, strategies and action plans for mitigation and adaptation.

Figure 5: National policy influences in climate change science and technology



Box 1: Key South African macro-economic policies

The New Growth Path (Ministry of Economic Development, 2010): The framework has been introduced as the vector determining the trajectory of South Africa's future economic growth path. It is explicit in its proposal to support employment creation in six priority sectors, one of which is described as "the green economy".

Industrial Policy Action Plan (IPAP2) (DTI, 2010): is the implementation plan of the National Industry Policy Framework (NIPF). It identifies 13 priority sectors, including the " 'green' and energy-saving industries" sector. This sector is primarily focused on renewable energy and emphasises the key opportunities of improved economic efficiency, increased domestic investment and long-run export earnings.

National Strategy and Action Plan for Sustainable Development (NSSD) (DEA, 2010): The strategy organises the action pans around the five priorities identified in the National Framework for Sustainable Development (NFSD), namely: i) the response to climate change (mitigation and adaptation); ii) the green economy; iii) building sustainable communities; iv) sustaining ecosystems and natural resource use efficiency; and v) the development of appropriate governance systems and capacity.

National Agricultural Research and Development Strategy (DOA, 2009): Climate change is recognised as a key driver of the need for a more robust agricultural R&D strategy. While sustainable natural resource management is identified as a key area of technology development, it is much less explicit about climate change mitigation and adaptation strategies in the agricultural sector.

National Research and Technology Foresight (NRTF) (DACST, 1999): The NRTF project was one of a number of initiatives undertaken by DACST, DST's predecessor, as part of its mission to review and reform South Africa's science and technology system. The environment sector report examined interventions under 17 themes, many of which inform the current dialogue on the science and technology required for a robust national climate change response.

Global Change Grand Challenge (DST, 2007): This is one of five grand challenges underpinning the Ten Year Innovation Plan (2008 - 2018) adopted by DST, which seeks to stimulate the growth of knowledge, high-level human capital and innovation. The global change science plan is a research and technology strategy focusing on terrestrial, marine and atmospheric systems and society's response to global change. It concludes with an examination of the skills and infrastructure required for South Africa to be able to compete in global change science, technology and innovation.

The policy environment informing climate change science and technology is clearly fragmented. The National Climate Change Response White Paper thus presents an important opportunity to provide a base for co-ordination and synergy as well as the possibility to strengthen the policy platform.

6 The State of Environmental Research in South Africa

Environmental science is the complex and dynamic interaction of diverse scientific disciplines. The fields commonly considered as parts of environmental research include: ecology, environmental engineering, environmental sciences, environmental studies, meteorology and atmospheric sciences, public environmental and occupational health and water resources (Science-Metrix, 2006). Box 2 provides a summary of topics included in each of these fields as catalogued by the Thomson-Reuters ISI database.

Box 2: Summary of topics included in each environmental science field

Ecology concerns the study of the interrelationship of organisms and their environments. Sub-disciplines include ecological economics, ecological engineering, eco-toxicology, ecological modelling, evolutionary ecology, biogeography, chemical ecology, marine ecology, wildlife research, microbial ecology, molecular ecology, and population ecology.

Environmental Engineering seeks to understand the effects of human beings on the natural environment and the development of controls to minimise environmental degradation. Relevant topics in this category include water and air pollution control, hazardous waste management, land reclamation, pollution prevention, bioremediation, incineration, management of sludge problems, landfill and waste repository design and construction, facility decommissioning, and environmental policy and compliance.

Environmental Sciences covers many aspects of the study of the environment, among them environmental contamination and toxicology, environmental health, environmental monitoring, environmental geology, and environmental management. This category also includes soil science and conservation, water resources research and engineering and climate change.

Environmental Studies covers subjects that are multi-disciplinary in nature. These include environmental policy, regional science, planning and law, management of natural resources, energy policy, and environmental psychology.

Meteorology and Atmospheric Sciences covers those topics that deal with the atmosphere and its phenomena, especially weather and weather forecasting. Topics in this category are concerned with the atmosphere's temperature, density, winds, clouds, precipitation and other characteristics, as well as the structure and evolution of the atmosphere in terms of external influences and the basic laws of physics. This category also deals with climatology.

Public, Environmental and Occupational Health covers social medicine, health behaviour, health education, safety research, and community mental health. Publications concerned with the health of particular groups such as adolescents, elderly, or women are included in this category.

Water Resources covers a number of water-related topics. These include desalination, ground water monitoring and remediation, hydrology, irrigation and drainage science and technology, water quality, hydraulic engineering, ocean and coastal management, river research and management, waterways and ports.

Figure 6 shows the number of South African papers on environmental related disciplines (as defined above) during the period 1981 - 2008. During the 2000s, the number of publications in ecology, public, environmental and occupational health and environmental sciences show an encouraging increase in publication outputs.

Figure 6: Number of South African Papers in environmental disciplines. (Source: National Science Indicators Database, ISI Thomson-Reuters)

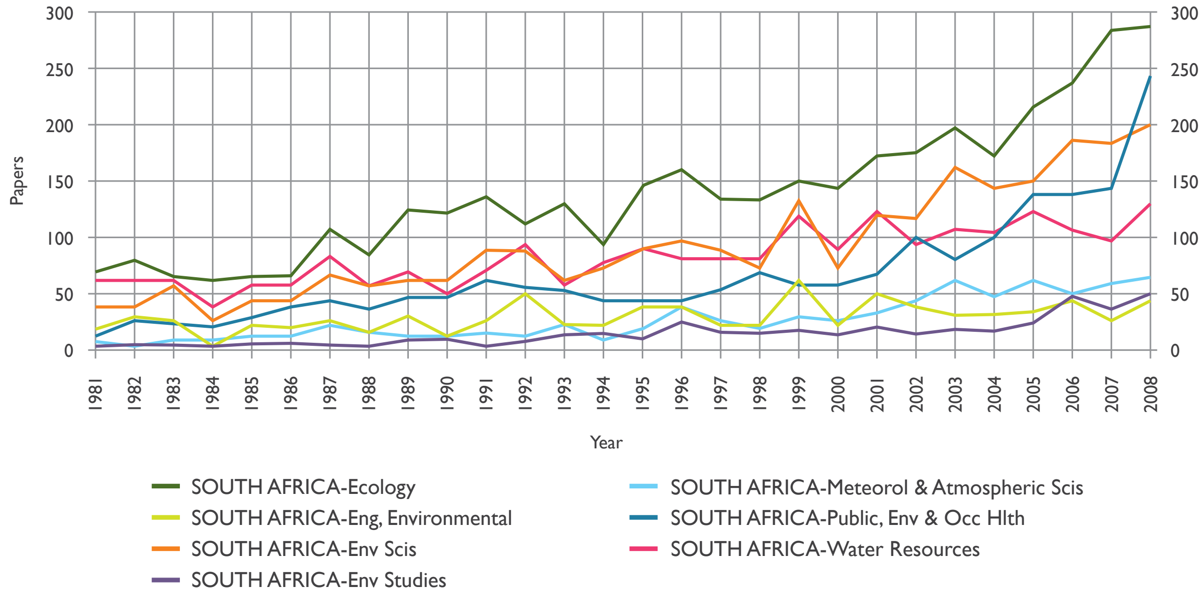


Figure 7 shows the contribution of South African papers to world literature. In contrast to Figure 6, all trends are flat or declining. The expansion in the number of publications is therefore a worldwide phenomenon and not particular to South Africa. Increase in the coverage of relevant journals by the Thomson Reuters ISI indices is one of the factors that affected the South African trends in environmentally relevant fields.

Figure 7: Share of South African papers in world literature (Source: National Science Indicators Database, ISI Thomson-Reuters)

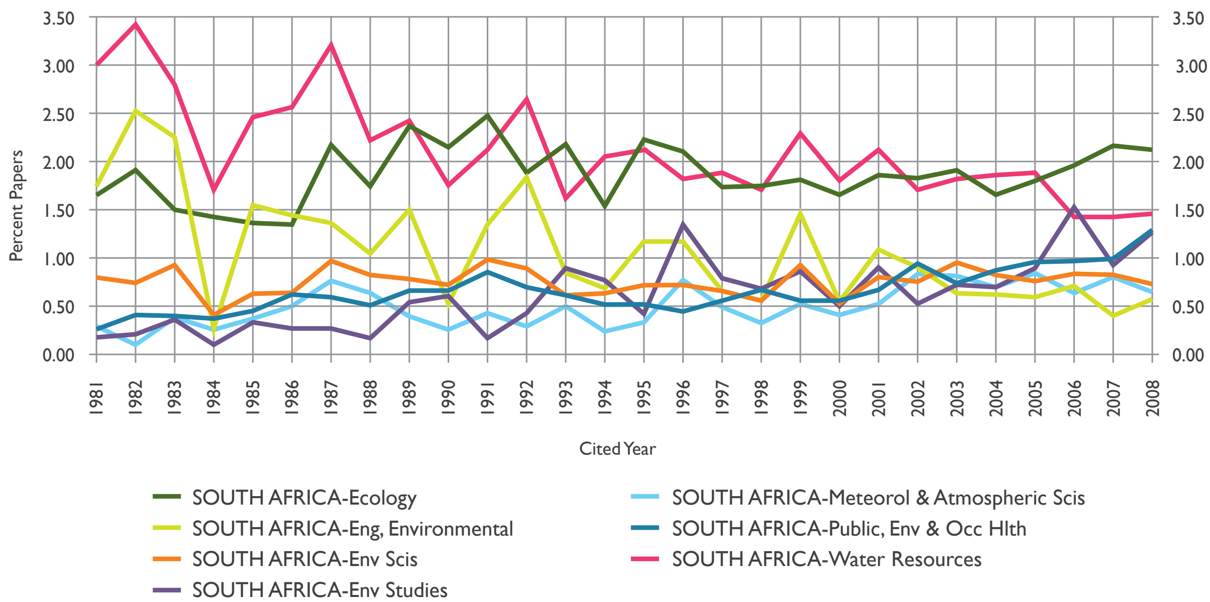


Table 4 shows the estimated percentage of South African papers in the particular fields and the activity indices[3] for the period 2004 - 2008. All activity indices are above 1, indicating that South Africa focuses on environmental disciplines. It is worthwhile noting that simply because a country emphasises particular disciplines does not mean that it performs research of adequate quality in the particular field. Only comparisons with other countries and regions can determine the quality of research.

Table 4: South African papers in environmental fields and activity indices

	% papers 2004 - 2008	Activity Index
Ecology	1.95	3.54
Engineering Environmental	0.58	1.05
Environmental Sciences	0.79	1.43
Environmental Studies	1.09	1.98
Meteorology & Atmospheric Sciences	0.73	1.32
Public, Environmental & Occupational Health	1.03	1.87
Water Resources	1.59	2.89
South African Papers as % of world total	0.55	N/A

Table 5 compares South Africa with four other countries in terms of their contribution to publications within environmental related scientific fields. The estimates presented in this table indicate that the comparator countries (representing both developed and developing countries) produce three to four times as many publications as South Africa in the environment related fields.

Table 5: Comparison of percentage papers in environmental fields for South Africa and four other countries

	Australia	Brazil	Canada	China	South Africa
Ecology	7.54	2.42	8.07	3.10	1.95
Engineering Environmental	2.89	1.50	6.63	9.27	0.58
Environmental Sciences	3.47	2.22	6.49	8.82	0.79
Environmental Studies	4.89	1.20	6.41	3.62	1.09
Meteorology & Atmospheric Sciences	3.29	1.83	5.94	6.96	0.73
Public, Environmental & Occupational Health	4.90	3.32	6.53	2.65	1.03
Water Resources	4.46	1.37	6.07	7.27	1.59
% Country Papers in world	3.02	2.06	4.67	8.37	0.55

3 *The activity index shows whether the particular field is producing more or less than the national total (i.e. taking into account the country's research output). Indices above 1 indicate that the country produces more in the particular field than what it was expected from its total research production.*

7 South African Inventiveness

Table 6 shows the number of energy related patents for both demand and supply technologies, granted worldwide and to South African inventors in particular, during a the period 1988 - 2008 and the 5-year period 2004 - 2008. The codes and key words used in order to identify the set of relevant patents appear in Appendix 1. The classifications developed by the Organization for Economic Cooperation and Development (OECD, 2009), the World Intellectual Property Organization (WIPO, 2009) and National Bureau of Economic Research (NBER) (Popp, 2005), constitute the basis for the classification utilised in this report.

The technologies in which South Africa has had a presence over the last 20-year period include: Coal Liquefaction - Fischer-Tropsch process; Nuclear - radiation acceleration/detection techniques; and carbon capture and storage. The Fischer-Tropsch process was still an active technology during the most recent five years, while the remaining two technologies became inactive. South Africa has been granted 5.8% of the patents in the Fischer-Tropsch process while the country in its totality received just above 0.001% of the USPTO patents.

Table 6: South African energy related patents: 1988 - 2008

Demand Technologies	World Patents 20 Years	World Patents 5 Years	SA Patents 20 Years	SA Patents 5 Years
Waste Heat: Liquid Heaters and Vaporizer/Industrial/Waste Heat	224	38	1	0
Waste Heat: Power Plants/Fluid motor means driven by waste heat or exhaust energy	1 645	590	0	0
Heat Exchange	16 043	4 597	7	1
Heat Pumps	660	175	0	0
Stirling Engine	517	120	0	0
Supply Technologies				
Coal Liquefaction: Mineral oils: Process and Products/by treatment of solid material	349	31	1	0
Coal Liquefaction: Fischer-Tropsch Process	894	328	31	19
Coal Gasification: Gas; Heating and Illuminating	248	40	2	0
Nuclear: reactor techniques	5579	716	7	5
Nuclear: radiation acceleration/detection techniques	12 233	3 471	17	0
Biomass	810	73	2	0
Wind Power	1 161	556	0	0
Solar Power: Materials, Cells and Modules	2232	377	0	0
Solar Power: Systems	4 569	1 859	6	0
Solar Thermal: Collectors	1 588	272	2	0
Solar Thermal: Heating	507	122	0	0

SASOL is the dominant assignee in Fischer-Tropsch process; ESKOM and the Pebble Bed Modular Reactor (PBMR) are the main assignees in nuclear technology and the assignees in carbon capture and storage are the Water Research Commission (WRC), SASOL and CSIR. SASOL also dominates the Hydrogen and Fuel Cells technology.

Demand Technologies	World Patents 20 Years	World Patents 5 Years	SA Patents 20 Years	SA Patents 5 Years
Hydropower	2 039	690	3	0
Geothermal Energy: Systems	258	56	0	0
Geothermal Energy: ground-coupled heat pumps	83	44	0	0
Wave and Tidal Power: Tidal power	342	136	0	0
Wave and Tidal Power: Wave power	421	166	0	0
Hydrogen and fuel cells: Hydrogen production	70	25	5	0
Hydrogen and fuel cells: Hydrogen storage	2632	766	6	3
Hydrogen and fuel cells: Proton-exchange membrane fuel cells	4 026	1 969	2	0
Hydrogen and fuel cells: Solid oxide fuel cells	1 134	484	1	0
Hydrogen and fuel cells: Molten carbonate fuel cells	872	342	0	0
Hydrogen and fuel cells: Other types of fuel cells	2539	997	0	0
Carbon capture and storage	5 988	1 316	16	2
Waste-to-energy: Refuge-derived fuel	2 764	390	1	0
Waste-to-energy: Mass burn	2 819	359	2	0

8 Discussion

South Africa needs to decide on what its desirable future is with respect to its climate change science and technology capability. South Africa has a justifiable reputation as a leading player in the global climate change dialogue. The various official South African delegations to the UNFCCC Conferences of the Parties (COPs) and summits have demonstrated leadership on a number of fronts, firstly in the rescue and full implementation of the Kyoto protocol, and more recently in the push for a new global deal on climate change. South Africa has also been a keen participant in the IPCC and a significant contributor to its scientific reports. However, the analysis presented in this report indicates that the scenario that currently best represents South Africa is one of medium political will, with relatively low scientific support and technology development capacity (See Figure 1).The rationalisation for this assessment is provided below.

When considering the levels of favourability of the implementation environment, the following factors need to be considered:

1. The level to which the expressed political will is translated into policies with budgeted action plans to support their implementation. This is a combination of climate change specific policy as well as re-prioritisation of related policy to emphasise climate change issues; and
2. The re-organisation of the regulatory environment to facilitate the implementation of climate change adaptation and mitigation strategies.

When considering the criteria above, South Africa's national implementation environment is at medium favourability (See Section 5). The national challenge is that while many important policy and implementation shifts have occurred, significant changes are still required, especially in relation to energy and transport policy and strategy. Having said this, important seeds have been planted in economic blueprints such as the National Government's Accelerated Shared Growth Initiative of South Africa (AsgiSA), NIPF (DTI, 2008) and its associated implementation plans, and most recently the New Growth Path (Ministry of Economic Development, 2010). These provide promising avenues for mainstreaming climate change science and technology into policy, budgets, implementation and regulation in the future.

Regarding national science and technology capacity, South Africa has world-renowned scientists that participate in the IPCC processes and other forums of the climate change dialogue. A more detailed examination of South Africa's research outputs in the environmental fields indicates the following:

- South Africa has a strong research base in the area of the environment, indicated by the fact that in three out of the seven environmental fields, South Africa produces more that 1% of the global output. If South Africa were an institution it would have been awarded an ISI Field Ranking in these three areas, namely Ecology (1,95%), Water Resources (1.59%) and Environmental studies (1.09%). The failure to attain 1% in the other four fields is both sobering and a cause for concern as this implies that South Africa is not a significant global player in these domains.
- Figure 6 indicates that there is an increase in the number of publications, particularly in the last 10 years. However, Figure 7 indicates that the rate of increase in South Africa's research outputs in the area of the environment were not sufficient to increase the share of South African papers in world literature. South Africa's increased production of environmental publications in the last 10 years has matched the global trend.
- When considering adaptation and establishing the infrastructure for mitigation success, the parameters that become important are the development of intellectual property (IP) and developing new knowledge in areas such as environmental engineering. The patent analysis indicates a very low South African presence in the climate change domain other than carbon capture and storage. In the environmental engineering category, South Africa produced 0.58% of the global output between the years 2004 - 2008, 5% of China's output.

Thus, climate change science and technology, as measured using broader environmental science and technology as a proxy, is relatively low.

A summary of the current scenario for South Africa is that South Africa is a leading player in the global climate change dialogue. In addition South African scientists make important contributions to the global body of knowledge collected under the auspices of the IPCC. However, this picture is not proportionately mirrored by the national situation, which is one of a better than average, but far from excellent, implementation environment with a medium level of political will expressed in the policy and actionable initiatives domain. This implies that the current levels and trends of human capital, knowledge generated, IP created and technology developed, are inadequate to support and empower a robust climate change response strategy.[4]

Based on this analysis, the implementation of adaptation and mitigation initiatives associated with such a strategy will need to rely heavily on imported knowledge, capacity and technology. This hampers any South African ambition to be internationally competitive, as envisioned by the New Growth Path (Ministry of Economic Development, 2010).

4 It is possible that the South African implementation environment will become more favourable as a result of the UNFCCC COP17.

9 Recommendations and Future Directions

It is desirable that South Africa develops a robust and highly functional climate change science and technology platform to enable both the development and implementation of national action plans. This will not only enable South Africa to minimise the negative impacts of climate change on its economy and society, but also to take advantage of the various opportunities that exist for becoming a significant global player in the green economy, and more specifically a leading supplier of climate change knowledge, know-how, technologies and services.

An examination of the national policy and strategy environment related to climate change provides two important insights. The first is that the there is no explicit policy environment directing the development of climate change science and technology and the related human capital. The second is that the macro-planning tools such as the NIPF and the New Growth Path have a high investment in both the potential of a green economy for contributing to overall South African development as well as the serious risk climate change presents to the country's development trajectory.

The decision at a national level to adopt new innovations depends on the benefits users expect from their adoption as well as on the expected costs related to the research investment and the mastery of the innovations.

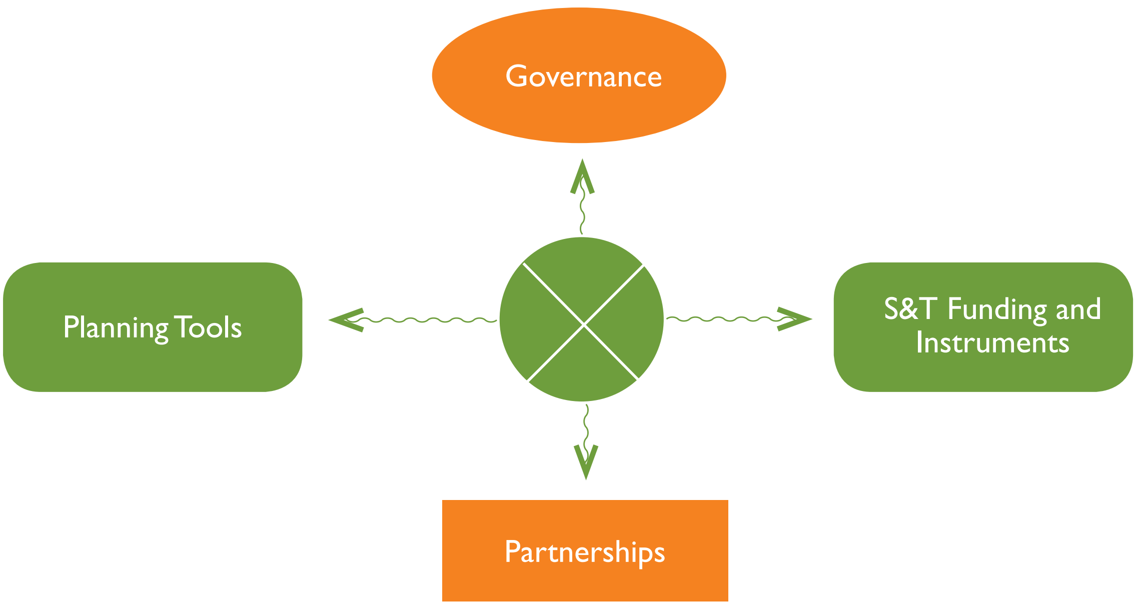
A crucial factor influencing and impacting on the diffusion of new technologies is the national technological capability to develop, imitate and adapt international technologies to national productive activities. The technological capabilities of national users and producers of complementary or alternative technologies influence the relative costs and benefits of the investment and adoption of new technologies.

It is envisaged that under a business as usual scenario, the existing infrastructure and international obligations will support the diffusion of existing simple, mature and low-cost technologies rather than the diffusion of new renewable energy technologies. The current situation in South Africa therefore appears to be an obstacle in the diffusion of new environmentally friendly technologies as articulated by Bodas et al. (2010).

In this light, the National Climate Change Response White Paper should consider a set of recommendations that may enable an environmentally friendly scenario.

The recommendations relate to four domains, namely governance, planning tools, science and technology funding and instruments, and partnerships, as illustrated in Figure 8 above. The first relates to highly informed decision-making at policy, strategy and implementation levels. In this light it would be useful for the White Paper to consider a governance arrangement that made provision for the position of a chief scientific advisor to the Minister of Environmental Affairs. The Minister, with the advice of the chief scientific advisor should establish and constitute a scientific advisory council that consists of a wide range of expertise. This council could be chaired by the chief scientific advisor.

Figure 8: Recommendations on science and technology related to climate change in South Africa



The second recommendation relates to the medium- and long-term planning for South Africa's climate change science and technology landscape. It is recommended that a rigorous planning exercise be undertaken in the form of a climate change foresight exercise. South Africa has had good experiences with this methodology and arguably, the South African Research and Technology Foresight Exercise (DACST, 1999) has been pivotal in developing the pathway for the current South African science and technology landscape. It is expected that such an exercise would deliver on a human capital development plan, a complementary science and technology plan on climate change in partnership with the DST Global Change Grand Challenge as well as a climate change technology roadmap for the country.

The DEA should also consider the development of a funding instrument to enable the development of science and technology capacity, new knowledge, IP and technology to enable the implementation of a robust climate change response strategy. The White Paper should give consideration to a specialised funding agency in the form of an environmental science council, or the development of specialist environmental funds in existing agencies. In the latter category the authors would like to point the DEA to instruments that have been very successful in the broader South African science and technology landscape. These include:

- Climate Change Research Chairs in the family of the DST/NRF South African Research Chairs Initiative (SARChI).
- The development of a Climate Change Technology and Human Resources and Innovation Programme (CC THRIP) within the modalities of the current NRF administered THRIP programme sponsored by DTI.
- The development of Climate Change Centres of Excellence to develop much higher levels of climate change science as well as develop more PhDs and Post-Doctoral fellows in this area; or Climate Change Centres of Competence to develop IP and technologies that will enable South Africa to take up a global leadership position in this area.
- The development of research and innovation partnerships in the area of climate change.

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ANNEXURE 1: CODES IDENTIFYING ENERGY PATENTS

Supply Technologies	Codes
Coal Liquefaction: Mineral oils: Process and Products/by treatment of solid material	208/400-435
Coal Liquefaction: Fischer-Tropsch Process	518
Coal Gasification: Gas; Heating and Illuminating	48/200, 48/201, 48/202, 48/210, 48/71, 48/72, 48/73, 48/77, 48/98, 48/99, 48/100, 48/101
Nuclear: reactor techniques	G21B,G21C,G21D,G21F
Nuclear: radiation acceleration/detection techniques	G01T, G21G, G21H,G21J, G21K, H05H
Biomass	C10L5/(42-44), F02B43/08, C10L1/14, B01J41/16
Wind Power	F03d, B60L8/00 and wind*, turbin*
Solar Power: Materials, Cells and Modules	E04D13/18, H01L25/00, H01L31/04, H01L31/042, H01L31/052, H01L31/18, H02N6/00
	Solarcell, solar-cell, photovoltaic*, solar, photo*, pv, sun, light, cell, batter*, panel, module*
Solar Power: Systems	E04D1/30, G02F1/136, G05F1/67, G01L25/00, H01L31/00, 01L31/042, H01L31/048, H01L33/00, H02J7/35, H02N6/00
	Solarcell, solar-cell, photovoltaic*, solar, photo*, pv, sun, control*, invert*, convert*, conversion, system, mount*, instal*
Solar Thermal: Collectors	F24J2/0*, F24J2/1*, F24J2/3*, F24J2/4*, F03G6/06, G02B5/10, H01L31/052
	CSP, concentrate* collect*, trough, dish, tower, sterling, stirling
Solar Thermal: Heating	C021/14, E04D13/18, F02C1/05, F03G6/00, F03G6/06, F22B1/00, F24C9/00, F24H1/00, F24J2/02, F24J3/00, F25B27/00, F26B3/28, H01L31/058, H02N6/00
	Solar*, sun*, heat*, thermal, accumulate*, power, generat*, warm*, boiler*, building, system, house, hot, boiling
Hydropower	E02B9/0*, F03B1/00, F03B3/0*, F03B3/1*, F03B7/00, F03B13/0*, F03B13/22, F03B15/0*, F03B15/1*, F03B15/20, F03B15/22, F03B17/0*, F03G7/00, F03G7/10, F16H41/00, H02K57/00
	Hydro*, flow, fluid, fluid pressure, dam, hydro*, water*, river, drainage*, float*, hydraulic* buoyancy, dam, tunnel, pump, pelton, turgo, ossberger, fransis, Kaplan, tubular, bulb, rim, turbine
Geothermal Energy: Systems	F24J3/0*, F03G4/00*, F03G7/04, F25B30/06, F01K23/10, F01K25/0*, F01K25/10, F01K25/12, F01K25/14, F01K27/00
	geothermal, hydrothermal, earth*, magma, ground, underground, lake, pond, hot water, water, rock, brine*, hydro, steam, heat source, resource, power, thermal, electric*, energy, system

Supply Technologies	Codes
Geothermal Energy: ground-coupled heat pumps	F25B30/00, F25B30/02, F25B30/04, F25B1/08, F24J3/08, F03G4/00
	GHP, geoexchang*, earthcoupled, earth-coupled, earth coupled, geothermal, hydrothermal, earth*, geo*, magma, ground, underground, terrestrial, lake, pond, water, hot water, hydro, steam, heat source, resource, power, thermal, electric*, energy, system
Wave and Tidal Power: Tidal power	(E02B9/0*, F03B13/0*, F03B13/1*, F03B13/2* , F03B15/0*, F03B15/1*, F0315/20, F03G7/00, F03G7/05)
	Tidal*, tide*, seawater, sea water, ocean
Wave and Tidal Power: Wave power	(E02B9/0*, F03B13/0*, F03B13/1*, F03B13/2* , F03B15/0*, F03B15/1*, F0315/20, F03G7/00, F03G7/05)
	wave*, bollow*, offshore*, onshore*, duck*, float*
Hydrogen and fuel cells: Hydrogen production	C01B3, C25B1/04, C07C4/20
	Hydrogen, produc*, generat*, obtain*, reform*, preparat*, manufacture*
Hydrogen and fuel cells: Hydrogen storage	B01D53/02, C01B3/0*, C01B3/1*, C01B3/2*, C01B3/3*, C01B3/4*, C01B3/5*, C22C22/00, C22C33/00, F25B17/12, H01M4/38, H01M8/06
	Hydrogen, storage*, reservoir*, alloy*, absorb*
Hydrogen and fuel cells: Proton-exchange membrane fuel cells	H01M4/00 , H01M4/86 , H01M4/88 , H01M4/90 , H01M8/0* , H01M8/1* , H01M8/20 , H01M8/22 , H01M4/24
	Fuel-cell*, fuel-batter*, fuel cell*, fuel batter*, PEM, PEMFC, polymer*, proton, ion, exchange*, membrane
Hydrogen and fuel cells: Solid oxide fuel cells	H01M4/00 , H01M4/86 , H01M4/88 , H01M4/90 , H01M8/0* , H01M8/1* , H01M8/20 , H01M8/22 , H01M4/24
	Fuel-cell*, fuel-batter*, fuel cell*, fuel batter*,SOFC*, solidoxide*, solid oxid*, zirconium, Zr0
Hydrogen and fuel cells: Molten carbonate fuel cells	H01M4/00, H01M4/86, H01M4/88, H01M4/90, H01M8/0*, H01M8/1*, H01M8/20, H01M8/22, H01M4/24
	Fuel-cell*, fuel-batter*, fuel cell*, fuel batter*, MCFC, molten, melt*, carbonat*
Hydrogen and fuel cells: Other types of fuel cells	(H01M4/00, H01M4/86, H01M4/88, H01M4/90, H01M8/0*, H01M8/1*, H01M8/20, H01M8/22, H01M4/24)
	Fuel-cell*, fuel-batter*, fuel cell*, fuel batter*, potassium hydroxide, phosphoric* acid, liquid phosphoric*, direct methanol, direct oxidation, alkaline, DMFC, AFC, PAFC
Carbon capture and storage	B63B35/*, C01B3/*, C01B31/20, C01B31/22, C02F1/*, C07C7/10, F01N3/10, F25J3/02, B01J20/*, B01D53/*, B01D11/*
	Carbon-dioxide*, carbon dioxide*, gas dioxide*, CO_2 storage*, captur*, recover*, deliver*, regenerat*

Supply Technologies	Codes
Waste-to-energy: Refuge-derived fuel	B09B1/00, B09B3/00, B09B5/00, 29B17/00, C02F3/30, C04B33/132, C10B53/07, C10G1/10, C10L5/48, C11B3/00, F23G7/0*, F23G7/1*, F23G5/*, F25B27/02, F02G5/*, F012K25/14, C10J3/86
	RDF, refuge derived*, solid recover*, solid*, waste*, used, refus*, garbage, trash
Waste-to-energy: Mass burn	B09B1/00, B09B3/00, B09B5/00, 29B17/00, C02F3/30, C04B33/132, C10B53/07, C10G1/10, C10L5/48, C11B3/00, F23G7/0*, F23G7/1*, F23G5/*, F25B27/02, F02G5/*, F012K25/14, C10J3/86
	Burn*, combust*, incinerat*, energy, heat, wast*, used, refus*, garbage, trash

Demand Technologies	Codes
Waste Heat: Liquid Heaters and Vaporizer/ Industrial/Waste Heat	122/7R, 7A, 7B, 7C, 7D,
Waste Heat: Power Plants/Fluid motor means driven by waste heat or exhaust energy	60/597-624
Heat Exchange	165
Heat Pumps	62/238.7, 62/324.1-325
Stirling Engine	60/517-526

Notes

Notes

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environmental affairs

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REPUBLIC OF SOUTH AFRICA

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On behalf of
Federal Republic of Germany
The Federal Government