SAME CONTINENT, WORLDS APART: A COMPARATIVE STUDY OF THE DEVELOPMENT OF RADIO ASTRONOMY IN SOUTH AFRICA AND KENYA

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CARRINGTONE KINYANJUI

School of Medical Sciences

Centre for the History of Science, Technology and Medicine

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Abstract

A comparison is made between the process of development of radio astronomy in Kenya and South Africa. We begin by comparing the historical development of the two countries. From our investigation, it can be seen that the two countries have had comparable economic development but have had different social and political development. We then carry out a comparison of the science policy documents developed by the two countries. From this we can see parallelisms in the approach of the countries towards the building of their national innovation systems. We can also see some important differences which set the context for the differential development of the two countries in radio astronomy.

We further develop this work by studying the state of astronomy and space science research in the two countries. We further seek to quantify the effect of policy interventions, thus invoking scientometrics. Using algorithmic methods implemented in Python, we scrape science publication data and analyse national productivity of Kenya and South Africa. This is contextualised within global and continental data, and also general scientific data. It can be seen from our work that South Africa dominates radio astronomy in the continent, judging by national production. We can also see that it is one of the main collaboration centers in the world. Kenya has an almost peripheral presence in radio astronomy, which we ascribe to social, political and temporal factors.

We conclude by discussing the case of science diplomacy, specifically in the case of radio astronomy in Africa. The presence of exogenous actors, for example the United Kingdom, is also discussed. The emergent issue of the land question in South Africa and Kenya is also discussed.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright Statement

Dedication

I dedicate this work to my Mother, Joyce Wanjiru Njoroge.

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Glossary

ESRO- European Space Research Organisation

CERN- Organisation Européenne Pour la Recherche Nucléaire-European Organisation for Nuclear Research

SKA- Square Kilometre Array

UNESCO- United Nation Education Science & Cultural Organisation

IEMP- Integrated Environmental Management Plan

NASA- National Aeronautics and Space Agency

OAU- Organisation of African Unity

AU- African Union

IMF- International Monetary Fund

SANSA- South Africa National Space Agency

ANC- African National Congress

KANU- Kenya African National Union

GDP- Gross Domestic Product

GERD- Gross Expenditure on Research and Development

NIS- National Innovation System

NRF- National Research Fund

ECOWAS- Economic Cooperation of West African States

SADC- South Africa Development Cooperation

EAC- East African Community

KALRO- Kenya Agricultural Livestock Research Organisation

KEMRI- Kenya Medical Research Institute

IAEA- International Atomic Energy Agency

SARAO- South African Radio Astronomy Observatory

ALMA- Atacama Large Milimetre Array

NRAO- National Radio Astronomy Observatory

LOFAR- Low Frequency Array

VLBI- Very Long Baseline Interferometry

GRAO- Ghana Radio Astronomy Observatory

VSAT- Very Small Aperture Terminal

KOTI- Kenya Optical Telescope Initiative

AVN- African VLBI Network

STFC- Science Technology and Facilities Council

URSI- *Union Internationale de Radio-Scientifique*-International Union of Radio Science

LTWG- Large Telescope Working Group

BRICS- Brazil, Russia, India, China, South Africa

CHPC- Centre for High Performance Computing

AMT- Africa Milimetre Telescope

1 Chapter One: Introduction and Literature Review

1.1 Introduction

Kenya and South Africa are two countries in the East and South of Africa. They are the dominant economies in their respective regions, and have enjoyed relatively stable political and social systems in the last two decades. This has led to the significant improvement of their respective economies.

As a result of this, the two nations have sought to improve their economies by encouraging innovation and technical development. They have made significant investments in "STEM" training, with the hope that this will further improve their economic position. Both countries have began paying attention to the development of local capacity and programmes in astronomy and space science. A specific area of concern to our project is their investment and output radio astronomy.

The aim of this project is to document the development of radio astronomy in Kenya and South Africa. The two countries are the largest economies in East and Southern Africa respectively. South Africa is a member state of the SKA (Square Kilometre Array) while Kenya is an African partner country. This focus is dictated by the weight of these two countries in the development of SKA and radio astronomy more generally as two of the largest African investors in developing the discipline, but also by their competing approaches to promoting these advances.

We select Kenya and South Africa as case studies for cultural, political and economic reasons. For comparative studies it is often helpful to select two case studies that are sufficient similar so that any divergences obtained in the outcome of interest is sufficiently traced into specific differences between the case studies. Culturally, Kenya and South Africa have significant similarities. The two countries are African and are dominated by the Bantu language groups. These groups originate from West Africa and have similar languages, dress, initiation and burial customs. They also have overlaps in the generation, preservation and transmission of knowledge systems. Kenya and South Africa also have a minority Asian and European population within them. Both are majority Christian, with minorities practising Hindu, Islam and African Traditional Religions.

Politically, the two countries have had similar experiences with waves of migration causing political turbulence. First was the Bantu migration wave which resulted in the displacement of aboriginal populations in the countries. Then was a wave of migration from Europe which brought significant contestation over land and power relations in the regions. Waves of independence movements founded on African nationalism then wrestled the countries from the control of minority populations. The African Nationalist governments are generally seen to have had varying degrees of success. While both experience democratic progress, the two still struggle with redressing colonial injustices.

However, the strongest reason for our comparison is on the basis of economical considerations. The two countries are the two largest economies in their region and also among SKA affiliated countries in Africa. They are also thought to be the most technologically advanced countries in the continent. They boast of the most attractive competitive technology ecosystems in the continent, with South Africa being the first and Kenya being the second. This means that there are sufficiently good knowledge ecosystems to underwrite this technological development. We hope that this will be sufficient basis on which to carry a comparative analysis of the development of radio astronomy in the two countries.

Radio astronomy can be seen as a type of "blue sky" research. This is research that is seen as not having immediate practical benefits to the society. Similar areas of research would include high energy astrophysics, particle physics and transfinite arithmetic. The continent of Africa is traditionally understood to be facing immediate challenges which require practical solutions. Ideally, the continents National Innovation Systems should be thus aligned to the addressing of these challenges. Science diplomacy between African countries should also be addressed to these challenges. It is thus of deep interest to us that African nation states are deeply interested with participating in the Square Kilometre Array, which is comparable to the European Large Hadron

Collider. What is the rationale these governments are giving for their commitment to the SKA? How does this commitment vary across these two countries, what is the amount of economic, political, and social capital expended in supporting the SKA? What are the measurable outcomes?

While South Africa has surged to the role of leading African sponsor of radio astronomy within its post-apartheid era, Kenya's investment has been more regular over recent decades, but, at the same time, its administration has been less enthusiastically supportive of large-scale projects. The comparison this thesis makes is thus very fruitful to map competing approaches to the sponsorship of radio astronomy in Africa. The study will carry out a comparison of the development of radio astronomy in these two countries with this as a basis. Since the development of radio astronomy in these two states is not independent, we will also study the radio astronomy networks created in the two countries. This will form an aspect of our work, primarily concerned with science diplomacy. Science diplomacy is the practice and study of mutually reinforcing intersection of science and diplomacy. Science diplomacy studies the interacting spheres of public policy, science, and diplomacy. The Royal Society pamphlet on Science Diplomacy classifies three main ways in which science and diplomacy interact [1]: Science in Diplomacy, Diplomacy for Science and Science for Diplomacy. Examples of these aspects are in the use of diplomatic structures in the establishment and development of science, or in the use of science and scientific channels to encourage, develop, and entrench diplomatic relationships between states. We will study this in the context of radio astronomy in Kenya and South Africa. One way of measuring the effect of structures built on the basis of diplomacy and science diplomacy is unstructured scientific collaborations. These can be measured directly through the analysis of author collaboration networks. This will form part of our quantitative study.

The empirical aspects of the study work will be conducted from qualitative and quantitative aspects. Quantitative aspects of the project will involve econometric and scientometric data.

[1] (Society, 2010)-*New frontiers in science diplomacy: navigating the changing balance of power*

Given the socioeconomic and political development of the two countries and the bearing this has on the development of Kenya and South Africa's technoscientific networks, what can be said about the development of radio astronomy in the two countries? To answer this we will carry out quantitative and qualitative studies. Qualitative aspects of the study will involve the reading and interpretation of primary documents. This will include official governments documents, documents of the SKA and other sources. These will be used together with the quantitative data to situate and contextualise our understanding of radio astronomy in the two countries. Further use will be made of secondary text sources to further augment or challenge arguments developed in this study.

We will begin by placing the development of radio astronomy in the two countries within the larger change in policy with regard to science within the two countries. This will be done by first considering the political economy of the two countries with Africa forming a wider context. We will then trace the evolution of science policy in the two countries, comparing their responses to the needs and obligation to the state. This will be followed up by a look at the state of radio astronomy in Kenya and South Africa. To do this we use scientometric methods. We will place this in a wider context of radio astronomy in the world, and science in Africa. Collaboration networks will also be traced. Next, the science diplomacy networks of the two countries will be explored, considering radio astronomy in particular and astronomy in general. We will study emergent issues that may affect the development of radio astronomy in Kenya and South Africa.

1.1.1 Radio Astronomy

We will first begin by an overview of radio astronomy. A good understanding of the instruments methods and needs of the field will help us map its development in South Africa and Kenya.

Radio astronomy is the observation of the universe in radio waves. This is different from optical astronomy, which entails observation of the universe using visible light.

Because of the long wavelength of radio waves, radio astronomy has unique methodologies, instrumentation and advantages accruing to it. For example, the long wavelength of electromagnetic waves allows the near undisturbed penetration of the radio emissions from celestial objects. Therefore, radio astronomy works almost independent of the weather. Since the sun is a minimal radio emitter, radiation from the sun does not generally interfere with radio astronomical observations. This allows twenty four hour observations[2].

Just like optical astronomy, radio astronomy is particularly sensitive to pollution from the electromagnetic spectrum. In the case of optical astronomy, this is known as light pollution. In radio astronomy, this is known as radio frequency interference. One possible mitigation is to locate the observatory as far away from urban centres as possible. In the case of radio astronomy, the telescopes are sensitive to interference from the radio part of the spectrum, usually used in telecommunication and broadcasting facilities.

A landmark event in the early history of radio astronomy is the work of a Bell labs engineer, Karl Jansky. As is standard practice in such engineering systems, he wanted to understand how much interference the antenna was receiving. He attributed some noise to thunderstorms, but part of the noise was still unaccounted for. Jansky hypothesised that they were detecting radiation from the sun. When further studied, it was seen that the radiation was not dependent on the motion of the Earth round the sun, but with respect to the fixed stars, Jansky thus concluded that the antenna was receiving radiation from the Milky Way galaxy. Radio astronomy developed into a sophisticated branch of astronomy in the post war period because of the pioneering activities of the United Kingdom physicist and Radio Astronomer Bernard Lovell[3]. It is currently considered one of the main branches of astronomy. Radio astronomy, like all branches of observational astronomy, depends on collecting area for resolution. There is a limit to how large a radio receiver can get. This is posed by the engineering trade off

[2](Burke, Graham-Smith, & Wilkinson, 2019)-*An introduction to radio astronomy*

[3]See (Saward, 1984)-*Bernard Lovell. A biography* for a depiction of Lovell's life and contributions to radio astronomy, the war effort, science policy and diplomacy

between steerability of the telescope and its size.

Figure 1.1: The Green Bank Telescope, the largest steerable radio telescope. From Daily Mail

Figure 1.2: Arecibo Telescope, the second largest radio telescope. In this scale, almost all steerability of the telescope is lost. From ucf.edu

However, it is possible to have a larger collecting area while still maintaining telescope steerability. To achieve this, the engineering feat of interferometry is invoked. A rough analogy that will serve as an introduction to this is human vision. The left eye has a field of view, so does the right eye. The brain takes information from the left and right eye and integrates them to produce a consistent field of view.
Because of the long wavelengths of the radio spectrum the distances between the two "eyes" can be significantly long. This is known as the baseline of the telescope. This allows a sufficiently large effective collecting area allowing for high resolution images of the sky.

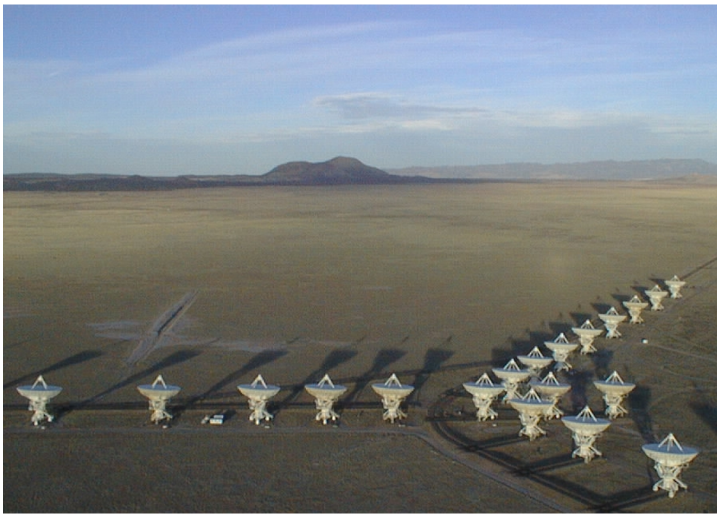

Figure 1.3: The Very Large Array, a radio telescope array which relies on the principle of interferometry. From nasa.gov

This technique was successfully used in the landmark imaging of the black hole at the centre of galaxy M87. This was the first direct image of a black hole. [4]
Because of the distances between the sources and the Earth, a significant portion of the emissions from sources arrives in the radio. Thus violent astrophysical processes can be studied effectively in the radio part of the spectrum. This underlies the construction of the Square Kilometre Array(SKA) in Africa and Australia.

1.1.2 The Square Kilometre Array

The SKA has been described as "a revolutionary telescope programme that will address a broad range of key science areas in galaxy evolution and cosmology, fundamental physics, and astrobiology.[5]" It represents an order of magnitude advance in sensitivity. It will have an effective collecting area of one square kilometre spanning Africa and Australia. This informs the special attention we will give to the development of the SKA in Kenya and South Africa. To understand the development of radio astronomy in the two countries, an understanding of the development and presence of the SKA in the two countries is important.

[4](Collaboration et al., 2019)-*First m87 event horizon telescope results. vi. the shadow and mass of the central black hole.*

[5](Cordes et al., 2010)-*The Square Kilometre Array, Project Description for Astro2010, Response to Program Prioritization Panels*

SKA arose initially out of the need to map the distribution of hydrogen in the universe. This survey would come with attendant advances in cosmology as argued by the British radio astronomer Peter Wilkinson:

> The time is ripe for planning an array with 1 km^2... The first task is to establish a clear set of scientific goals. To my mind one goal stands out-a volume of the 'Encyclopaedia of the Universe' is written in 21 cm typescript. Unfortunately the printing is rather faint and we need a large lens to read the text! Hence the reason for dubbing the proposed instrument. 'The Hydrogen Array' or H1A for short.[6]

Hydrogen is the simplest and therefore the most abundant element in the universe. One of its major emmissions is the so called "spin flip" transition, which transmits in 21 centimeters. However, because the emission is rare, one needs sensitive detectors with a wide collecting area to capture and resolve the emissions. If it is possible to develop such telescope, one would be able to use the instrument to essentially "read" the structure of the universe, as the quotation above claims. However, the technological challenges that existed to achieve such a feat were significant.

In the early 1990s, technology had sufficiently developed to allow for the mooting of the construction of an interferometer array with a collecting area of 1 square kilometer. This triggered to the formation of the Large Telescope Working Group (LTWG) under the auspices of the *Union Internationale de Radio-Scientifique*-The International Union of Radio Science-(URSI). The working group was established in September 1993. This was followed up by the signing of various memoranda of understanding in 1997 and subsequently in 2000. This culminated in a "Memorandum of Agreement to Collaborate in the Development of the Square Kilometre Array" in 2005 [7].

The SKA is the outgrowth of a number of dynamic international forces. One of these is the emergence of supranational cooperation in the sciences (especially in physics). This internationalist paradigm of science has helped shape the national policies of

[6](Wilkinson, 1991)-*The Hydrogen Array*

[7]See "The History of the SKA Project"-https://www.skatelescope.org/history-of-the-skaproject/ for a short history of the SKA

the two countries. This has led to local effects on the populations of these countries, especially to the hosts of these projects. The development of radio astronomy in these two countries has not yet been systematically and comprehensively documented and discussed. The hope of this work is to lay groundwork for further studies and documentation of this development.

In the literature review, we will first study of the geopolitical development of Africa, paying attention to the change in attitudes towards science in the region. This will be instructive for the contextualisation of the political economy of Kenya and South Africa. This will be followed by a study of the science policy and state of radio astronomy in Kenya and South Africa. Because scientometrics is important for our study of the state of radio astronomy, we will also review part of the literature in scientometric methods. We will then study the policy of scientific collaboration that has been adopted by the post-war West. This will help us set the necessary context for understanding the development of radio astronomy collaboration in the context of the SKA.

1.2 Literature Review

1.2.1 Geographical and Political Background

Kenya and South Africa are African countries, thus the African continent forms the logical basis of our analysis of the policy approaches of the two countries towards science in general, and radio astronomy in particular.

Africa, like much of the world, experienced significant and rapid changes in the past century. It has moved from an exploratory frontier, through a system of colonial spheres of influence, to independence. From the attainment of independence, she has undergone catastrophic and paralysing civil wars which have marked the beginnings and ends of autocratic regimes.[8] Although vestiges of autocracies and sectarian conflicts remain, she is largely stable. Burbach[9] points out:

> "Africa" and "conflict" are words all too often linked in Western minds. From Cold War proxy wars, to what Robert Kaplan saw as "the coming anarchy" in the 1990s, to Boko Haram massacres today, news from Africa may seem dominated by never-ending conflict. That image is out of date.

The change in Africa's security state can be attributed to geopolitical innovations in the continent, which have been studied by Moller [10]. He shows how these innovations began with the replacement of the Organisation of African Unity (OAU) with the African Union (AU). One of the innovations that have been implemented is what Moller calls the "departure from sacrosanct sovereignty." In the case of the AU, state sovereignty is not an "untouchable" legal principle, but a set of conditions. The solution of conflict in Africa, using mechanisms internal to Africa is however work in progress in Dersso's evaluation[11].

With this stability has come an appreciable acceleration of economic growth in the

[8] (Meredith, 2011)-*The State of Africa: A history of the continent since independence* is a comprehensive overview of Post-Independence Africa with a short history of partition and colonialism, independence and the contemporary challenges she faces.

[9] From:www.oxfordresearchgroup.org.uk/blog/the-coming-peace-africas-declining-conflicts. See (Burbach & Fettweis, 2014) for a systematic quantification of the reduction of conflict in Africa.

[10] (Møller, 2009)-*The African Union as a security actor: African solutions to African problems?*

[11] (Dersso, 2012)-*The quest for Pax Africana: The case of the African Union's peace and security regime*

continent, documented by the International Monetary Fund(IMF)[12]. The report shows that Africa contains five of the ten fastest growing economies in the world. Enowbi et al.[13] have shown how the economic expansion of the continent, coupled with the liberalisation of political space has led to the emergence of privatisaton and decentralisation in the continent. They have seen that in the case of Africa, "reforms, stability and democratic rule to be favourable for development of the financial sector in the continent." Irikefe et al. described the concurrent rise of science and science research in Africa. Carrying out a survey of science in Africa using scientometric methods, they showed that South Africa and Kenya are the two top collaboration hubs in the continent. Writing in 2011, Irikefe et al. concluded: [14] "Despite the many problems confronting scientists in sub-Saharan Africa, there are signs that they are starting to build momentum. After a period of relatively slow growth during the 1990s and early 2000s, the output of publications is now rising rapidly."

Mirjana et. al. have carried out a survey of astronomy and space science activities in Africa. They point out that Kenya and South Africa have witnessed significant advancements in astronomy and space science in their respective regions of East and Southern Africa. In the case of Kenya, there have been several developments in different branches of astronomy. The country is one of the partner countries in the SKA. There exists a defunct telescope in Longonot which is currently under acquisition processes. The hope is to integrate the satellite dish into the African Very Long Baseline Interferometry Network (AVN). There are also talks with the United Kingdom's Science and Technologies Facilities Council (STFC) for the establishment of the Kenya Optical Telescope Initiative (KOTI). The country has also established the Kenya Space Agency in 2017. Its stated mission is to "To coordinate, nurture and develop Kenya's Space sector towards enhanced utilization of Space opportunities". It was established to do this by acting as a coordinator and regulator of space activities in Kenya.[15] In

[12](Dept, 2019)A report by the International Monetary Fund showing the current state of the world Economy. Parts of Africa still enjoy appreciable levels of economic growth.

[13](Enowbi-Batuo & Kupukile, 2010)*How can economic and political liberalisation improve financial development in African countries?*

[14](Irikefe et al., 2011)-*Science in Africa: the view from the front line.*

[15]Retreived from Kenya Space Agency website. Link:https://ksa.go.ke/ on 14th September, 2020

collaboration with the United Nations Office for Outer Space Affairs (UNOOSA), The Japanese Aerospace Exploration Agency (JAXA), together with Italy's *Agenzia Spaziale Italiana* (ASI), the country has launched a CubeSat [16]. South Africa is the foremost contributor to astronomy in the continent. It has an established space agency, the South African National Space Agency (SANSA). The stated vision for the organisation is "An integrated National Space Capability that responds to socio-economic challenges in Africa by 2030"[17] The agency has launched two satellites. The Department of Science and Technology (DST) has astronomy as being central to the scientific and economic development of the country. The country is a member state of the SKA. MeerKAT is a precursor array to the SKA. It is operated by the government through the DST. The country can be considered the core of astronomy in Southern Africa, and in the wider continent at large. It should be noted that Mirijana et. al. Do not give justification for having these developments. They only explore the state of Astronomy and Space Science in the continent. They are only concerned with the state opf Astronomy and Space science in the continent. For our first and second chapter, we will attempt to pull out the rationale these governments give for the development of Astronomy and Space Science in the continent.

1.2.2 Science Policy

To understand these local developments in the sciences in Kenya and South Africa, it is important to look into the policy documents of these countries with regard to science. The primary concern of science policy is how governments interact with science. Science has grown more relevant to the public for two reasons: the impact it has in society, and the support it requires from society. For these reasons it has become important for governments to find new ways of interacting with science. Colebatch[18] models public policy formulation as an interaction between two general schema of information exchange: the vertical flow and the horizontal flow. The vertical

[16](Pović et al., 2018)-*Development in astronomy and space science in africa.*

[17]Retrieved from: South Africa National Space Agency Website: https://www.sansa.org.za/about-sansa/ on 14th September, 2020

[18](Colebatch, 2009)-*Policy (concepts in the social sciences)*

flow of information from the bottom to the top in the form of instructions to the bottom. Conversely, information may flow bottom up in the form of feedback, suggestions or new data. Apart from this, there is the horizontal aspect of policy formulation. In this case, officials, committees on the same level of administration exchange information. This may take place in the form of negotiations. He argues that in actual governments and organisations, there is an interaction between the two types of policy formulation. Colebatch is against the image of government as a type of black box bureaucracy from which policy is issued. Often, policy comes from the society in the form of pressure or activist groups attempting to bring an issue of interest to the government's attention. Once the government begins to consider action on the issue, the pressure groups generally take the roles of supervision or shift their interest to other issues. Governments consult and employ experts to suggest, modify and implement policy. Krige, in agreement points out: "It is commonplace that, particularly since the war, scientists have become part of government. They play an important role in government policy."[19] Colebatch describes Government as a dynamical body with "rewritable memory". It reacts to the information presented to it by agents in society. It also influences society through policy implementation. Krige et. al. share this view when they consider the policy of Britain with respect to the formulation of the European Organisation for Nuclear Research. In his analysis, he models policy flow as a type of directed initiative, a "policy vector". Changing government policy is difficult. This is because of the tendency of government bureaucracy to attach itself to tradition, a kind of "bureaucratic inertia". Guston [20] takes a different view of the science and policy interface. In his view, the public, represented by the Government, serves the function of a principal. The principal needs to achieve an objective for which it does not have the necessary expertise. It therefore contracts or forms another body within it to achieve the said objective. This body is called the **agent**. The agent then performs the set objective and reports back to the government. Guston points out interesting parallels with the social contract theory.

[19](Hermann, Krige, Mersits, Pestre, & Belloni, 1987)-*History of CERN V1*
[20](Guston, 1996)-*Principal-agent theory and the structure of science policy.*

> Such a contractual perspective has metaphoric significance in science policy, as analysts and policymakers often speak of a "social contract for science" as the promise of science "to deliver goods to society in return for its patronage with no strings attached".

A different conceptualisation of the interaction of government and science is in the context of National Innovation Systems. Here, a "social network" approach is preferred in understanding this interaction. Godin has explored the long tradition of the development of schools of thought around National Innovation Systems [21]. He traces this to the development by the Organisation of Economic Cooperation and Development in the 1960s. He sees the interest of the development of deliberately structured innovation systems in European countries. The innovation systems were proposed and formulated partly as a response to the socioeconomic conditions of the time. Europe was thought to have been lagging behind in innovation as compared to the rapidly industrialising Union of Soviet Socialist Republics (U.S.S.R) and the United States of America (USA). A long tradition of scholarship and implementation was developed since then.

We can build a set of tentative hypotheses to be tested from these models of science policy interaction. The point of interest here is to what extent these three models have explanatory power over the social phenomenon of the development of radio astronomy in Kenya and South Africa.

From Colebatch we can infer an emphasis on communication and the exchange of communication. The horizontal and vertical flows of information can be used as a probe in official documents like memos. For example, it would be very interesting to consider whether horizontal communication dominates over vertical communication or vice versa. This would give us an indication of whether the development of radio astronomy is a government-driven, high-level top down process, or the result of more organic processes with strong government. In summary, what is the origin of the Colebatch "policy vector?"

It is also important to note that the internal horizontal communications between

[21] (Godin, 2009)-*National innovation system: The system approach in historical perspective*

governments in Africa. This might lend support for extending and expanding Colebatch's model for the description of science diplomacy in the case of the development of Radio Astronomy in Kenya, South Africa and other African and European Countries.
We can also consider the principal agent relationship proposed by Guston. Here, a parallelism can be drawn with Colebatch's vertical communication model. Here we will check to see for the strong presence of government in the development of Radio Astronomy in Kenya and South Africa. How strong is the presence of principal-agent relationships in the two countries? Can we trace the presence of implicit and explicit social contracts between the governments and the people they represent, or between the governments and and the scientists?
The social network model can also be used to understand our development There is opportunity for the development of quantitative measures here, for example the use of Barabasi-Albert scaling laws. Does South Africa and Kenya for example behave like an agent in a social network if at all we can model the radio astronomy collaboration network as a social network? This is where quantitative data collection and analysis will be crucial for the verification of the social network model. Also, an exploration of the qualitative structure of the network will help us verify the model.
With this in mind we can perform empirical data collection for the verification of these hypotheses and answering whether these models can be verified within the context of radioastronomy development in the two countries. With this in mind, we can move on to the proximate cause of this development in radio astronomy.
What were the historical factors which led to the development of radio-astronomy in Kenya and South Africa? What is the historical context of this development? How can we trace out the science policy context of the development? Given the historical-cultural and economic similarities between the two countries, can we trace out and understand the differences between the two countries' approach to science?
Mazzuccato uses the analytical tool of National Innovation Systems to understand the science and innovation policy of post-crash United Kingdom. She sees how neoliberalism, coupled with fiscal conservatism and conditioned by a historical misunderstanding

of the role of government in innovation systems, has led to the adoption of a minimalist approach towards innovation systems. She argues that this minimalist, "condition creating" approach will probably be ineffective. Citing examples from agencies and programmes from the United States such as the Defence Advance Research Project Agency (DARPA), she argues for targeted, systematic and sustained public investments in growing the UK's innovation system. She is deeply critical of the contemporary policy ("China is building one power station a week and Britain is fiddling with play money").

Muchie [22] applies the notion of National Innovation systems in the context of Africa. Coming from Pan-African school of thought, he argues for the existence of a continentally coordinated Innovation System. This will allow the limited national systems to pool resources and in essence "punch above their weight". Arguing from the fact that most nation states in Africa were failing or weak, and that there was a new wave of Pan-Africanism and that there was a sophisticated enough structure in the African Union, Muchie holds the position that it is in fact urgent that Africa develops such a continental NIS.

Using econometric methods, Sesay, Yulin and Wang have investigated the effect of the growth of National Innovation Systems on the growth of Brazil, Russia India, China and South Africa (BRICS). They have found that for BRICS countries, investments in the growth of the NIS, such as STEM education and infrastructural expansion, leads to an improvement in the growth rate of the economy [23].

1.2.3 Square Kilometre Array(SKA): The Science and the Social Science

We wish to understand how public policy makers in South Africa and Kenya have reacted to international and continental developments in science, astronomy and radio astronomy in particular. To do this we need to understand what can be considered the flagship radio astronomy project of the world, the SKA.

[22] (Muchie, 2004)-*Resisting the deficit model of development in Africa: Re-thinking through the making of an African national innovation system*

[23] (Sesay, Yulin, & Wang, 2018)-*Does the national innovation system spur economic growth in Brazil, Russia, India, China and South Africa economies? Evidence from panel data*

The funders and developers of the SKA say that it would be useful as a scientific instrument that a major progress to radio astronomy would come from its completion. It is helpful to first understand the scientific case before carrying out an analysis of the geopolitical and policy structures surrounding it.

Carilli & Rawlings have outlined the scientific motivations for building the telescope [24]. The general theory of relativity, proposed by Einstein in 1915[25], replaces the Newtonian operation of gravity with a mechanistic description. Einstein elucidated the equivalence principle. He then used this principle to give an identity to gravity: the curvature of spacetime. Beginning with Eddington in in 1916, several tests of general relativity were devised. It has successfully passed all of these tests.

However, it has been pointed out by Geroch [26] that general relativity "breaks" at sufficiently large energy scales. This motivates the search for this break down in violent astrophysical processes, of which the SKA will be sensitive to.

Tarter[27] has pointed out that the sensitivity of the SKA telescope makes it a potent tool for the Search for Extra-Terrestrial Intelligence, and in general Astrobiological research. She points out that "The SKA is an instrument that could potentially end our cosmic isolation and help us understand how we got here."

Molecules like atoms have specific absorption and emission spectra. This can be used to identify them. The specific spectra can be used to identify complex molecules such as amino acids. Radio astronomical methods are also useful in the detection of exoplanets.

Blake et. al[28] have also discussed that the SKA is also well posed to help in the answering of a cosmological mystery: dark energy. It was noticed in the closing years of the twentieth century that the universe was undergoing an unexpected acceleration in its expansion. While there has been a profusion of theoretical models trying to explain the observation, there is no agreement on the microscopic structure of dark energy

[24]See (Carilli & Rawlings, 2004)-*Motivation, key science projects, standards and assumptions.* for a comprehensive overview of the scientific motivations of the SKA

[25](Einstein, 1915)-*The field equations of gravitation*

[26](Geroch, 1968)-*What is a singularity in general relativity?*

[27](Tarter, 2004)-*Astrobiology and SETI*

[28](Blake, Abdalla, Bridle, & Rawlings, 2004)-*Cosmology with the SKA*

or even whether there's an actual microscopic structure at all. Observations from the SKA might help constrain these models.

But judging the SKA project only in terms of scientific merit is potentially problematic. Being a big science project, one should be showing its merit also for national economy and the stability of the Pan-African project as a whole. While the scientific objectives of the SKA are well discussed and explored in literature, the local effects of the organisation have also been of significant academic interest in the social sciences. The effects of the development of the SKA has attracted a lot of academic attention of mostly South African social scientists. Gastrow & Oppelt have pointed out the contradictions between the national scientific development goals of South Africa and the effect this has on local communal, economic structures in the regions of interest to the SKA: "At the same time, a local public discourse has arisen with regard to perceptions of the SKA. A small minority of media messages have reported marginal voices that pointed out the juxtapositions, conflicts and sacrifices that have arisen as a consequence of the SKA..."

They point out that a proportion of people who live in the geographic area surrounding the SKA radio telescope facility have objections against the project. This has also been explored by Gastrow[29]. Here, the theme of the representation of the SKA in local South African media, and the land situation in the Northern Cape is explored. The land situation is also used as an important thematic concept by Smorenburg[30] in a fictional novel.

Chinigo has discussed the possible effects of the SKA on the economies of the local communities [31]. The Northern Cape is with the chief activity being sheep farming. The SKA has bought land from the locals, and compensated them at market value. Also, the government in order to support its research objectives, has enacted regulations that place radio astronomy research at an advantage [32]. The use of mobile phones

[29](Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media 88 − 89*

[30](Smorenburg, 2016)-*A Trojan Affair: The SKA at Carnarvon*

[31](Chinigò, 2019)-*From the 'merino revolution'to the 'astronomy revolution': Land alienation and identity in carnarvon*

[32](A. G. A. Government Act, 2007)-*Astronomy Geographic Advantage Act*

near the site is prohibited, certain telecommunication technologies, such as wi-fi internet is also prohibited.

The sheep farmers have an interest employing the latest technologies for their sheep farms. This may lead to economic tension between the locals and the SKA. There are also economic impacts in the rerouting of flights from Johannesburg to Capetown. Walker has described the environmental impacts of the SKA are largely seen to be positive by the environmentalists. This is because the SKA provides a legal framework for the closing off of the Nama-Karoo biome [33]. which will enable conservation studies and efforts. A similar situation is explored by John Agar in the context of the development of Jodrell Bank [34]. He explores the various dynamic financial, political, academic forces that drove, militated, hampered, and threatened the development of the instruments at Jodrell Bank. Of interest to us is local concerns emergent in the area. Agar traces these concerns in which he points out that there was a development of concerns among local parties that the presence of Jodrell Bank would hamper development in the region.

Moyo has carried out a comparative study of land management in Southern Africa[35]. He has pointed out that the land problem is a cause of tension in South Africa. This is because of land inequality which is often unbalanced on a racial fulcrum. The white minority population own majority of the agricultural land. It is also tied to economic production in the largely agrarian nature of these Southern African societies. As such, Moyo argues that:

> Unequal ownership of and access to land are, increasingly, a central threat to stability in Southern Africa. Large farmers – white and black – occupy the best farmlands in Southern Africa and dominate their agricultural and natural resource export economies. Consequently, the region faces growing rural poverty, enforced high population densities, poor land

[33] *Integrated Environmental Management Plan(IEMP) for SKA Phase 1 mid-frequency array(SKA1MID) in South Africa*, retrieved from https://www.ska.ac.za/about/strategic-environmental-assessment/ on 13th November 2019

[34] (Agar, 1994)-*Making a meal of the big dish: the construction of the Jodrell Bank Mark 1 radio telescope as a stable edifice, 1946-57*

[35] (Moyo, 2007)-*The land question in southern Africa: a comparative review*

management and diminishing investments into adequate land management.

Walker [36] points out that this general depiction holds in the Northern Cape, where the SKA research facility is to be located. The economy is structured on the basis of a white-land owner population who have employed black and colored labourers in their sheep farms. The SKA, under the auspices of the government through the Department of Science and Technology, has acquired 13,406 hectares of land in the Northern Cape. This introduces further complication to the problem of land in the municipality. This introduces a tension in the area, derived form an uncertainty about what the future portends for the locals, which she discusses.

With this in mind, we can now trace the various depictions of the interaction of astronomy and science in general with various political powers in Kenya and South Africa. Dubow[37] traces the history of astronomy in South Africa with the beginning of Britain's imperial project in Africa. Astronomy served as a tool of empire in furthering the geopolitical aims of Victorian Britain on the continent. Later on, astronomy was used by the increasingly isolated Apartheid regime to maintain ties with the international community. Increasing pressure from members of the public in the international community led to the National Aeronautics and Space Agency cutting ties with South Africa. It is in these conditions that radio astronomy in South Africa began. There was a satellite tracking facility in Hartbeesthoek. This was converted to a radio astronomy facility.

Dubow then traces the development of the science in Post-apartheid South Africa. The government developed an ideological support for basic scientific research. It took an overtly post-utilitarian position on science, stating:

> Scientific endeavour is not purely utilitarian in its objectives and has important associated cultural and social values. It is also important to maintain a basic competence in flagship sciences such as physics and astronomy for cultural reasons. Not to offer them would be to take a negative view of our future - the view that we are a second class nation, chained

[36](Walker, 2019)-*Cosmopolitan Karoo: Land, Space and Place in the Shadow of the Square Kilometre Array*

[37](Dubow, 2019)-*200 years of astronomy in south africa: From the royal observatory to the 'big bang'of the Square Kilometre Array*

forever to the treadmill of feeding and clothing ourselves.[38]

Dubow then shows that having a strong research tradition in astronomy in general and radio astronomy in particular, South Africa put in a bid to host the proposed SKA project. Its main competitor was Australia, a country with an admittedly stronger research tradition. After significant controversy which we explore in the Chapter 4, the project was awarded to both countries. Gastrow [39] explores this controversy in full. He opines that the split site decision was made on account of the fact that Australia and South Africa had already invested heavily on building precursor instruments. South Africa has since then formalised agreements with eight African countries to host the SKA nodes in their respective countries.

The construction of the SKA precursor MeerKAT is now complete. Goedhart[40] has described the early science results of MeerKAT, coupled with other "first light" science results.

Gastrow & Oppelt have however pointed out policy challenges that may exist from the full implementation of the project. A problem that SKA faces is the significant land problems in South Africa. This has been the cause of numerous other social problems, legacies of South Africa's apartheid past. While Gastrow acknowledges that the SKA is itself not a cause of the problems, the locals however expect that the organisation will contribute to the solution of these problems. This is pointed out by a manager of the SKA: "[w]e're such a major project within the area, everything becomes the SKA's fault or the SKA's problem to solve. And that's quite a huge difficulty as well"[41].

Gastrow & Oppelt have pointed out a second problem: the problem of reconciling national and globalist aspects of the project with local concerns. Chief among this is the the effect of the project on the economic development of the areas protected by the astronomy Advantage Act of the South African Government. Radio astronomy

[38](Department of Arts & Technology, 1996)-*White Paper on science and technology.*

[39](Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media, pg 120*

[40](Goedhart, 2019)-*Early science with Meerkat.*

[41](Gastrow & Oppelt, 2019)-*The square kilometre array and local development mandates in the karoo.*

is hostile to the hallmarks of modern development: spark plugs, mobile phones, wireless internet networks. Therefore the development of astronomy in an area may not correlate with general development of the economy in that specific area:

> However, the universalist techno-economic argument that underpins this mandate at the global level and the innovation and growth argument that underpins the mandate at the national level do not necessarily apply at the local level, where the localised development effects include both significant benefits and significant losses that are distinct from the telescope's impact on the planet and the country.

Gastrow has described the collapse of local and communal authority in the Karoo. The local sphere of authority seems to have reduced itself to a mere appendage of the state. Communal authority of the locals is non existent. While the SKA has consulted community leaders of the San, their genealogical connection to Karoo's native inhabitants is challenged. Thus, a proper understanding cannot be established between the organisation and the locals.

Speich points out that Kenya had a different approach to the question of science and its place in the new republic [42]. The formulators of public policy in independent Kenya accepted that science forms the basis of technical development. Accepting the then commonly held view that all social problems are fundamentally technical, and can thus be solved by technical intervention. Kenya was particularly keen on industrialization.

Lewis [43] has documented the fact that Kenya had ideological support for the "Africanisation" of science, that is, the encouragement of indigenous Kenyans to get into scientific research. This was in support of a wider policy of Africanising the local professional and intellectual community. It also pertains to an understanding that the perspective of the locals was important to carrying out research in a specific area. Especially in

[42] (Speich, 2009)-*The Kenyan style of "African socialism": developmental knowledge claims and the explanatory limits of the Cold War*

[43] (Lewis, 2018)-*Africanizing science in post-colonial Kenya: Long-term field research in the Amboseli ecosystem*

the case of field studies. Lewis documents this transition stating "all had begun to recognize the importance of African perspectives in the significance of their research." Eisemon, Owen & Davis argue that partly because of the way Africanisation was implemented, combined with other factors such as the rapid rise of population of University students, led to a crisis in the scientific community of Kenya. Scientific output had been compromised even in the applied science of agriculture, which Eisemon, Owen & Davis focus on. This led to a drop in Kenya's scientific output, in the field of agriculture. The scientific output of Kenya specifically in the field of astronomy in this period has not been measured.

Thus,The Africanisation of science had ramifications for the development of science in Kenya. This affected the capacity of the country to develop science in the country both positively and negatively. Kenya had significant difficulties in her scientific infrastructure which which was the result of oversubscription of students in the university pipeline. This serves as a context for the exploration of the development of science and specifically of radio astronomy in Kenya. We will explore this while discussing the science policy development of Kenya.

Mwangudza et. al.[44] have however documented Kenya's activities in the use of space technology for meeting the utilitarian objectives of government. Such activities include the monitoring of drought and agricultural cover, profiling of the ozone layer and upper atmosphere, sedimentation of the Gulf of Aden and Lake Victoria. They have also argued for the decentralization of the Kenya Space Agency, having it carry out different objectives in different areas.

Waswa & Juma[45] proposed the development of a space sector programme from scratch in Kenya. They propounded a phased development of the space programme, beginning with the necessary laws, delineating of the objectives, setting up the capacity and infrastructure, this will hopefully result in the "maturity" of the space industry and related activities. They have pointed out challenges that will be inherent to the formation

[44](Mwangudza, Nyawade, Kimani, & Maimba, 2013)-*A Perspective of the Kenyan Space Programme: Past, Present and the Future*

[45](Waswa & Juma, 2012)-*Establishing a space sector for sustainable development in Kenya*

of a space industry from scratch. Mwangudza et. al have described some of the activities that have already been undertaken by the already formed Kenya Space Agency [46].
Povic et al.[47] have carried out a survey of astronomy in Africa, with Kenya as one of the focal points of study. They point out that Kenya was selected as one of the host nodes of the proposed phase two of the SKA project. There was first the establishment of the Undergraduate Astronomy and Astrophysics programme. Majority of the students in the programme were trained under government bursaries. There are mooted plans to re-engineer a moribund telecommunications facility to a radio astronomy facility. The facility would come under a consortia of local Kenyan universities and be integrated with the AVN.

1.2.4 Scientometrics

One way to explore science and policy connections including the measurement of the impact of these connections is to carry out scientometric analysis. Scientometrics is the use of publication data to draw insights about a specific scientific field. Scientometrics can be used to measure the impact of specific policy interventions. It can also be used to inform science policy decisions.
Mingers & Leydesdorff have carried out a review of Scientometrics. They begin from early bibliometric methods in the science and trace a bifurcation in the field beginning in the 1980s to 2000s. They also explain the practical concerns of the field, including citation analysis, tracing out citation and collaboration networks. They also explain why it is important not to use measures of central tendency, especially in citation analysis.
Archambault et. al. have used scientometric methods in the investigation of collaboration networks. They have done this by suggested a scale adjusted metric for the measurement of scientific collaboration networks[48]. Brambila et al. have used scientometrics in the context of the global south[49]. They have shown that for their study area, there seems

[46](Government Gazette, 2017)-*Kenya space agency order.*
[47](Pović et al., 2018)-*Development in astronomy and space science in africa*
[48](Archambault, Beauchesne, Côté, & Roberge, 2011)-*Scale-adjusted metrics of scientific collaboration*
[49](Gonzalez-Brambila, Reyes-Gonzalez, Veloso, & Perez-Angón, 2016)-*The scientific impact of*

to be rapid improvement in scientific production. They however do not attribute this to the economic, goeographic or demographic characteristics of the country. They attribute this to idiosyncratic policies adopted by the respective governments.
Berthelmot[50] have applied the methods of scientometrics to measure production in Africa in the period 1991-1997. They have found that South Africa and Egypt dominated production. Kenya seems to have had a decline in scientific production in this period, or may not have been growing as fast as other African states. This may be attributed to the academic crisis in the scientific community explored by Eisemon and Davis [51]. Part of this is the documentation of the decline of research institutes such as the now defunct Kenya Agricultural Research Institute. The two authors found that these institutes had spoilt or unusable instruments, bloated or understaffed, and could in some cases have no clear picture of their current state of assets.
Another study carried out by Tijssen[52] shows similar trends, marked by a decline in Africa's scientific production as a proportion of the world. The author advocates the measurement of tangible numbers of output, rather than input statistics. Output statistics include the number of publications, other associated measures. Input statistics includes the amount of money invested in training a scientist, and the number of scientists trained. He argues that input statistics are difficult to measure. He also argues that output statistics provide a good measure for the effectiveness of policies aligned towards the improvement of input statistics. He also observes that the best performing countries in terms of citation rates are South Africa and Kenya.

1.2.5 International Cooperation In Science

An interesting aspect measured by collaboration networks in scientometrics is international collaboration in the sciences. The SKA and other international radio astronomy projects being carried out in South Africa and Kenya are manifestations of a much longer

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developing nations

[50](Narváez-Berthelemot, Russell, Arvanitis, Waast, & Gaillard, 2002)-*Science in Africa: An overview of mainstream scientific output*

[51](Eisemon & Davis, 1997)-*Kenya: Crisis in the scientific Community*

[52](Tijssen, 2007)-*Africa's contribution to the worldwide research literature: New analytical perspectives, trends, and performance indicators*

tradition of cooperation in the sciences. In this literature review, we will trace this tradition from the early post war years. We begin by a reading of literature related to international cooperation in the sciences to contextualise our understanding. This will allow us to ease on into the European Organisation for Nuclear Research (CERN) as an example of international co-operation in physics. Since we are discussing the development of radio astronomy in Kenya and South Africa using the Square Kilometre Array, we are deeply interested in international scientific collaboration because the SKA is the product of international collaboration between scientists. We will explore these collaboration networks within and without of the continent. We will attempt to relate this to African diplomatic structures. With the rise of costs in operating scientific research, it becomes necessary for countries to pool resources to finance these projects. This forms the basis of international collaboration in the science, a case of "diplomacy for science" as pointed out by Koppelman et al.[53]. Science can be used as a diplomatic tool, for example in nuclear security negotiations. This is a case of "science for diplomacy". We are interested in the "diplomacy for science case"-harnessing international geopolitical structures for the achievement of scientific objectives.

A well documented example of this is the United Nations Education Scientific and Cultural Organisation (UNESCO). UNESCO forms the skeleton on which the flesh of international, systematic and formalised scientific collaborations were formed. We can see its legacy in the organisational structure of the SKA and in other collaborative structures in physics and radio astronomy such as the European VLBI Network (EVN) and CERN. It forms a good basis for the understanding of the beginnings of science diplomacy and scientific collaborations in the post-war era.

With the formation of the United Nations whose objective was to promote peace among nations, came UNESCO. It set out:

> to contribute to peace and security by promoting collaboration among the nations through education, science and culture in order to further universal respect for justice, for the rule of law and for the human rights

[53](Koppelman, Day, Davison, Elliott, & Wilsdon, 2010)-*New frontiers in science diplomacy: Navigating the changing balance of power.*-page 9

> and fundamental freedoms which are affirmed for the peoples of the world, without distinction of race, sex, language or religion, by the Charter of the United Nations.[54]

Petitjean [55] discusses how the birth of UNESCO as a reaction to the nationalism and jingoism of the second world war. Globalism, or cosmopolitanism, developed among intellectual circles in the West. Part of the globalist narrative was a change in the West's intellectual movements towards an internationalist, or cosmopolitanist worldview. These wider narratives formed the intellectual basis of UNESCO, as shown by John & Richard Toye[56], and Petitjean [57] in their discussion of UNESCO's founding luminaries, Julian Huxley and Joseph Needham respectively.

Sluga[58] critiques this ideological basis of UNESCO. He discusses how Huxley made links to liberal imperialism to inform his view of one worldism-cosmopolitanism. He then shows how this cosmopolitan view came under criticism by Soviet bloc intellectuals, and extreme left intellectuals in the West. However, the "liberal imperialist" positions were not operationalised by UNESCO officials, who in the end learned to adapt to culture-specific requirements or attitudes in the achievement of their objectives. Thus Sluga concludes that "Huxley himself represented the world out of which the United Nations was formed, rather than the future it was meant to represent. "

We can see that there are competing views on the ideological and structural basis of UNESCO as pointed out by Sluga. However the fact that UNESCO was formed under the auspices of the larger United Nations structure, it can be inferred that it had significant diplomatic resources to be employed in developing scientific collaborations. We can make these connections between the structure and operationalisation of UNESCO. This can be seen particularly lucidly in the example of the construction of CERN.

Since either little or no scholarship has been focused on the SKA as a science diplomacy organisation, we will use CERN here as a template for probing international structures

[54](Constitution, 2018)-*Constitution of the united nations educational, scientific and cultural organization.*
[55](Petitjean, 2006a)-*Defining UNESCO's scientific culture: 1945-1965.*
[56](Toye & Toye, 1945)-*Brave new organization: Julian huxley's philosophy'.*
[57](Petitjean, 2006b)-*Needham and UNESCO: perspectives and realizations*
[58](Sluga, 2010)*UNESCO and the (one) world of Julian Huxley*

for scientific collaboration in the literature.

In later work, Petitjean [59] discusses how UNESCO soon set to work with facilitating the formation of a new nuclear physics laboratory in Europe. Pierre M. Auger personally went round Europe to try and convince physicists of the importance and possible benefits of the project, which earned him the reputation of the "traveling salesman". Soon, the western European countries that wave approached understood the benefits and reacted positively to the idea. The justifications of this were cooperation and cost. It was hoped that the direct collaboration in the setting up of the facility would set the context for further economic and political collaboration. The sharing of costs would allow European countries with much smaller science budgets to compete with the United States. In Petitjean, we can see the indirect role the bureaucracy of UNESCO played in setting up diplomatic infrastructure for collaboration in the sciences-"diplomac for science" and also the setting up of scientific structures to enhance further collaboration in Europe-"science for diplomacy".

Hermann et al.[60] have discussed that part of the justification for this is the rise of the cost of participating in frontier science research. The energies that were under investigation were out of the reach of continental scientists operating within national frameworks of research. Thus this made obvious the need for the countries in Europe to pool their resources to compete favourably with the United States:

> European states needed to be shaken up and made to understand that they were entering a new techno-scientific era. That science needed money, a lot of money, that it was a long term investment, but a profitable one; that it involved a kind of wager, but it was a wager they had to take. [61]

They have also discussed that the need for cooperation also served a political purpose. Europe had just come out of a damaging war. Both the victors and the vanquished felt the need to ensure that such as a war would not occur again. Science was seen

[59] (Petitjean, 2006c)-*Pierre auger and the founding of CERN.*
[60] (Hermann et al., 1987)-*History of CERN. V. 1*
[61] (Hermann et al., 1987)-*History of CERN. V. 1*, pg 117

as a tool to help the integration of European society through scientific collaboration. Germany saw science partly as a tool of foreign affairs. Germany had been considered one of the powerhouses of science in the world. Because of the Third Reich's interference with the science, there was significant damage to the field in the country.

CERN is particularly useful as a template because like the SKA, it is a big science physics project. Big science has been defined by Solla Price in terms of finances invested over time. He notes a nonlinear growth which is faster than the nonlinear growth of the number of scientists. This is a phenomenon where the cost of running a science experiment grows much faster than the rate of growth of the number of scientists involved in the experiment. As more scientists are enjoined in the project, the sophistication of the project grows faster than the number of scientists. This can be possibly ascribed to the phenomenon of emergence. He thus rejects the notion of the development of big science as purely an issue of scale [62]. We label the SKA as a big science project because it contains many of the traditional characteristics associated with big science. One simple one is the fact that SKA is financed by a collaborations of governments. We hold that this term is appropriate to use on this basis. We don't seek to run into the danger of a sorites-type paradox attempting to delineate between little science and big science. We therefore settle that the SKA has sufficient geographical, infrastructural, policy, financial and demographic scale to satisfy the conditions for it being considered a big science project. It is also important to note that big science projects are tied together by specific objectives. For example, the fields of genetics, and particle physics are not in of themselves big science. However the Human Genome Project and the Large Hadron Collider are big science projects.

Science diplomacy has been the subject of scholarly interest as it has enjoyed increasing prominence in foreign policy circles and in research centres around the world. Wagner has systematized the interactions of foreign policy and diplomacy, looking into various aspects of tension and collaboration that exists in the interaction of these spheres [63]. Positive development for the global south have been highlighted for example by

[62](de Solla Price, 1963)-*Little science, big science* pp 15,52
[63](Wagner, 2002)-*The elusive partnership: science and foreign policy*

Pandor[64] specifically for South Africa. Other partnerships have been highlighted by Hotez [65].

From a reading of the literature, we can see that there has been sufficient work done in expounding various aspects of our work. However, there remains work to be done in some aspects. For example, a scientometric study of radio astronomy has not been carried out. This is crucial in the measurement of impact of policy in radio astronomy. Although studies have been made into the science policy structures in Africa, together with proposals for their further entrenchment and development, studies into policy as a context of development in radio astronomy have not yet been carried out. We aim to address some of these gaps in our work.

1.3 Summary and Overview of The Work

To achieve the aims of the project set out in the introduction, we first begin with tracing out the social, economic and political development of the two countries. This is done in the first section of the Chapter 2. The tracing will be done using a reading of secondary and primary documents, coupled together with econometric data. In the second section of the Chapter 2, we will trace the modern development of the National Innovation Systems (NIS) of the two countries. We will understand these systems as a response to, and as a result of, the socioeconomic conditions of the countries. The primary function of Chapter 2 is to set a context.

Having set a context, we will now proceed to measure the state of radio astronomy in the two countries using scientometric methods. We will first consider general science publication data, and then proceed to develop algorithms for the scraping, analysis, and presentation of scientometric data in radio astronomy. This chapter will primarily be quantitative in nature. However, interpretation will be provided to further contextualise the data.

The fourth and last chapter will be primarily concerned with qualitative work analysing

[64](Pandor, 2012)-*South African science diplomacy: Fostering global partnerships and advancing the African agenda*

[65](Hotez, 2014)-*"Vaccine diplomacy": historical perspectives and future directions*

collaboration structures that have been built to encourage the development of radio astronomy in the two countries and in the African continent at large. The chapter will also discuss emerging endogenous and exogenous issues related to the development of radio astronomy in the continent. The chapter will be mostly qualitative and thus the source documents will include memoranda of understanding, press releases, articles of international organisations, and recently published articles exploring emergent concerns.

We begin by tracing out the political, social and economic development of the two countries, with the wider African continent as a context. This context is crucial, as we will see.

2 Chapter Two: Two Nations Apart in Science: Historical Perspectives in Research Systems in Kenya and South Africa

2.1 Introduction

This chapter provides political, social, and economic background information about Kenya and South Africa as African nations in order to clarify on their different stances with regards to investment in radio astronomy on the basis of their home and foreign policy as well as their science policy and diplomacy.

We begin our comparative study by first explaining our view regarding the status of Africa as an object of study. This will hopefully clarify on what basis aspects of South Africa and Kenya's science programmes can be compared.

There has been recent movement in the intellectual and academic community away from the "monolithisation" of Africa. There are no such things as "African language", "African culture", "African market". This change in view has been motivated by the justifiable need for a more nuanced understanding of Africa in the academic community. Summarizing the need to move away from this view of Africa, Kuper opines: "Some geopolitical phrases obscure reality rather than reveal it. 'Africa' does not exist."[66].

While the spirit of this more sophisticated approach is laudable, care must be taken in coming to any permanent conclusions about the nature of an entire continent of 1.3 billion people. We point out some of the problems with coming to such a conclusion. The acceptance that homogenizing Africa is reductive does not necessarily imply that the label "Africa" is meaningless. In any case, taking such a view leads to a kind epistemological disintegration. Let us accept, for example, Kuper's argument that "The experience of African countries has diverged so starkly that it hardly makes sense to talk of Africa anymore". The implication being that we can only understand

[66](Kuper, 2013)-*Africa? why there's no such place.*

Africa purely as a collection of states. Similarly, an argument can be made for the fact that we can understand these states purely as a collection of tribes. Dunn for example, has made an antistructuralist argument against the existence of states, showing them, to be the result of a sequence of discursive, performative actions [67]. In the case of both Kenya and South Africa, an argument can be made that the discourse occurs on the level of tribal identities[68]. Tribes can then only be understood as a collection of clans, and clans as a collection of families, families as a collection of individuals. We thus have a *reductio ad absurdum* by demanding that "Africa does not exist", except as a collection of states.

Similar problems can be faced by attempting to clarify the boundaries of science. The reaction to be expected here is not "Science doesn't exist" but to accept that the boundaries are difficult to draw. Pickstone, elucidating his problem with polarising epistemological camps describes the situation: "This is another reflection of most of the monism of philosophy of science and its sociological step children- the assumption that science is much the same any time and any place-or that the differences are so many and various that nothing systematic can be said about them" [69].

While we accept that Africans are not the same "anytime and any place", we also challenge the notion that there is so much diversity in African discourse on political, social, and economic identity that "nothing systematic can be said about" Africa. This forces us to plead a "pragmatic structuralism" argument. That we accept, pragmatically, that there are some elements of historical and cultural commonality between South Africa and Kenya based on their geographical location in the same continent. This will hopefully allow us to understand and explain the structure of development of radio astronomy in Kenya and South Africa, with Africa being the logical basis for the comparison of the two countries.

[67](Dunn, 2010)-*There is no such thing as the state: Discourse, effect and performativity.*
[68](Muigai et al., 2004)-*Jomo kenyatta and the rise of the ethno-nationalist state in kenya.*
[69](Pickstone, 2001)-*Ways of knowing: A new history of science, technology, and medicine. Page 137*

2.2 Comparative Growth of Kenya and South Africa

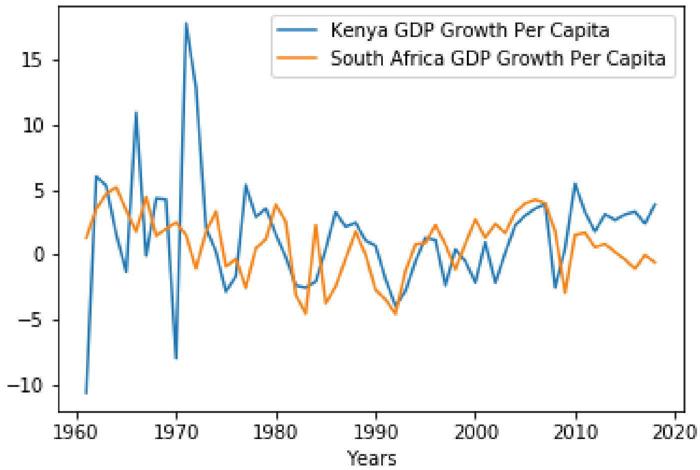

Figure 2.1: A comparison of South Africa's and Kenya's GDP growth per Capita

We begin by taking comparative econometric data on GDP growth. This will give us an indication of the growth and development of the two countries. It will also give us a picture of how strongly or weakly the two countries are related. The data for the next two sections was obtained from the Organisation for Economic Co-operation and Development (OECD).

We can formalise our comparisons of the dynamic activities of the two countries. Before 1994, a qualitative view of the economic dynamics of the two countries is only weakly correlated. This is a manifestation of the fact that the apartheid state was interested in building a "self sufficient state". This was in the period of apartheid. The attempt at building an autarkic economy, closed off from the continent and the rest of the world was being made. However, the country still enjoyed good levels of exports as a result of cheap local and migrant labour from the neighbouring countries[70] Kenya, being more open to the world, was more responsive, appreciating good levels of growth. However Kenya was therefore more sensitive and vulnerable to the inflation of 1970 which was amplified by an import-export asymmetry in the country[71].

[70](Wolpe, 1972)-*Capitalism and cheap labour-power in South Africa: from segregation to apartheid*

[71](Rwegasira, 1987)-*Balance-of-payments adjustment in low-income developing countries: The experiences of Kenya and Tanzania in the 1970s*

In the 1990s the regimes of both countries began to pursue liberalisation policies which manifests as better correlation in the graph. The period of weakest correlation can be attributed to the transition period that saw the collapse of the independence party in Kenya. The country had been in a 24 year dictatorship under Daniel Arap Moi. For an entire 40 years since its independence, the government had been under the Kenya African National Union (KANU) party. This transition may have been a period of uncertainty in the financial markets.
Kenya however caught up and was able to appreciate good levels of economic growth. Her peak performance occurs in the same period as South Africa's peak performance. This is before the global financial crisis. Both countries have been able to recover, although South Africa has been more tardy in her recovery. This may be attributed to several factors:corruption, inequality, and other global and local factors.

2.2.1 Gross Domestic Expenditure on Research and Development(GERD)

Another econometric indicator we are particularly interested in exploring is the gross expenditure on research and development. The gross expenditure on research and development is measured as a percentage of the GDP. In developing countries, the onus is usually on governments to ensure spending, since the private sector cannot ensure this on its own. There has been sustained effort by some African governments to improve investment in research and development. A good example of this is South Africa, which we show below.

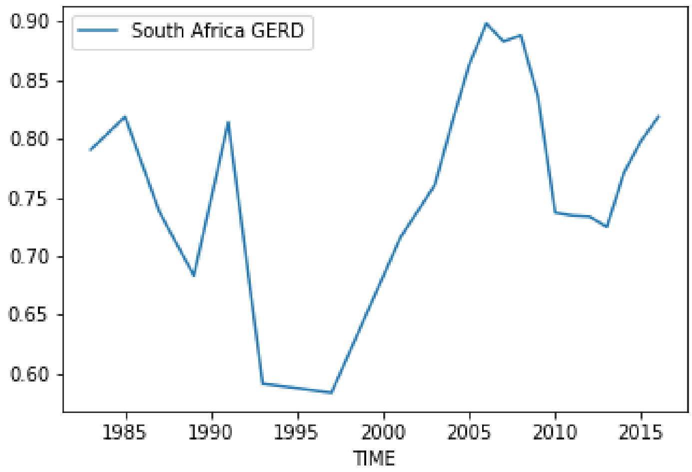

Figure 2.2: Gross Domestic Expenditure on Research and Development

From the late 1990s, South Africa enjoyed a steady appreciation of its research and development budget, militated by a government which had strong ideological support for science and science research. The guiding document for this is the 1996 White Paper on science and technology, which we explore later. The steady investment in science and technology is almost unique in Africa in this period. South Africa's investment in R&D peaked at 0.90 % of the GDP and declined probably because of the decline in revenue collection occasioned by the internationa financial crisis of 2007/2008. Like all emergent BRICS economies, South Africa suffered economic downturn from depressed financial investment.

South Africa has since then began to climb out of the 2010 R&D pit by reinvesting in research and systematically increase its investment in the sciences. South Africa has maintained these levels and is slowly climbing up into its pre-crisis levels.

We could not obtain useful data from which to make useful comparisons with South Africa. Kenya has only two recorded data instances for her gross expenditure on research and development, and this is not enough to make any useful conclusions.

The governments of both countries view science and innovation as being essential to the accelerated and sustained growth of their countries. They have at various periods acted to intervene and redesign these innovation systems, as we will explore below.

2.3 National Innovation Systems (NIS)

Now that we have developed an understanding of the social, economic and political state of the two countries, we can now look at the National Innovation Systems in the two countries. These national innovation systems draw both draw resources from, and respond to, the political economy of the two countries. We will thus see how these systems are developed in this context.

An analysis of the relevant science policy documents of both countries shows that there is a deliberate attempt at viewing science and technology systems as networks. An example is the South African Government White Paper on Science and Technology [72].

The paper views bodies which interact with science and technology as part of a "National Innovation System". This is reminiscent of Pickstone's "Technoscientific Networks" [73]. These networks constitute of academia, industry and certain government departments, and certain independent agencies. These networks interact by exchanging funds, information and people. The use of the word "networks" is more than simply suggestive. Networks imply the existence of nodes and information flow. Dense networks have stronger information links, while sparse networks have less information links. We can therefore use social network analysis to understand how these systems are designed, at least normatively [74].

We examine the cases of South Africa and Kenya through social network analysis literature making inferences from assumptions about how the similarity and diversity of nodes and connections informs the strength of the networks being created. This paradigm can be used for the understanding of innovation networks, otherwise called "national innovation systems".

We begin by exploring the restructuring of South Africa's NIS in 1996. Attempts were made to take stock of the weaknesses of the network, and to correct for these weaknesses.

[72] (Department of Arts & Technology, 1996)-*White Paper on science and technology*
[73] (Pickstone, 2001), *Ways of KnowingChapter 7, 162 − 187.*
[74] (Durland & Fredericks, 2005)-*An introduction to social network analysis*

2.3.1 South Africa's NIS

South African society had integrated into a world which had changed in fundamental ways. The rise of information technology on the basis of computational hardware and networking developed by various companies and government research institutions in the west had led to the developing of the internet. There was the rise of environmental activism which was the result of a reaction to pollution and concerns around the greenhouse gas emissions and its attendant effects on the environment. South Africa was thus faced with a dual problem, creating a just and equitable society for its citizens to live in, while at the same time reacting to a rapidly changing world. A class of bureaucrats, academics and politicians saw the leveraging of science and technology as being central to the creation of a "modern" South Africa. Out of this discussion emerged the "White Paper on Science and Technology of 1996"[75] whose main objective was the harnessing of science and technology for the development of a new post-apartheid South Africa. The aim was to improve and further accelerate the development of its industrial and technological problems of the country. There was also the need to develop and improve relations between South Africa and the continent, and in the wider context, relations with the world.

The South African government thus wished to lay out a plan of how it could strengthen its national innovation system. It first began by taking stock of the weaknesses of its innovation system. We shall classify these weaknesses as weaknesses of number, type and quality of nodes, connections or links, and weaknesses of independent nodes. Because the minority government was elected on a minority, it was primarily concerned with stabilising society and achieving a self sufficient economy. It can be seen as a hyper-strong control node. It thus put significant amount of funds into defence and security contracting. Aspects of science which had links to these general objectives were strongly funded. These strong links led to the creation of a considerable military industrial complex rivaling those of Europe.

[75](Department of Arts & Technology, 1996)-*White Paper on science and technology.*

Systemic weaknesses in the funding of the education of blacks[76] led to the weakening of the general education state of the country, regardless of the near world class state of the universities. This is particularly manifest in astronomy.

South Africa has strong cultural affiliation to the production and dissemination of knowledge in its history. First was the local traditional knowledge systems of the indigenous Khoekhoe and San[77]. Second was the knowledge systems of Bantu groups who came from Central Africa but were indigenous to West Africa. Third was the arrival of Dutch and British communities who had systems of knowledge developed by the Enlightenment. The interaction of these peoples, problematic as it was, resulted in a strong affinity to knowledge systems.

This is true for astronomy as it is for medicine and agriculture. In fact, like all traditional communities, the boundaries between these knowledge systems simply did not exist. Astronomy informed agriculture, and agriculture informed herbalist practices, which informed medicine[78]. The Venda people of South Africa used the rise of Canopus to plan their agricultural activities[79]. The arrival of the British and the Dutch resulted in the rapid modernisation of astronomy in the area with the establishment of the Cape Observatory[80].

As pursuit of knowledge in astronomy became an established institutional concern, the apartheid state was uninterested in teaching astronomy to the Bantu and Khoekhoe groups in the country. This did not lead to a degeneration of astronomy in these communities. Books in astronomy were published by authors from these groups: an example is Tse Leholimo le tse Lefatse-"The Heavens and the Earth" by Samuel Duby in 1910. Noting this idiosyncratic development, Snedegar[81] notes that "Scientific training was not a priority of "Bantu Education". That a widespread receptivity to fields such as astronomy survived decades of governmental suppression deserves serious investigation".

[76](Thobejane, 2013)-*History of apartheid education and the problems of reconstruction in South Africa*
[77](Medupe, 2015)-*Indigenous Astronomy in Southern Africa*
[78](Ntuli, 2002)-*Indigenous knowledge systems and the African renaissance*
[79](Snedegar, 1995)-*Stars and seasons in Southern Africa*
[80](Dubow, 2019)-*200 Years of Astronomy in South Africa: From the Royal Observatory to the 'Big Bang'of the Square Kilometre Array*
[81](Snedegar, 1995)-*Problems and prospects in the cultural history of South African astronomy*

The government had significantly skewed the NIS along racial and political lines. This had resulted in the weakening of the NIS. While there were examples of black scientists and engineers in South Africa's apartheid system, these were "exceptions to the rule" of a largely white academia.

Because of strong sub-networks weakening other competing networks, there was little funding for some aspects of scientific research. This led to the degeneration of certain programmes. There were industries that did not exist in in South Africa, partially because the isolationist stance taken by the control network led to the stifled development of these industries.

The post apartheid "Rainbow" government recognised this strong cultural affiliation to knowledge in the country. It sought to encourage, develop and build this into a sophisticated knowledge production and deployment system. This can be seen lucidly in the introductory sections of the White Paper of 1996[82]:

> Basic science also has a crucial role to play in our country, not just because it is the platform on which applied science and technology are based, but because it has cultural and intellectual foundations as profound as those underpinning music, literature and other products of the human mind.

As a more pragmatic concern, links between academia and industry were also too weak, leading to a sparse network. This led to a polarization of research agendas where the output of universities and research institutions was either irrelevant or not known to businesses, and the flow of talent from academia to industry was problematic. On the reverse, problems which were of relevance to industry were generally not in the purvey of academia. The absence or sparsity of these links problematised information flow in the national innovation systems [83].

The 2018 White Paper sought to improve the connection between academia and industry, as response to the fact that innovation numbers had flatlined. The drafters of the

[82](Department of Arts & Technology, 1996)-*White Paper on science and technology*

[83](Department of Arts & Technology, 1996)-*White Paper on science and technology.*

document thus made this a priority, stating that: “Support for, and partnerships with, industry can be made an explicit policy mandate of the public research institutions, particularly science councils and will be monitored as part of their annual performance plans”.

There were also dual problems which came with the thawing of relations between South Africa and the global community, which can be seen as the sudden addition of new nodes to the network. The government had spent decades in the attempt to develop a self sufficient economy. This had led to the development of radical protectionism of South African industries[84]. There was a danger that with liberalisation of South African markets, an inevitable collapse of local industries would occur[85]. This was a concern that the government thought could be solved using science and technology. The rise of information technology systems in the late 80s had matured in the late 1990s with the emergence of the world wide web. The infantile inflation from the speculative rush on the world wide web, and burst of the dot com bubble had yet to occur. The South African government seems to have recognised the power of this new change in world affairs[86]:

> The world is in the throes of a revolution which will change forever the way we live, work, play, organise our societies and ultimately define ourselves. Unlike previous revolutions which were focused on energy and matter, this fundamental change involves our experience of time, space, distance and knowledge. Although the nature of this information revolution is still being determined, its implications, which are global and inescapable, are being felt with increasing force. In the world-wide race for competitiveness the finishing line keeps moving away. The ability to maximise the use of information is now considered to be the single most important factor in deciding the competitiveness of countries...

In the updated 2018 white paper, the Government still recognised that it needed to

[84](Wolpe, 1972)-*Capitalism and cheap labour-power in South Africa: from segregation to apartheid*
[85](Lundahl & Petersson, 2013)-*Post-apartheid South Africa: an economic success story?*
[86](Department of Arts & Technology, 1996)-*White Paper on science and technology*

respond to the challenges posed by the world[87]. New technological developments have occurred. This includes the rise of artificial intelligence, and social media built on the infrastructure of the internet. The 2018 White Paper wants to take advantage of these new developments while at the same time mitigating the threats posed by them. These new developments have been reflected in the White Paper and are intended to focus the attention of the government towards these new developments. In response to these challenges, the Department of Arts, Culture and Science sought to encourage interventions which would encourage the development of South Africa's NIS into a robust system. It proposed certain interventions that would enable this. The complete dependence of the scientific community on the apartheid state was regarded as problematic for the NIS. Thus the stranglehold of the dismantled apartheid state was to be eliminated. This was to help allow the free flow of information in the form of talent, especially black and female talent to academia. The ideological stranglehold had curtailed this flow by introducing systematic inequities in the education of blacks. Because of the legacy of apartheid, there were serious race and gender disparities in academia. The government thought that the reversal of this position was necessary: "Currently the race and gender disparities in S&T are unacceptably high. We need to address this imbalance pro-actively, not just because it is right to do so, but because if we do not we will simply not have adequate human resources to deal with our problems."
There were to policy interventions to be developed to improve the education of girls and the Bantu and Khoekhoe communities in the country. The hope was to make the formal education pipeline accessible to majority of the public.
For the case of the 2018 white paper, certain successes were noted. The ST&I landscape had expanded rapidly. This can be understood as the growth of the diversity and numbers of the network. There was a threefold increase in publication. This was taken as the sign of a research ecosystem under accelerated growth. There had also been a marked increase in the participation of black people and women in science and academia. Postgraduate graduation rates had also risen

[87](of Science & Technology, 2018)-*White Paper on science and technology*

On the other hand, certain persistent challenges were also noted. The National Innovation Systems were not yet fully inclusive, it was noted that there needs to be improvement. Innovation numbers had not improved with growth in scientific research. Rapid advancements in science and technology had effectively made certain aspects of the 1996 White Paper moribund.

The 1996 White Paper proposed strengthening the links between nodes by ensuring better information flow between all sectors of the NIS. The 1996 White Paper proposes the strengthening and centralising of all matters of funding to the National Research Fund (NRF). This system would help all sectors carrying out research have access to government funds. This would include Universities and other research institutions in the country.

There was an attempt to bring marginalized sectors of the population into R&D. Women and blacks were underrepresented in the sector. The government sought to deracialise and eliminate sexism in academia and in government research institutions. The first step was to dismantle apartheid structures and encourage the education of disadvantaged groups in post apartheid South Africa. Measures of affirmative action were put in place to help develop a robust educational pipeline that would further assist in diversifying the number of nodes.

In further attempts at growing her NIS, South Africa sought to collaborate with other African countries, and with the world at large. South Africa saw science and technology as a tool of cooperation. This cooperation emphasised interaction with her geographical neighbours, Zimbabwe, Botswana, Zambia Malawi, Mozambique and Madagascar. After decades of frosty relationships with these countries, the new government was interested in cooperation with her neighbours, who had directly and directly supported the struggle against Apartheid state. They sought to build on existing networks to hopefully build sophisticated regional scientific collaboration structures[88].

This was built on active networks built by the African National Congress during the struggle for majority government. These networks had been developed in the

[88](Department of Arts & Technology, 1996)-*White Paper on science and technology*

underground. They allowed ANC members to sneak across the border and receive all the necessary papers that they would have needed to travel. Some were supported by being granted diplomatic asylum in the neighbouring countries. South Africa was cognizant of these contributions to her struggle. She also and recognised that most problems in Africa were shared problems. She thus sought active collaboration with the region of Southern Africa and Africa in general: "The development of a national system of innovation in South Africa will have to take into account social and economic developments in neighbouring countries with a view to eventually developing a regional system of innovation as a crucial long-term guarantee of regional stability and upliftment."[89]

It is instructive that South Africa intended to engage in science diplomacy two years after the formation of democratic government. South African government was interested in integrating itself into regional and continental structures.

The 2018 White Paper has an even stronger Pan-Africanist bent. Since 1996, the Organisation of African Unity had been dissolved in favour of the African Union. The African Union has developed a stronger commitment to Pan-Africanism as we have discussed. It also has a much stronger security and political presence in African countries, manifested through regional substructures like the Economic Cooperation of West African States (ECOWAS), Southern Africa Development Community (SADC), and the East African Community (EAC) [90]. South Africa, being one of the leading countries advocating for the formation of the African Union, has over time become committed to Pan-Africanism, stating "South Africa's future is linked to the rest of the African continent, and therefore the potential for ST&I for African development and continental integration needs to be fully applied."[91].

This ideological commitment is translated in to practical, deliverable concerns. South Africa supports the formation of a Pan-African scientific agenda in the continent. She aims to do this by facilitating the formation of continental research networks such

[89](of Science & Technology, 2018)-*White paper on science and technology*, pg 5
[90](Møller, 2009)-*The African Union as a security actor: African solutions to African problems?*
[91](of Science & Technology, 2018)-*White Paper on science and technology*, pg 5

as the African branch of the Square Kilometre Array, shared technology innovation platforms, and mutual learning. South Africa prioritizes the formation of an integrated ST&I agenda in the continent.

Since 1996, South Africa has made significant strides not only in integrating itself into the continent, but in the world at large. By targeted investments, it has become an international cultural, commerce, and academic attraction. South Africans have been able to travel, study and settle in the West. Following modern trends in thinking, the White Paper seeks to move away from "brain drain" paradigms to "brain circulation" networks. It seeks to leverage these brain circulation networks: "Properly leveraged, these "brain circulation" networks could help drive knowledge generation in South Africa and improve science diplomacy between countries."

It is clear that South Africa has come far from the isolationist, autarkic attitudes which informed the foreign policy of the Apartheid state. So far, she has been able to comfortably tread the thin line between Pan-Africanism and the more strident, extreme forms of African Nationalism. This is unlike other BRICS countries which are under the control of nationalist movements. It remains to be seen whether the ANC government will maintain its declining control of the country [92], and what implications the rise of African nationalism will have for the strong continental and international science diplomacy networks the country has built over 20 years. This is especially of interest to us since in the next two chapters, we will study the SKA collaboration network which the country has been instrumental in building, especially for Africa. This informs us that there were appreciable improvements in the NIS of South Africa. We will explore the effect of this strengthened NIS in the next chapter while considering scientific productivity. This will inform our understanding contextualisation of the radio astronomy development in South Africa.

[92] (Mbete, 2015)-*The Economic Freedom Fighters-South Africa's turn towards populism?*

2.3.2 Kenya's NIS

We compare this with Kenya's portrayal of her NIS in 2012[93]. Kenya, like South Africa has a relatively well developed scientific ecosystem. Kenya does not have a knowledge culture as strong as South Africa's. Kenya however does have a significantly sophisticated innovation culture [94]. The Kenyan market is relatively quick at adopting new technological developments. A case in point is the M-Pesa mobile transfer system[95]. In recent years the Kenya government policy has aligned more to the further cultural development of this innovation despite the traditional reluctance of its political class to engage structurally and directly with science investment [96].

Kenya restructured her NIS in 2012 after adopting a new constitution in 2009. The violence of 2007 seems to have forced a introspection on Kenyans. The country promulgated a new constitution after decades of amendments to the earlier colonial constitution, coupled with failed attempts at replacing it. In this wider soul-searching period for Kenya, her scientific community also saw it fit to search its soul for ways of improving science research in the country. Kenya had already been recognised as one of the innovation centres of excellence in Africa with a widespread innovation and entrepreneurship culture in the country. The scientific community and bureaucracy in the country wanted to understand how to best formalise and support the NIS in the country. Like South Africa, there were challenges which existed, which can be understood in the sense of social network analysis.

The Kenya government's objective was the creation of a local ST&I system which was "appropriate to national needs, priorities, and resources". Government policy is strongly aligned to local concerns. Kenya, like most African countries, shares significant socio-economic challenges. These include food insecurity, strained health services, poor urban planning, low levels of public services and amenities in rural areas, and a youth unemployment and bulge, among other challenges.

[93](Kenya Ministry of Higher Education, 2012)-*A Policy Framework for Science, Technology and Innovation*

[94](Ndemo, 2017)-*The paradigm shift: Disruption, creativity, and innovation in Kenya*

[95](Jack & Suri, 2011)-*Mobile money: The economics of M-PESA*

[96](Ministry of Science, & Technology)-*Science Technology and Innovation Policy and Strategy*

The National Science Policy Framework is meant to leverage ST&I for the meeting of these challenges. The government identified certain scientific fields as being of concern: "Specifically, the following areas of innovation will be given a high priority: biotechnology, space science, telecommunications, electronics and computers, automobiles, and nuclear electricity."

The science framework policy document acknowledged that the national innovation system is a fragmented network. This is to be understood in this case to be the existence of a small series of subnetworks that themselves are at best tenuously connected to each other. Existing research institutes had weak links with universities which themselves operated autonomously from the government. The only dependence on the government was for funds. The universities determined their research programmes entirely independently of the government. Both the university and research institutes had weak connections with industry. This fragmentation was acknowledged by the policy framework developers. They saw that this introduces difficulties by limiting synergies expected to emerge out of interconnected sub-networks.

The fragmentation was partly a result of the weak funding for research by government. As a result, there was significant development of autonomy in the research community which developed dependence on external donors. It was by default accountable to their donors rather than the government. This led to problems of prioritisation. Were the researchers doing what's best for Kenya, or what the world thinks is best for Kenya? The framers of the policy acknowledged this difficulty.

The dyadic relationship of public institutions and the government can best be understood as a principal-agent relationship embedded in a larger network. The principal provides the funding, the agent carries out the work assigned to them by the principal. This relationship had deteriorated over time, having negative impact on the research environment of Kenya.

Partially because of the absence of funding and industry links, science and innovation was not seen as a promising career prospect in Kenya. Kenya was and still is, an agrarian economy. The industrial centres in the country relied heavily on imported technology. This led to a significant reduction in the interest especially in the sciences. While the numbers of engineering graduates rose steadily promising a concurrent expansion of the technology sector, this was not to be the case as there weren't enough nodes in the industry to absorb the newly trained engineers. The rapid expansion of the commercial economy led to some engineers instead opting to pursue careers in the financial sector as opposed to the technology sector. The absence of enough technological nodes was thus a problem.

The weakening and closing of research institutes meant a reduction in the number of scientists needed in the economy. The reduction in demand saw talent move away from science into other careers, especially in the financial sector. These factors historically contributed to a weak, small and therefore inefficient NIS. The absence of "information flow" in the network, in the form of money, trained personnel, feedback and instructions was a manifestation of the weakness of the network.

Kenya has always been a highly hierarchical society. The behavior of the people in power determines the country's culture. Theft, identity politics and corruption have propagated into the public consciousness because it was instigated by a political class who defined the culture of the country[97].

Rapid expansions in the population of students was unmatched by the expansion of the capacity of the university research ecosystem of the country. The absence of dynamism led to a stalling of innovation in the country's innovation system, the country depended on international innovations for its technological progress. With the liberalisation of the economy in the late 1990s, there was sufficient infusion of private capital to strengthen the innovation system. Although this can be viewed as a good, there are reasons to worry that it may not be prudent to run a NIS explicitly on private capital. These concerns were raised by Pickstone at around the same time[98], for the case of the United Kingdom's NIS. Recognising that government intervention was needed to regulate research and development, the government saw it fit to step in.

[97](Muigai et al., 2004)-*Jomo Kenyatta and the Rise of the Ethno-nationalist State in Kenya*

[98](Pickstone, 2001)-*Ways of knowing: A new history of science, technology, and medicine page 205*

A clarification is in order: while the government in Kenya has been significantly strong, in the sense that it maintains control over the military and police, and indirect control of other public institutions, it maintained weak interest in Kenya's NIS. Thus, from the point of view of this network, the government of Kenya was a weak institution. NIS thrive on having a stable source of funding. This might be from government or the private sector, or a mix of the two. The strength of the node of a network is determined by its ability to integrate into the network by the exchange of information. Governments are typically seen as a source of funding and regulatory framework of the NIS. The government of Kenya was weak in both aspect and thus was a weak node in the network.

In 2012, the formulators of the national science policy framework recognised that the government had to have a stronger relationship with research institutions and universities. The proposal was to do this through the strengthening of funding, developing a more robust regulatory framework, and developing agencies to handle specific aspects:

The commission was created by the Science, Technology Innovation Act of 2013 to advise the government on matters relating to science and technology. Its precursor agency was considered to be a sub-ministerial department.

The commission was however to be considered as a semi-autonomous branch of government, subject only to legislative checks and control. The commission's chief function is to inform the government on key priority research areas aligned to the government research agenda. The commission also regulates the research environment of the country. Research by external institutions must obtain permits before being able to carry research. The opening of any research institution is also regulated by the commission. Through it, the government forges links between itself with universities and research institutions.

The National Science Policy Framework recommended that the Kenya Government increases financial investments to sustain the NIS which had been in near collapse at the time. Kenya did not have publicly available data on how much of the country invested in research and development, as we have seen. There was need to measure this, and create a formalised structure for providing funding to all research related activities in the country. The chief aim of the research fund is to strengthen and existing links through finance. Within the policy framework, it is hoped that the money will help strengthen Kenya's domestic research programme. The use of the money is to be aligned with the advice of the National Commission on Science Technology and Innovation (NACOSTI) to the government regarding research priorities. Thus as is regulated, the activities of publicly funded professionals was envisaged to be part of this framework.

The Kenya National innovation Agency(KENIA) is basically in charge of Kenya's NIS. The agency was proposed to strengthen the links between industry and academia, academia and government, government and industry. It is also in charge of encouraging an innovation culture in the country. It was envisaged to liaise with the NRF to finance new innovation startups, and also run competitions and other related activities.

Kenya seeks to make itself into an innovation hub in the continent. Certain developments show this commitment: KEMRI[99] and KALRO[100], which are medical and agricultural research parastatals respectively, are world recognised. Kenya has recently signed into law articles for the formation of Kenya Space Agency[101], which will be embedded in the country's military-academia nexus. The government has a significant stake in Safaricom, a telecommunications conglomerate in the country. The country has strong technology innovation networks. There are independent groups such as Fablab and Gearbox [102] and Nairobi AI[103], which government agencies strongly support.

The government is actively pursuing the development and deployment of nuclear energy in the country, through KNEB[104]. It has already been certified by the International Atomic Energy Agency(IAEA) for this purpose.

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[99] *Kenya Medical Research Institute*

[100] *Kenya Agricultural and Livestock Research Organisation*

[101] *Kenya Space Agency Order*, 2017

[102] Gearbox is a electronics prototyping company, http://www.gearbox.co.ke/

[103] *Nairobi Artificial Intelligence*-A social group of software engineers with 6000 members as of May 2020

[104] *Kenya Nuclear Electricity Board*

Thus, government actions have generally been consistent with government policy maintaining a coherence which the drafters of the South African White Paper admit to lacking. However, the drafters of the Policy Framework in Kenya also admit to needing a change in the culture of the country. They admit that there is a need "to establish a culture that respects knowledge, and embed this in the various educational curricula."[105]. *pg 2*

We can see that the two countries face different socioeconomic conditions and problems. The NIS of the two countries have specific aims at addressing these problems and responding to these conditions. We have seen that South Africa has developed a policy of addressing social inequities within the NIS. It has also stressed support for the "pure" sciences and also emphasised support for integration with regional and continental structures. Kenya on the other hand has strengthened its NIS structure to further develop the country's innovation culture. In contrast with South Africa, its aims are mostly local. It also supports the pure research in so far as this research can be aligned with its NIS and national objectives.

2.4 Conclusion

We have provided background historical and economic information helping us to better understand the two countries' investment in radio astronomy. With this as a context, we have described the state of the National Innovation Systems by a reading of policy documents developed by the two countries. We have seen that the state of the these innovation systems is a reflection of the socio-economic states of the two countries. We have also seen how proposals were made to improve these NIS to respond to the challenges and opportunities posed by the socio-economic state of Kenya and South Africa.

Having set out a context, we will now turn to the development of astronomy and radio astronomy in the two countries. We will turn to mostly quantitative methods in the measuring of the development of radio astronomy in the two countries, with the

[105](Ministry of Science, & Technology)-*Science Technology and Innovation Policy and Strategy*

African continent and the world setting a context.

3 Chapter Three: In the same continent, but worlds apart: Comparative Development of Radio Astronomy in Kenya and South Africa

3.1 Introduction

We now want to compare the effect of the policy interventions by the government on the scientific community in Kenya and South Africa. In this chapter, we shall include other African countries to better situate the two countries with respect to the continent. It will give us a better indication of how the two countries are faring on with respect to each other. We had earlier discussed how the governments of the two countries sought to change their policy approach towards science.

We begin by exploring whether this change has had an effect on the scientific production of these two countries.

3.2 National Production

Have the policy structures changed the use and deployment of science in their countries? An indicator which can provide a measure of any positive changes is the number of papers authored or coauthored by specific nationals of a country. This can give us an indication of any changes in the policy of the country and the development of science in the country. This measure falls under the field of study known as scientometrics.[106].The position that we can measure the scientific productivity of a country, region or institution by calculating the number of papers published and related statistics is the underlying principle of scientometrics. While these methods are certainly not perfect, we adopt them on the basis of pragmatism. The culture of disseminating scientific information by publication in journals is for the most part global practice. Thus the productivity numbers of a country is a safe indication of the scientific productivity of a country.

We do not consider measures like conferences and prizes because we consider them

[106](Mingers & Leydesdorff, 2015)-*A review of theory and practice in scientometrics*

too simplistic to be a measure of scientific productivity. If we for example consider the contribution of the entire African continent to oral literature, it is not proportional to the number of Nobel Prizes in Literature awarded to Africans. We can make similar arguments for the Nobel Prizes in the sciences, considered the most international of prizes in the sciences. We also may consider the time delay in the awards of these prizes and the fact that only one is awarded per year. This makes it difficult for us to consider prizes as a useful measure of scientific productivity.

We are going to use some of the methods of Scientometric analysis for the rest of this chapter. Since we are interested in radio astronomy in specific, we will consider metrics which are most associated with radio astronomy. We extracted data from *Scopus*, an online paper metadata and database [107], as our methodology below will show. We used two search terms: "Square Kilometre Array" and "radio astronomy". The "square kilometre array" search received a response of 330 paper metadata while the "radio astronomy" search received a response of 5000 paper metadata.

In the practice of scientometrics, it is standard to attempt a measure of normalisation. This can be done either by measuring the individual output of a researcher[108], or by the gross domestic product[109] or by custom normalization methods[110]. We have however not normalised our results because this will not adversely affect the results especially in the case of Africa's results. We thus present the data as is.

Just as in chapter two, we developed a Python script to help download and visualize the data. Our data extraction and visualization methodology followed three steps similar to the case in chapter one.

The first step was Data Extraction. The process here was a bit more involved than the process in chapter one. The *Scopus* database does not allow a direct download of data in a local server, ready for processing. It however maintains a special interface that allows the accessing of data. This is the Application Programming Interface (API).

[107] Scopus Website-https://www.scopus.com

[108] (de Souza Vanz & Stumpf, 2012)-*Scientific output indicators and scientific collaboration network mapping in Brazil*

[109] (Biljecki, 2016)-*A scientometric analysis of selected GIScience journals*

[110] (Archambault et al., 2011)-*Scale-adjusted metrics of scientific collaboration*

There is a specialised API developed by Elsevier for this purpose. To access the data, one needs a special kind of license, known as the API Key.
After this we also installed Pyscopus [111], API Interface. This is a "wrapper" which can be understood as an interface of the interface. It allowed us to load the data into a dataframe, the spreadsheet version of Pandas. We then used these tools to download the data.
Secondly was Data Reduction. We were only interested in the country statistics, which is in the "affiliations" column of the dataframe, we isolated the column, reducing our data to 330 rows in the case of the SKA search term and 5000 rows in the case of the radio astronomy search term. We then isolated the country column. We invoked a statistical method which could count the number of times the name of a country appeared in the column. This would be an indication of the number of papers published by a specific country.
Finally, there was Data Visualization. We then produced a quick bar graph plot of the data as shown below, using Matplotlib-A visualisation library in Python We however wanted to visualise the data geographically. This was to be done by Geopandas, geographical data visualisation library. However, before geographical data visualisation, we needed to transform our data into data of longitudes and latitudes. This is called geocoding. There are several geocoding modules in Geopy which is another geographical data library in python. We used Nominatim, which is a free geocoding service. After getting our coordinates we located them on a world map produced by Geopandas and then performed a spatial join. A spatial join is when the statistics or data represented by a point on the map are spread out to some polygon. In our case, we performed a spatial joint associating the centroid coordinates of a country to the country itself. This allowed us to produce choropleths and cartogram, as is shown below.
There exists proprietary software developed specifically to do the same work we have done with this algorithm. Indeed, consultancy firms exist to deal with "big

[111] Pyscopus is an independent python wrapper for the *Scopus* database, see for example (Zuo & Zhao, 2018)-*The more multidisciplinary the better?–The prevalence and interdisciplinarity of research collaborations in multidisciplinary institutions* for a deployment of the algorithm in scientometrics by the developers.

scholarly data". It may then be justifiably asked why there is need to develop a new algorithm from scratch. There are reasons for this which we discuss.

Some of the software developed are not compatible with Linux based systems, on which we developed this project. While windows based systems exist in the University office, this was inaccessible because of the lockdown. However other solutions exist which can mitigate this problem. While third party firms can do the work and produce the data visualisation schemes needed, there are charges which accompany the service. Thus it was simpler, and cheaper to build an algorithm from scratch.

Developing the algorithm from the ground allows us certain advantages including the ability to make custom visualisation, together with the ability to extract data at various stages of the pipeline and be able to deploy it in different pipelines depending on the task at hand.

The hope is that the system can be fully developed into open source, free software.

We were also interested in general science publication data, which we thought would be interesting for us as a baseline. The data for science publication numbers was gotten from prepared data. The data was prepared by Worldmapper, a geospatial data visualisation firm [112]. The data was already discriminated geographically, so we only extracted the data for Africa to better situate Kenya and South Africa in African Academia. We found two specific data sets to be of import to our work[113].

The first dataset shows the number of scientific papers published in 2005 subtracted from the number of papers published in 2015. In the interpretation of World Mapper, this should ideally give an indication of the growth in scientific enterprise of these countries. The second data set is science papers published in 2016.

Both these data sets are particularly relevant to us because they are data taken in the period the governments introduced policy interventions described in chapter two [114].

We begin by looking at the graph of science production in Africa in 2016.

[112] See website at worldmapper.org We had intended to subcontract the firm to do geospatial data analysis, but as discussed, it was much more convenient (and cheaper) to develop the algorithm.

[113] The data was downloaded from https://worldmapper.org/maps/science-growth-2005to2015/ and https://worldmapper.org/maps/science-paperspublished-2016/ on 30^{th} of March, 2020.

[114] Kenya's policy formulation was in 2008-2011, South Africa's science white papers were written in 1996 and 2018

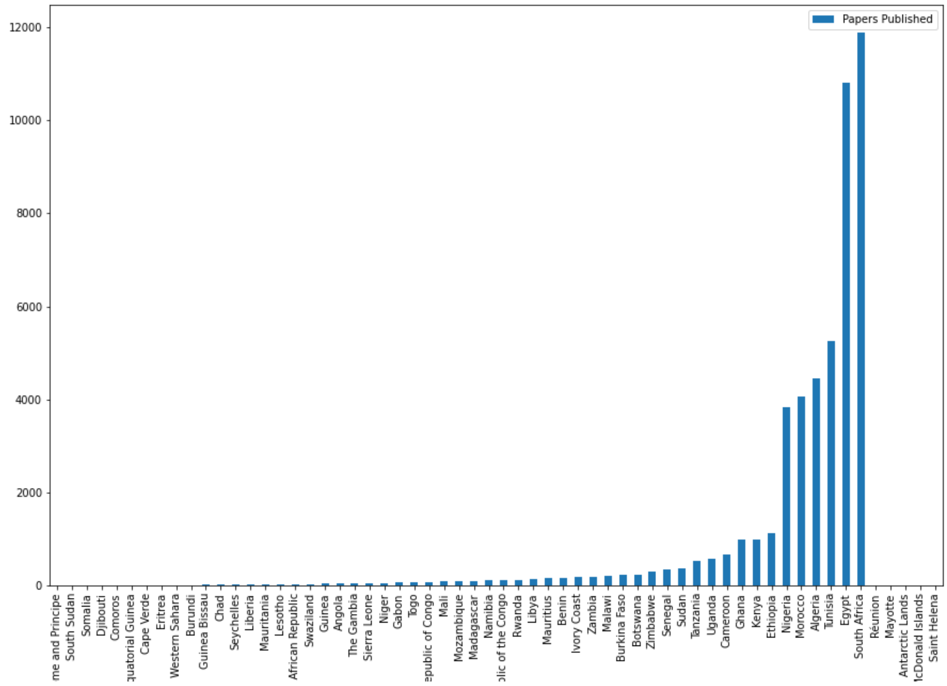

Figure 3.1: Number of Science Papers Pulished in 2016 by country in Africa

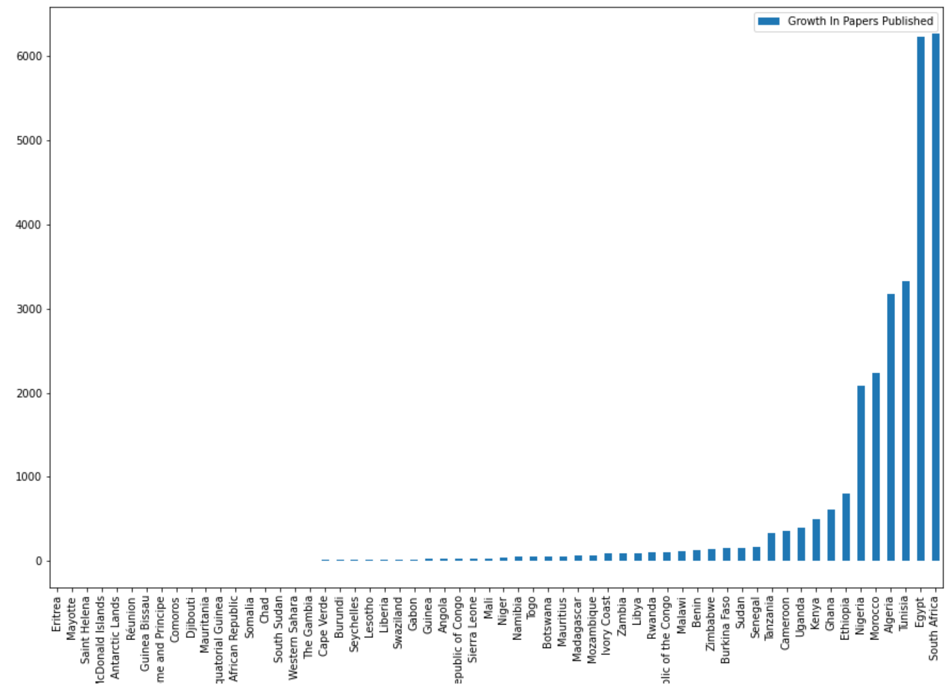

Figure 3.2: Growth in number of papers published from 2005 to 2015 by country in Africa

From the graph, it is striking that there effectively are “scientific hegemonies” in Africa: Egypt and South Africa. Both have witnessed an improvement of number of papers published by upwards of 6000. Tunisia and Algeria follow with an improvement of around 3000 papers published. Nigeria and Morocco follow with an improvement of around 2000 papers. Ethiopia, Ghana, Kenya, Uganda, Cameroon and Tanzania follow with between 500 to 1000 papers published.
It is also striking that most of the African Continent has not witnessed any improvement in the number of papers published. Only 7 out of the 54 African countries have seen an improvement of more than 1000 papers published. By comparison Europe has 25 countries improving by more than 1000, with the top 6 nations improving by more than 10,000 papers. Unlike Irikefe et al.’s interpretation of a rapid rise in scientific productivity, sub-Saharan Africa rise is slow [115].
If we focus our interest on SKA countries, we see that most All SKA countries made small to moderate improvements, with South Africa as an outlier. Kenya ranks third among the SKA countries. Namibia ranks last with an improvement of 107 papers in the period.
It seems therefore that the policy innovations made by South Africa and Kenya were effective in improving the production of academia in science, at least from the point of view of papers published. It is important to note that since Kenya and South Africa are developing economies, the government has significant control over the National Innovation Systems. Thus we can safely ascribe improvements in the statistics of papers published to government policy.
The case of papers published in 2016 shows similar trends. South Africa and Egypt lead the continent with above 10,000 papers published. Egypt and South Africa seem to have sophisticated and well established knowledge production systems. Kenya, Ghana and Ethiopia are also coming up in scientific production.
We can now attempt to situate radio astronomical research within the context of general scientific research, and also in the context of the world.

[115](Irikefe et al., 2011)-*Science in Africa: the view from the front line*

The existence of South Africa as a scientific hegemony is the result of several cultural, economic and political factors. We have discussed how South Africa's long cultural association with the knowledge economy, ranging from deep rooted knowledge systems from the aboriginal population, to the knowledge systems of the immigrant Bantu and European populations. The apartheid state sought to fashion a knowledge economy rivalling those of Europe. This was the basis on which the Post-Apartheid state sought to strengthen the nascent and fledgling knowledge systems ion the country.

South Africa is a significantly large economy in Africa with the third largest economy in the continent. This gives the government financial muscle to pursue any projects it wishes to pursue. Seeing as the post apartheid state was deeply interested in the development of education, science and technology, it was able to invest in this and achieve measurable improvements in scientific productivity. South Africa has also evolved from a pariah state only afforded cautious engagement by her continental neighbours to a central political player in the continent. This has allowed it to develop links with other nations on which it is constructing a scientific collaboration infrastructure. These developments have had implications for Kenya, which is seen as an East African technological and Scientific powerhouse. As it jostles for a stronger position in the region and in the Continent,. However, with an Economy three times smaller than South Africa's, Kenya does not yet have the financial muscle to challenge South Africa scientifically. She has thus sought to strengthen her ties with South Africa We will explore these links in detail in the fourth chapter of the work. Kenya is however actively angling herself to be a technological powerhouse in the continent. In this she is in direct competition with South Africa.

The asymmetries in scientific development in the continent can be understood to be a confluence diverse streams of factors. For example there are active warzones in the continent in the Congo, Horn of Africa and the Sahel which affect the possibility of scientific development. On the other hand, South Africa has enjoyed relative stability over the last twenty years which has allowed her to improve her scientific position. Strong investments and interest by the government has allowed South Africa to strengthen her Position vis a vis that of Kenya.

We can better visualise this by generating maps which reflect the number of papers published in a specific country. Generally, there are three types of maps that can do this: choropleths and cartograms.

Choropleths are colour coded maps. The maps reflect a variation in color depending on the measure being visualised, say population. A legend is usually included to reflect the scaling of the measure being taken. Cartograms normalize the area of certain regions according to the measure given. There are two types of cartograms. These are contiguous and non contiguous cartograms. Contiguous cartograms adjust the area and maintain the adjacency of the individual countries, thus distorting the shape of the countries. On the other hand, non-contigous cartograms maintain the shape of the country, sacrificing the continuity of the map. Usually, non contiguous cartograms are plotted with the normal areas of the regions of interest as a background. This is done for reference purposes.

Other methods of geographically representing data exist, including heat maps. We used choropleths and non-contiguous cartograms to generate the maps we discuss below. This is because Python has well developed methods for generating these maps, in the form of GeoPandas a geographical data visualisation library.

We begin our analysis with the radio astronomy data we got from the 5000 paper titles and author metadata. The data represented papers published from 2013-2020.

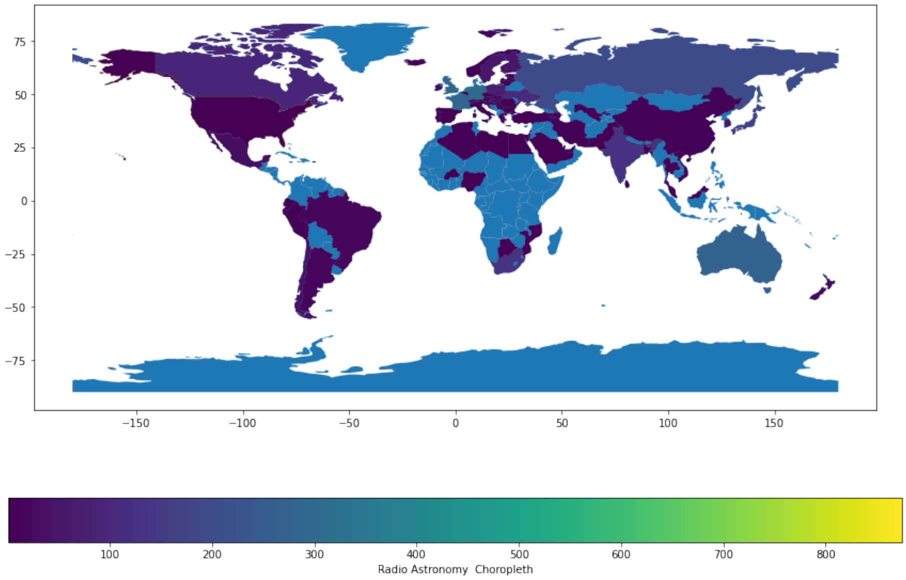

Figure 3.3: Global Choropleth, search term:"radio astronomy"

A short description of the global situation will help us better contextualise the situation in Africa. This in turn will better help us situate Kenya and South Africa. Out of the sample represented, the United States dominates scientific production in radio astronomy as expected. This can be explained by the significant financial muscle the United States has. For example, the budget request for the American National radio astronomy Observatory for the financial year 2019/2020 was 79 million dollars[116]. This is double the entire research and innovation budget of the Republic Of Kenya[117]. China comes second. China has undergone a well documented rise in its industrial, scientific and technological capabilities[118]. In radio astronomy, China currently operates the largest filled aperture radio astronomy facility in the world, the Five Hundred metre Aperture Spherical Telescope (FAST)[119]. China's growth in investment in ST&I significantly eclipses that of the United States. China has developed into a country of strong interest for African states. Its rapid rise and technological development has attracted the attention of policy makers, academics and the general public of Africa. In reverse, China has increasingly become interested in Africa, first as a market for

[116] Obtained from https://www.nsf.gov/about/budget/fy2019 on the 10^{th} of April, 2020

[117] Obtained from https://www.capitalfm.co.ke/news/2018/05/govt-allocates-sh3bn-to-research-innovation-in-2018- on the 10^{th} of April, 2020

[118] (Xie, Zhang, & Lai, 2014)-*China's rise as a major contributor to science and technology*

[119] (Nan, 2008)-*Introduction to FAST: five hundred meter aperture spherical radio telescope*

the goods she produces and as a growth opportunity. The lifting of millions of Africans out of poverty has direct implications for China, which produces a significant amount of the goods produced by Africa. China also seeks to strengthen her international position by developing and strengthening relations with the continent. This is in a bid to develop soft power which allows it to influence the continent politically, economically and culturally For these reasons both parties have sought to increase engagement with each other. Africa is a part of the (China Belt and road?) initiative which seeks to imporove the movement of goods and services between Africa and the East further entrenching the Chinese production market. China on the other hand is involved in infrastructure expansions throughout the continent, with particularly heavy presence in economic hotspots in the continent, South Africa Kenya, Nigeria, Ghana and Ethiopia.

There is thus appreciable levels of economic collaboration between the continent and China. We will attempt to see whether these have carried on to the development of scientific collaboration networks between Kenya, South Africa and China. In particular, we will explore the development of collaboration networks in radio astronomy. This will be done in section 3.3 when we do quantitative and qualitative analysis of the collaboration network.

A qualification is however in order, since the United States has a well developed scientific ecosystem. Europe also maintains significant numbers of publications in the field, owing to a sophisticated radio astronomy research system in the continent. This is the Joint Institute for Very long baseline interferometry European research infrastructure consortium (JIVE) headquartered in Netherlands. The JIVE consortium operates and maintains the European VLBI Network (EVN)[120], an interferometer consisting of 20 telescopes. This collaboration has allowed the continent to maintain visibility in radio astronomy.

Australia and New Zealand have a strong presence in radio astronomy research. Australia is a member of the Square Kilometre Array Organisation and maintains

[120](Charlot, 2006)-*The European VLBI Network: A Sensitive and State-of-the-Art Instrument for High-Resolution Science*

the Australian Square Kilometre Array Pathfinder (ASKAP)[121] telescope, a precursor instrument. Part of the future SKA research facility will be in the subcontinent. Although New Zealand has left the project, it maintains a small but active radio astronomy research community.

South America, also maintains a little visibility through collaborations with the United States. The Atacama Large Millimeter Array (ALMA)[122], is an interferometer funded by the governments of the United States, Chile, South Korea, Canada and Taiwan.

Russia also maintains a small presence in radio astronomy.

From the data we have analysed, we can infer that Africa still lags behind in radio astronomy research, and scientific research in general as can be shown with the contiguous cartogram shown below:

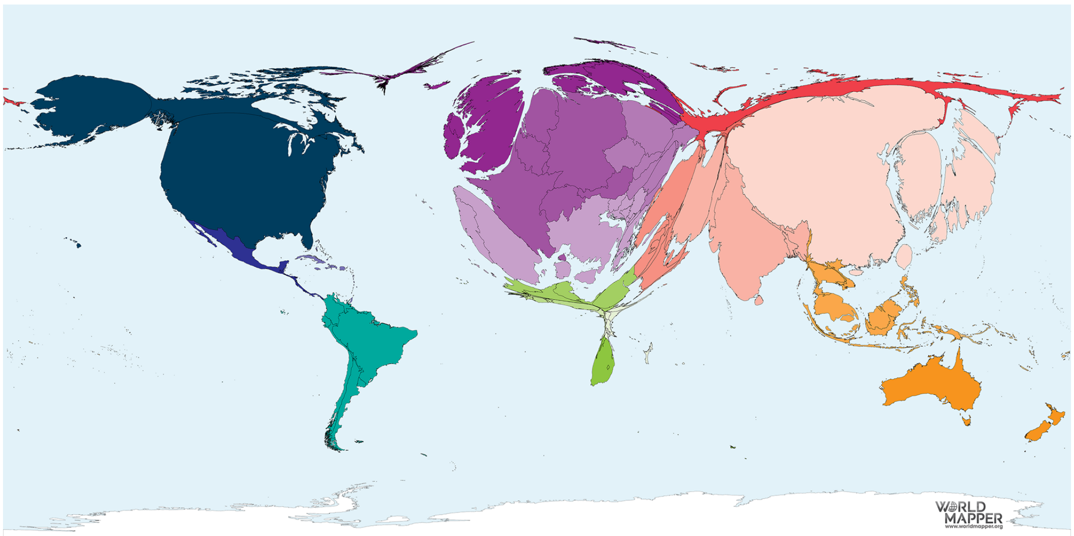

Figure 3.4: Contiguous Cartogram of Number of Scientific Papers Published. From worldmapper.org

We can see that by adjusting area for the number of papers published, a number of interesting features become apparent. Africa and Latin America practically vanish. We can also make out a "scientometric equator" dividing the global north from the global south. It is clear that this not just the case in radio astronomy, but also in science in general. We can now consider the case of radio astronomy in Africa.

[121] (Johnston, Feain, & Gupta, 2009)-*Science with the Australian square kilometre array pathfinder (ASKAP)*

[122] (Wootten, 2003)-*The Atacama large millimeter array (ALMA)*

Figure 3.5: Measured scientific production of African countries. Search Term: Radio Astronomy

We can easily see the dominance of South Africa in radio astronomy. This can be explained by the policy developments of the South African government, buttressed by the historico-cultural reasons we have explored above. South Africa has a long history of being at the forefront of Astronomical research and knowledge[123]. South Africa seems to have a disproportionate dominance compared to her closest competitor, Egypt.

South Africa has consolidated two major "big science" facilities: Hartbeesthoek Radio Astronomy Observatory (HartRAO) and the Square Kilometre Array- Africa (SKA-Africa) into the South African Radio Astronomy Observatory (SARAO)[124]. The status of this organisation in South Africa's bureaucratic structure is similar to NRAO of the United States. Egypt does not have similar bureaucratic structures, although it maintains a small radio astronomy community.

There is a "squeezing of the middle" apparent. Huge swathes of central Africa have not appeared in our search of the database. This is partially supported by the science publication statistics we have discussed. The North and South dominate scientific production. However, for the specific case of radio astronomy, South Africa seems to be the single biggest scientific "hegemony" in the field. This is an upwards of 120 papers published in radio astronomy. All other African countries seem to have published

[123](Dubow, 2019)-*200 Years of Astronomy in South Africa: From the Royal Observatory to the 'Big Bang'of the Square Kilometre Array*

[124]see SARAO's website-https://www.sarao.ac.za/

less than 20 papers in the field. Care should be taken however in coming to the conclusion that these are the only papers these countries have published. Our sample size is only 5000 papers.

However we can conclude that South Africa dominates the field, at least in Africa, since our sample search is spatially randomized. One other fact is interesting to note. Although Ghana operates a radio telescope facility under the auspices of the proposed African VLBI Network (AVN), we were unable to get paper publication data out of the facility in Kuntunse.

Nigeria has contributions to radio astronomy, despite having no affiliations with either AVN or the SKA. We want to investigate how many countries affiliated to the SKA in Africa we were able to capture in our sampling. The SKA African partner countries are Kenya, Ghana, Botswana, Mozambique, Madagascar, Mauritius, Zambia, and Namibia as shown in the global SKA map below:

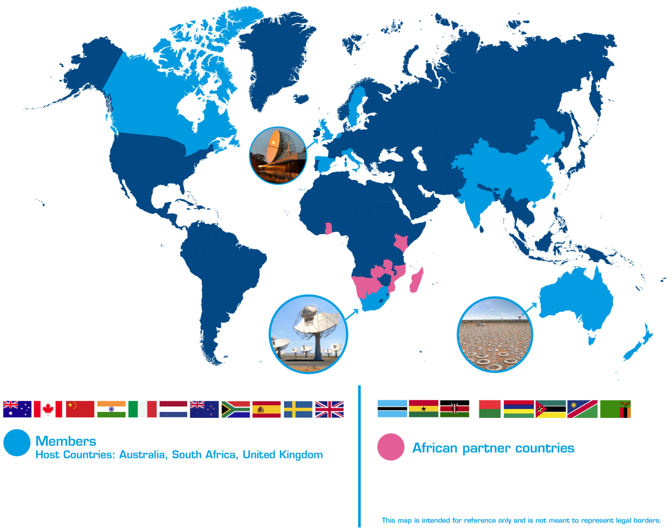

Figure 3.6: Map Showing SKA member states and African Partner Countries. From: skatelescope.org

We were only able to capture Botswana and Mozambique in our sample size. All other African partner countries do not show productivity in radio astronomy or related research. This may be the result of inefficient search methods employed in obtaining the search sample. If not, it may speak to imbalances in research in radio astronomy in Africa. These imbalances might reflect an imbalance that exists in terms of investment in the field by these countries.

After this, we narrowed our search term to specifically capture paper metadata related to the SKA, a radio astronomy project of import in both Kenya and South Africa.

We queried the *Scopus* data base and received a response of 330 papers. We put the results through the data pipeline developed above and generated the maps below.

We will start with a high level look at the world as we did, and then zero in on the two countries which are the subject of our study.

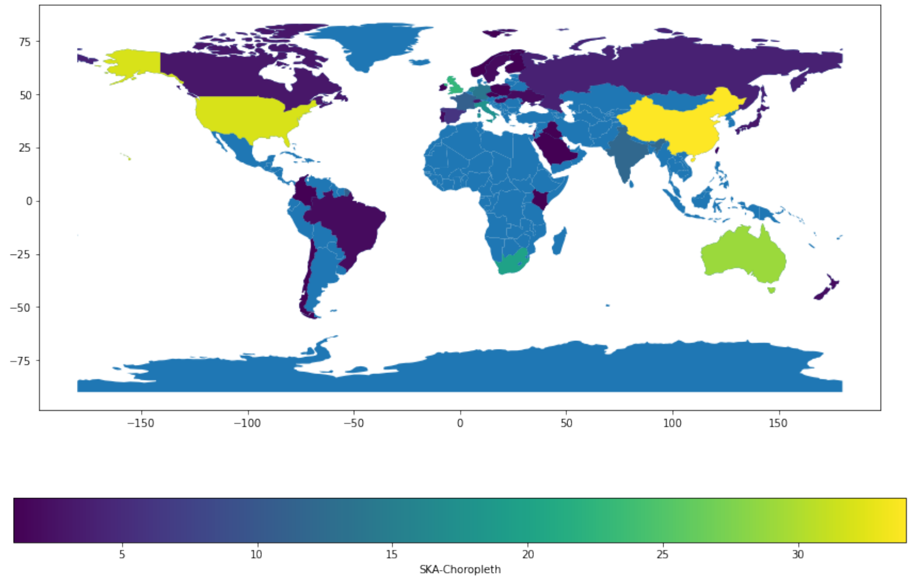

Figure 3.7: Choropleth of paper publication statistics, search term:"square kilometre array"

No country seems to dominate scientific production, especially in the case of the SKA. China tops global production with 35 papers published. China is in charge of the instrumentation technology of the SKA. Since the project is at the developmental stage, China is highly active and engaged in the project as it develops new technologies for the undertaking. The SKA can be understood primarily as a data intensive project. Thus, new data capture, relay, reduction and analysis mechanisms need to be developed to keep up with the technological challenges the project faces. China, "the world's factory", is thus best placed to meet these challenges.

It is surprising that the United States, although bearing no official affiliation to the project, comes second in scientific production. The United States, alongside Europe

and China, dominate world scientific production, from Fig 3.4. America is thus expected to have wide ranging presence in any randomly sampled dataset of scientific publications. Parts of western Europe especially Germany, Italy, Netherlands and France have published upwards of 20 papers in our sample size. A quick check of Fig 2.9 shows that Italy, Germany, Netherlands and France are member states of the SKA.
However in Europe, the United Kingdom stands out as having the most impact in our sample. The United Kingdom is the headquarters of the global SKA project. The United Kingdom also has strong cultural ties since she contributed significantly to the development of the methods of radio astronomy through the initiatives of Bernard Lovell in the post-war period. The origins of the project can also be ascribed to the University of Manchester in the early 90s. The United Kingdom thus has a central position in this project.
Australia also has a significant role to play in the project, considering that it is one of the host sites of the project. Australia will host the Low Frequency Array (LOFAR) part of the project[125]. Thus Australia, along with the United Kingdom, are the main state actors. Australia and New Zealand have built up an active radio astronomy research community, making Australasia one of the radio astronomy research regions of the world. It seems that on this specific project, Australia is able to maintain a competitive edge over Europe, excepting for the United Kingdom. This is in contrast to the state of science in general. We can gleam this from Fig 2.7 While Australia seems to be maintaining visibility in general scientific research, it seems to be lagging behind comparable countries in Europe, like France, Germany, and the United Kingdom. Eastern Europe, Russia, Saudi Arabia and parts of South America have a presence in the project.

[125](Röttgering, 2003)-*LOFAR, a new low frequency radio telescope*

Figure 3.8: Measured scientific productivity of African countries. Search Term: SKA

In the map, one thing is apparent. At least for the case of the SKA, one African country is matching up to the indicators of Europe China and the United States. This is the result is due to years, if not centuries of building up a knowledge economy connected to the stars. We have already mentioned South Africa's strong cultural connection to astronomy. South Africa has invested heavily in radio astronomy and related research. South Africa also approached the various African partner countries for a joint bid to host the project. This bid, as has been documented, was successful.
The continental headquarters of the SKA project are in Cape Town South Africa[126]
. The SKA is embedded in SARAO. It operates the SKA precursor, MeerKAT. The facility has already attained research capability and has been integrated into the wider SKA Phase-1. It is this that we hypothesize might contribute to South Africa's international presence in the field.

[126]see SARAO's website-https://www.sarao.ac.za/

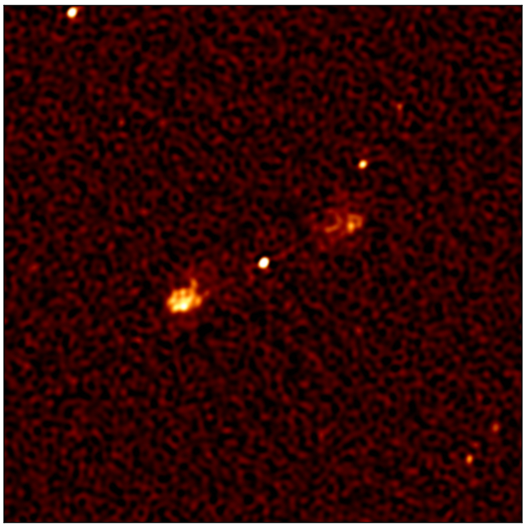

Figure 3.9: Picture MeerKAT first light results. This is an image of a black hole. From:sarao.ac.za

However, when the rest of the continent is considered, the imbalances that have maintained themselves throughout our discussions are maintained. Our algorithm only captured 330 papers in the remaining SKA partner countries combined. As we have discussed earlier, this could be because of the insensitivity of the search algorithms employed by the *Scopus* API. Kenya has only 1 paper or collaboration appearing. Upon further investigation, we confirmed that this is a paper that is related to technology development for the SKA[127].

Finally, we were interested in knowing the content of the papers published in relation to the SKA. The process followed in establishing this presented a few difficulties. One was the fact that our database access method did not offer the abstracts which would help us have a glimpse of the content of the papers. This was resolved by moving to another data base, *Lens*[128]. However the database had 2344 abstracts. It was not going to be possible to read and classify the abstract content manually. We thus fell on machine learning methods to help us classify the abstracts and to give us a quick indication of the content of these abstracts. To help the model, we used

[127](Rotich Kipnoo, Gamatham, Leitch, & Gibbon, 2017)-*Simultaneous signal amplification and clock distribution employing backward Raman pump over an optical fiber for applications such as square kilometer array*

[128]See website at *lens.org*. *Lens* has significant overlap with *Scopus*, as argued by Aaron Tay in "7 Reasons Why You Should Try Lens.org" from https://medium.com/@aarontay/6-reasons-why-you-should-try-lens-or

inbuilt natural language processing tools in the Python machine learning library to help train the model. The model generated three clusters: Cluster 0: {radio galaxies, ska, galaxy, surveys, magnetic, sources, survey, redshift, cosmic}, Cluster 1:{ska, radio, telescope, frequency, square, kilometre, antenna, design, low}, Cluster 3: data, time, model, using, based, used, high, array, new, paper. We can infer that cluster 0 is primarily concerned with actual observations, cluster 1 can be thought of as a design cluster, and cluster 2 can be thought of as a "methodology cluster".
We then used the model to classify the 2344 abstracts we got. This result was then loaded to the Pandas dataframe and the result was plotted in a bar graph.

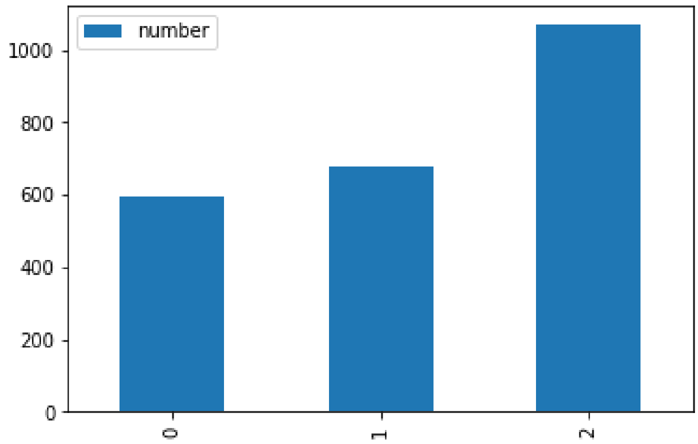

Figure 3.10: Abstracts Classified by Cluster

We can see that the "methodology" cluster has the highest number of papers. However there is a more or less equal distribution of papers between the three clusters. We can infer that as many papers are being written about the design of the SKA as are being written about observations. A caveat is however in order here. The SKA has not yet been constructed. Thus, these papers could fall into one of two classes. They could be exploratory papers published which discuss the future capabilities and capacities of the SKA. Secondly, they could be papers published out of observations carried out with SKA precursor instruments. An example of an ongoing active collaboration is the MeerTRAP collaboration[129]. The collaboration is using the MeerKAT telescope in South Africa.

[129]See their Website: https://www.meertrap.org/

It is interesting that the SKA is already generating academic interest. It is generating interest not just as a problem of engineering given its stage of development, but also as a scientific instrument. Of more interest to us is whether the papers published in South Africa are primarily science papers and engineering papers. It was not possible to establish this since the database we queried for the abstracts did not have author location information. However we can argue, using qualitative evidence, that a significant portion of the papers published in South Africa are scientific.

To support this, one can see that the Universities associated with radio astronomy in the country have an active radio astronomy research group. An example is the University of Cape Town [130] and Rhodes University [131]. These groups amongst others are involved in the technical and scientific aspects of radio astronomy. They also engage in collaborations with other groups in other parts of the world. It is these collaboration patterns that we seek to map out next.

3.3 Mapping Collaborative Networks in Radio Astronomy

Another important way to situate Kenya and South Africa in the landscape of international radio astronomy research to map existing collaborations. In our case, it is difficult to trace memoranda of understanding, or diplomatic agreements signed between countries with a view to further collaboration. Even in the case where the parties involved make all the details of these agreements public, it is often useful to measure the impact of these agreements [132].

This militates the need to measure the outputs of research agreements, which themselves carry implications for science policy and science diplomacy. In principle, stronger diplomatic ties between countries, or the drafting of agreements of scientific collaboration

[130] See http://www.ast.uct.ac.za/ast/research/meerkat_surveys for the research activities of the University of Cape Town

[131] See https://www.ru.ac.za/physicsandelectronics/radioastronomycentre/ for the Rhodes University Research Group

[132] See for example https://www.dst.gov.za/index.php/media-room/latest-news/2933-joint-media-statement-on-the-outcomes-of-the-6th-ska-africa-partner-countries-meeting for the Joint media statement on the outcomes of the 6th SKA Africa Partner Countries Meeting. Obtained from the South African Department of Science and Technology on the 20^{th} of April, 2020

between countries, will further encourage scientific collaboration between countries[133]. This is because countries with strong diplomatic ties have a higher probability of having historico-cultural ties. Countries with stronger ties of history and culture have a higher probability of having scientific collaboration networks. This effect has been observed in scientometrics by Archambault et al. [134].

Collaborations have been understood to be effective for science and scientists themselves. Collaborations improve productivity visibility and quality of the research as discussed by Iglič et al.[135] This further strengthens the need to study these collaborations, and understand their development and structure.

For our analysis, we traced two collaboration networks, the SKA collaboration network and the radio astronomy Collaboration Network. We will first discuss the general global cases. We will then discuss South Africa's network. Kenya will not be a part of this discussion as it does not yet feature in both networks. We will also explore other collaboration networks which we will use to explain Kenya's absence and South Africa's dominance, which we saw when studying national production numbers.

An algorithm was developed and implemented in the Python programming language. The algorithm, like all earlier ones, carried out three basic tasks. These are Data extraction, Data reduction, and Data visualization. Similar to the methods employed in the measuring of national output, the data was extracted from the online paper metadata and indexing service *Scopus*. The data consisted of 330 SKA and 5000 paper metadata Both were arranged in terms of a table of n rows and 17 features as columns, where n is the number of papers published. As is the case with section 3.4, the data was extracted using Pyscopus[136].

Data reduction formed the core of the algorithm. The first step was to isolate the column we were interested in. This was the "affiliations" column of the data. This was done using Pandas. As is the case with national output, we were interested in

[133](Colglazier, 2016)-*Diplomacy for Science and Science for Sustainable Development*
[134](Archambault et al., 2011)-*Scale-adjusted metrics of scientific collaboration*
[135](Iglič, Doreian, Kronegger, & Ferligoj, 2017)-*With whom do researchers collaborate and why?*
[136](Zuo & Zhao, 2018)-*The more multidisciplinary the better?–The prevalence and interdisciplinarity of research collaborations in multidisciplinary institutions*

the names of the countries. We extracted these names using the PyCountries library which contains a list of names of countries. When extracting this from the column, care was taken not to merge the results of individual rows as maintaining the integrity of the paper metadata entries was critical to mapping individual collaboration networks per paper. This was done by making sure that the algorithm added a separator which allowed our extraction to tell the difference between different entries in a row and different rows.

After this reduction process we had a list of countries. Papers with multiple Authors had multiple columns. We then created a list of pairs of connections[137]. The rationale for pair generation was that this would help the visualization of the connections much easier, while not negatively impacting the structure of the network. At the bottom of this was an assumption behind mutual collaboration networks. We assumed that the relationship between A and B is as strong as the relationship between B and C. While this cannot be justified in general, it is a simplification that we must make nonetheless, because we do not have any statistical weights that can help us draw such connections regarding mutual pairs. After the pairs were successfully extracted, various visualisation tools were employed to help develop a visual feel for the data. First we needed to attach the name of each country to a given coordinate of latitudes and longitudes. We did this using Nominatim. A python library called GCMapper was used to develop a plot of the paths between two country pairs, computing the paths using the section of a Great Circle. Second, we employed Matplotlib together with Basemap to create the background of the map and to add more flexibility. Lastly, the library Networkx was used to further visualise the network as an abstract structure. From this we were able to pull out South Africa's network of collaborations

We now proceed to do quantitative and qualitative analyses of the networks generated by the algorithm for both cases.

[137]This was implemented with Itertools, a Python algorithm which performs the mapping:

$$(A, B, C) \to (A, B)(A, C)(B, C)$$

Without double counting, i.e without generating (B,A)(C,A)(C,B) as independent pairs.

Figure 3.11: SKA Map of 239 connections with background

From the map above, it is clear that the SKA collaboration network is a “young” network. From our database, we can see that papers having to do with the SKA date back to the year 2000. This is around the time the SKA became an active topic in the astronomy community, after signing of the Memorandum of Agreement in this year [138]. The project is still under active development, therefore we have only began to see the outputs of the project. However, it can be seen that the SKA relies on global collaboration networks. Despite the fact that African countries have began showing interest in radio astronomy and the SKA, the network is still centred on Europe. There are some reasons for the centering of the network on Europe.

First is a claim that much of radio astronomy research is centred in Europe. The continent has developed considerable infrastructure through the European VLBI Network

[138] The History of the *SKA*-https://www.skatelescope.org/history-of-the-skaproject/ obtained from the SKA website, obtained on 29th April, 2020.

(EVN) under the structure of JIVE, as earlier discussed. This dates back to the pioneering work of Bernard Lovell in the 1970s and 80s, who sought to build a VLBI network[139]. Europe has thus seen significant long term development in radio astronomy. This is despite significant investments by the United States in the field. Nobody can deny that Europe pioneered research in radio astronomy. However ultimately if South African and Kenyan policy makers wish to make it a tool for cultural and economic change, this should mirror in metrics that place Africa in a more central role. The network will thus be consistently monitored to see whether this evolution will take place.

Second is the fact that the headquarters of the organisation are in the United Kingdom. This is partially due to historical reasons, as the idea of the telescope was initially developed and built upon in the United Kingdom. There are also symbolic reasons for this, as Lovell built, and worked in the Jodrell Bank Observatory, which is where the SKA headquarters are located.

It is also interesting to note that some of the collaborations come from the United States and South America region, who have no direct official involvement in the project. The only African country which is visible in the network is South Africa, whose investment in the SKA we have discussed. It is interesting to note that South African collaborations are mostly with Europe, and not with Australia, where a portion of the project is under development, or with other African countries, including the SKA partner countries. This can be argued to be a manifestation of the notion of preferential attachment, developed by Barabasi and Albert [140].

This however is only a qualitative assessment and we will verify this in the larger radio astronomy dataset.We can understand this attachment using the sociological effect variously described as the "rich get richer" effect or the Mathew Effect. This is where nodes in a social network, say an economic system have the tendency to attach themselves to more central nodes in the network. This has the effect of further reinforcing the centrality of the these already strong nodes. This can also be seen

[139](Saward, 1984)-*Bernard Lovell. A biography*

[140](Barabási & Albert, 1999)-*Emergence of scaling in random networks*

as the sociological phenomenon of path dependency. We can understand this is as seeing the network holistically. The present state of the of the network depends on the previous state of the network. That is, the network is evolving deterministically, or pseudo-deterministically.

In our case, we have traced out from primary and secondary documents, that the United Kingdom and Europe have been central to the development of Radio Astronomy. This ranges from the pioneering work of Jansky to the establishment of radio astronomy as a study under Lovell and the eventual collaboration with continental Europe. As South Africa began joining the radio astronomy network, it attached itself to this "European" node. We can see from our map that Europe considered collectively is still the strongest node in the network.

Apart from the network-theoretic understanding of the phenomenon, we can understand this attachment using political, cultural and diplomatic connections between South Africa and Europe. Specifically between the country and the United Kingdom and Netherlands, with whom it has strong cultural ties.

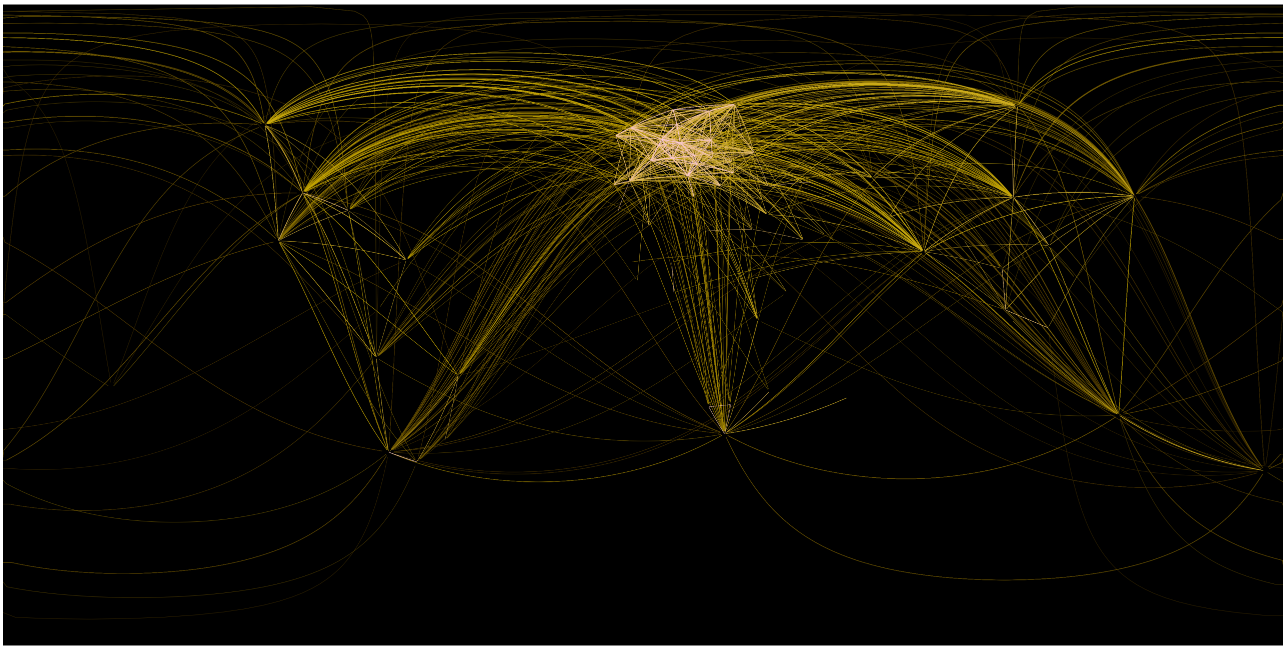

Figure 3.12: 9,476 collaboration connections extracted from the 5000 paper Data Set. Search Term: SKA

Figure 3.13: The connections plotted with global map as background

By inspection, we can see that radio astronomy has a much richer and well developed network. Our search was able to return 5000 paper metadata which was used to map this network. The claim that Europe is the centre of radio astronomy research, despite the United States' significant investments in the area, has been verified. It seems that Europe's strength lies in her mutual collaboration patterns. The cross collaboration patterns are significantly dense, resulting in Europe being the centre of the "radio astronomy network". It is also important to note that it is Western European countries that are central to the network, with Eastern European countries playing a peripheral part in the network. We hypothesize that the reason for this is the lack of significant and sustained involvement of the Eastern European countries in European radio astronomy projects.

There are several countries with strong attachment to the European core. The United states is a world hegemony in scientific production and collaboration[141]. The nation commands significant resources in the field of radio astronomy and is helping run massive collaboration projects in this field. This includes ALMA in Chile[142]. These facilities are maintained through NRAO. This also explains collaborative links between

[141] (Basu, 2014)-*The Albuquerque model and efficiency indicators in national scientific production with respect to manpower and funding in science*

[142] (Wootten, 2003)-*The Atacama large millimeter array (ALMA)*

the United States and South America, though these links are not as strong as those with Western Europe.

As discussed China has seen a significant upsurge in its scientific and technological capacity in the last three decades. It is now regarded as one of the most productive nations in the world, in terms of scientific and technological output. China has recently began heavy investments in pure scientific research as we have discussed, including investments in radio astronomy. This has resulted in the construction of FAST and maintains a deep space network. This is an array of radio dishes meant to assist in Deep Space communications[143]. China is also a member state of the SKA contributing to technological production for the international project. Australia has had a long history with radio astronomy. The country had put in a competitive bid to host the SKA project. It was decided that the SKA will be implemented on a split site basis, resulting in Australia holding the LOFAR part of the project, while South Africa would host the mid range array[144]. Australia maintains a central position in the project. The country is a contributing member state.

We can also note a connection between New Zealand and Australia. However, new Zealand while having an active astronomy community, has decided to leave the SKA project. The circumstances of this exit are unclear and are mired in controversy, as covered by local New Zealand media[145].

India has had a long cultural association with production of astronomical and mathematical knowledge[146], which she has sought to leverage as she positions herself to becoming a world scientific contributor. India is one of the member states of the SKA

Here we can verify the Barabasi- Albert behaviour of the network. South Africa's collaboration network with Europe is much more pronounced than her collaboration networks with any African country. While this may be sociologically surprising-("I

[143](Dong, Xu, Li, & Zhou, 2017)-*Initial result of the Chinese Deep Space Stations' coordinates from Chinese domestic VLBI experiments*

[144]The History of the *SKA*-https://www.skatelescope.org/history-of-the-skaproject/ obtained from the SKA website, obtained on 29th April, 2020.

[145]See for example the Newsroom article *Smears and fury in big telescope lobbying* -https://www.newsroom.co.nz/2019/04/15/531143/smears-and-fury-in-big-telescope-lobbying

[146](Seife, 2000)-*Zero: The biography of a dangerous idea*, *Chapter* 3, *Page* 20

am my neighbour's keeper")- it is not surprising once one considers the nature of the network. It has been demonstrated severally that scientific networks exhibit the behaviour of growth, and preferential attachment. This is true in many other types of social networks [147]. We will verify this phenomenon in the radio astronomy network and then try outline the socio-historical reasons for this behaviour.

We are interested in the structure of the network. We want to understand whether it satisfies Barabasi-Albert conditions. The conditions are two: growth, and preferential attachment. Specifically, we will test for preferential attachment since it is the most amenable to our analysis. Preferential attachment is a phenomenon in social network analysis in which nodes of a network tend to attach themselves to nodes with more pre-existing attachments. This has been shown to manifest itself in bibliometric analysis [148]. It has also emerged in other social networks, such as the world-wide web[149] We tested this by checking that the network satisfies exponential decay. Mathematically, this can be expressed by the relation[150]:

$$P(k) = k^{-\alpha}$$

Where:

P is the statistical measure being investigated. In our case it is the number of connections.

k is an independent variable. In our case it will just be a counting number starting from the country with the largest amount of connections to the one with the lowest.

α is a constant. It is negated to show that exponential decay.

In our context, this law means that there will be a few countries with a large number of collaborations, and a large number of countries with a few collaborations. This is a manifestation of preferential attachment; new nodes in the network prefer to attach themselves to highly connected nodes, i.e nodes with high centrality. This results in an unequal distribution of "resources" in the network. This effect has been called the

[147](Barabási & Albert, 1999)-*Evolution of the social network of scientific collaborations*
[148](Price, 1976)-*A general theory of bibliometric and other cumulative advantage processes*
[149](Barabási & Albert, 1999)-*Emergence of scaling in random networks*
[150](Barabási & Albert, 1999)-*Emergence of scaling in random networks*

Mathew Effect or the "rich get richer" phenomenon. This has been demonstrated in citation and collaboration networks in science[151].

To test this we need to load the collaboration data into Networkx, which has been designed specifically for the analysis of networks. We are interested in knowing the strength of connections for each node, i.e their degree. We used an inbuilt function to generate this. We then loaded the data into a Pandas dataframe. Quick plot of the data frame showed exponential decay.

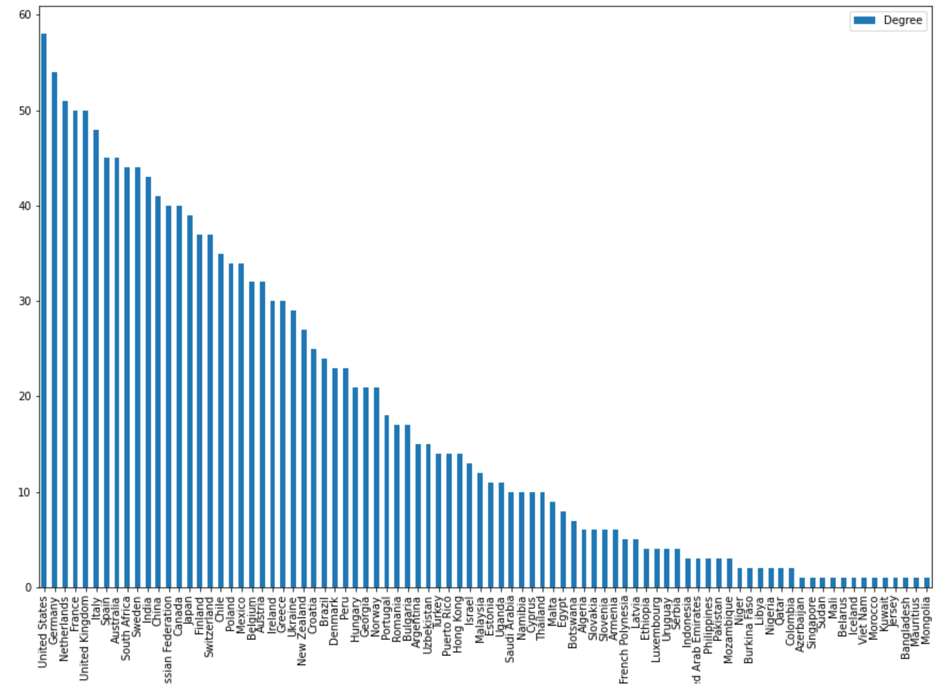

Figure 3.14: Bar graph of the number of connections a country has with another country

The decay can be seen clearly. The United States, United Kingdom, and France share a majority of the collaboration network. Like all social networks, the radio astronomy collaboration network has manifest inequality. This verifies the Barabasi-Albert network, at least qualitatively.

We want to find out the most important nodes in the radio astronomy network. We do this by computing the centrality of a node. We will compute this using the Eigenvector

[151] (Wagner & Leydesdorff, 2005)-*Network structure, self-organization, and the growth of international collaboration in science*

centrality of nodes in the network.[152]

Networkx has an inbuilt function that allows us to automatically generate the centrality of each node in the network. We performed the computation using this inbuilt function and plotted the centralities:

We show the first twenty data sets in the table in the next page.

Country	Degree
Germany	0.205660
United States	0.204705
Netherlands	0.197671
Italy	0.193120
France	0.191921
United Kingdom	0.191653
Spain′	0.190059
Australia	0.185714
Sweden′	0.184953
India	0.180446
South Africa	0.179925
Japan	0.177246
Russian Federation	0.176887
Finland	0.175227
China	0.174802
Canada	0.174578
Switzerland	0.168346
Chile	0.164470
Poland	0.161955
Mexico	0.161617

Table 1: Table of Eigenvector Centralities of the top 20 countries

We notice that from the data the most important node in the network is Germany,

[152]The eigenvector centrality is given by the relation[153]:

$$x_i = \frac{1}{\lambda} \sum_{j \neq i, \in N} a_{ij} x_j \tag{3.1}$$

Where: x_i is the centrality of node i,
λ is a scalar usually known as the eigenvalue,
$\sum_{j \neq i, \in N}$ denotes that we sum over all other nodes of the network. We avoid repetition hence $i \neq j$ where nodes j and i belong to the network N,
a_{ij} are elements of a matrix known as the adjacency matrix,
x_j is the centrality of node j. It may seem jarring that the that the centrality of one node is defined in relation to another node. This reflects the fact that networks are relational structures. In other words, most of the properties of a node relevant to a network are defined in terms of other nodes in the same network.

followed by the United States. Out of the top 10 countries, 7 are Western European. This quantitatively demonstrates that Western Europe is central to the network. Thus the network is concentrated in Europe. The only other non-European countries in the list are India and Australia.

The next five countries show better global distribution. The next five countries. are South Africa, Japan, Russia Federation, Finland and China. They have centrality ranging from 0.174802 to 0.179925. The centrality statistics show the same general trend of inequality.

3.4 Discusssion

After conducting our data analysis we can see that Kenya is not as productive as South Africa or Ghana. We however found one collaboration link that is relevant to Kenya[154]. So while Kenya is not as productive as South Africa, Kenya has some activity in the field. We can compare this with Kenya's connections with other countries. We do this for agricultural research.

Figure 3.15: Kenya's agricultural collaboration network

[154](Rotich Kipnoo et al., 2017)-*Simultaneous signal amplification and clock distribution employing backward Raman pump over an optical fiber for applications such as square kilometer array*

We see that the country has developed good networks in the field. This means that the country has sufficient investments in the field of agricultural research and thus maintains activity in these fields. This is largely because of historical reasons. Kenya was, and still is, an agricultural economy. The country has thus aligned its research priorities to the improvement of agriculture.

Apart from the priority attached to agricultural science we have discussed the fact that space science is a scheduled science in the Kenya Science Technology and Innovation act of 2013 and the National Science Policy framework of 2008. However, this does not measure in the radio astronomy measures we have isolated. However, Kenya maintains activity in remote sensing, with strong relationships with Italy and Japan in space science and satellite technology[155].

This measures in the space science and remote sensing output of the country. Kenya is the top 10 most collaborative countries in remote sensing. The author has normalised the citation links for GDP which they call the "efficiency"[156].

However, Kenya has little active research in radio astronomy science and engineering. There are capacity building programmes currently going on in the country. The Government of Kenya supports an average of 9 students per year in their studies of Astronomy and Astrophysics in the University of Nairobi. International programmes such as the Development of Africa with Radio Astronomy(DARA)[157]. Thus, it is still early days for radio astronomy research in the country. There are expected developments, in the building of the node of the SKA country. The production of the country will be measured during and after the development of these projects.

In the case of South Africa, the country has sufficiently well developed radio astronomy network, which we are interested in. We began by using NetworkX to extract South Africa's radio astronomy collaboration network from the wider global collaboration network. The network we extracted is shown below:

[155]See for example, (Mbuthia & Ouma, 2016) *First Kenyan University Nano Satellite-Precursor Flight project1KUNS-PF*

[156](Biljecki, 2016)-*A scientometric analysis of selected GIScience journals*

[157](Pović et al., 2018)-*Development in astronomy and space science in Africa*

Country	Number of Collaborations
United States	50
Netherlands	49
United Kingdom	47
Australia	41
Germany	40
France	39
Sweden	31
Italy	25
India	21
Spain	18
Canada	17

Table 2: South Africa top 10 connections

Figure 3.16: South Africa's collaboration network in radio astronomy

We can immediately see that the country has a diverse network of collaborations, with countries across all continents, we show the country's top and bottom 10 collaborators in tabular form: From our sample size, South Africa seems to have significantly strong collaborations with the United States and Western Europe. The United States tops the collaboration table a manifestation of the well documented phenomenon of the scientific hegemony of the country, as we have discussed[158]. This manifests itself

[158](Basu, 2014)-*The Albuquerque model and efficiency indicators in national scientific production with respect to manpower and funding in science*

Country	Number of Collaborations
Malta	1
Botswana	1
Uganda	1
Cyprus	1
Estonia	1
Romania	1
Puerto Rico	1
Georgia	1
Greece	1
Hong Kong	1
Iceland	1
Armenia	1

Table 3: South Africa's bottom 10 Connections

in radio astronomy too, as can be seen here. However, the next five links are all from Western Europe, accounting for 74 % of all collaboration links. The countries all have significant ties with radio astronomy: The Netherlands is the headquarters of the Joint European VLBI Network. The United Kingdom is the headquarters of the SKA project. It also has an intricate history with radio astronomy, with the pioneering work of Lovell. Australia is the co-host of the SKA project, alongside South Africa and the African partner states. Germany, through the Max Planck Institute for Astrophysics, and other institutions, has a strong research base in the field, it is a member of the European VLBI network. Germany is a member of the SKA. France is also a member of the SKA and a member of the European VLBI network.

One feature of the collaboration network is also apparent, this is the weak collaboration links with other African countries, seen by the table above. The total number of collaborations with other African countries is 9 which is $\approx$ 2% of the total number of collaborations South Africa has. There are two ways of explaining this, which we will generally class as quantitative and qualitative. We begin with the quantitative

Quantitatively, we have confirmed that the radio astronomy collaboration network matches Barabasi-Albert behaviour[159]. We have confirmed this for both the degree of connectivity for individual countries and for the eigenvector centrality of the countries.

[159](Barabási & Albert, 1999)-*The Emergence of Scaling in Random Networks*

We discussed how these networks display preferential attachment, the fact that new nodes in the network will prioritize the formation of links with more central nodes compared to less central ones. As such it is expected that South Africa's strongest connections will be with the European Research Area[160], The United States, and Australia. The existence of these links is the manifestation of this phenomenon.

This can be understood as the direct result of policies put in place by the Post Apartheid Mandela government. First was to seek engagement with the world as opposed to the autarkic apartheid regime. Second was to place the country in a strong technological and scientific position. To achieve the latter, the former was necessary. Thus from a qualitative reading which will be done in detail in the next chapter, we can infer that it was in the interest of South Africa to build scientific links with Europe and then serve as a link to which other African countries could attach to the radio astronomy network.

As we have discussed, the strongest explanatory power we can develop for the actions of South Africa and Kenya is the National Innovation System(Technoscientific Networks). This model, built on the basis of social networks explains South Africa and Kenya as a node in a social network of international collaboration in radio astronomy. There isn't enough data for us to properly come into strong conclusions about Kenya's nascent activities in radio astronomy network. However, we can see that the behavior of South Africa can be modelled effectively by the technoscientific network picture. First South Africa can be seen as a node of an international network as evidenced by our map. It has a centrality typical of agents in a social network. It also exhibits preferential attachment, which contributes to the overall path dependency of the network. Qualitatively, from our reading of policy documents from South Africa and Kenya lends credence to the fact that the policy drafters of these documents saw the scientific systems in their countries as technoscientific networks.

A simple sociological account for preferential attachment especially in collaboration networks is money and prestige. South African Academics have a better chance at

[160] As defined by (Archambault et al., 2011)-*Scale-adjusted metrics of scientific collaboration*

professional development when collaborating with a European researcher than an African one. Collaboration with European academics increases the chances of access to funding for conferences, postgraduate research and other research related activities. Thus given the choice, a rational actor would attach themselves to the European research area. From the point of view of social network analysis, a new node joining a network maximises its chances of remaining a stable member of the network by attaching itself to the strongest node of the network.

Qualitatively, South Africa has sought to place herself in a position of global competitiveness in terms of research in radio astronomy and other field. South Africa currently attracts global research talent in the field[161]. From these ambitions, it is clear that the country prioritized the formation of links with internationally research competitive countries as opposed to other African countries.This can be understood as the direct result of policies put in place by the Post Apartheid Mandela government. First was to seek engagement with the world as opposed to the autarkic apartheid regime. Second was to place the country in a strong technological and scientific position. To achieve the latter, the former was necessary. Thus from a qualitative reading which will be done in detail in the next chapter, we can infer that it was in the interest of South Africa to build scientific links with Europe and then serve as a link to which other African countries could attach to the radio astronomy network.

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[161](Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media*

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There is also an issue of temporal disparity. Our investigation of the stage of development of radio astronomy in Kenya and South Africa show that there is significant disparity in the stages of development of radio astronomy in the two countries. This is replicated by the productivity of the two countries, measured in our earlier production data. Kenya and other African partner countries are behind the South African developmental stage in the field. We have seen that Kenya has sophisticated collaboration networks in other fields of research, for example in remote sensing and agriculture. She however has no research capability in radio astronomy, although interventions have been put in place to address this through DARA and other national government interventions. A look at other African partner countries shows that they are at similar stages of development[162].

3.5 Conclusion

We have traced the development of radio astronomy in Kenya and South Africa using scientometric methods. We began with the measuring of the general scientific development of the two countries within the context of the wider African continent. We established the scientific dominance of South Africa in the sciences.

Moving on to radio astronomy, we were able to measure the dominance of South Africa in the field. We have seen how the country can be understood as one of the main contributors to the global radio astronomy output. This can be seen through productivity numbers and the collaboration networks in radio astronomy.

In the next chapter, we will see how the country has positioned itself as a globally relevant player in radio astronomy. We will also see how South Africa is building collaboration networks in the continent.

[162](Pović et al., 2018)-*Development in astronomy and space science in Africa*

4 Chapter 4: Radio Astronomy Diplomacy and Emergent Issues

4.1 Science Diplomacy in African Radio Astronomy

We have now studied global and African collaboration networks in radio astronomy. This development has been also explored in the national production statistics in radio astronomy publications. The scientometric measures for radio astronomy were contextualised within general science publication statistics for the two countries, situated within those of Africa. We can now have a look at the structures which have underlined the new developments in the field, concentrating our efforts on the African continent and specifically on Kenya and South Africa. We will study this using two lenses.

One lens is the aspect of science diplomacy. We will study the development of collaboration networks between the two countries and with the rest of the SKA African partner states. We will use official SKA press- releases, government policy documents, university websites, Parliamentary records of proceedings to trace the connections of the two countries to each other and the world.

Another is the frame of Science Policy. Here, we will use the documents named above to trace the policies these governments have adopted in response to the development of radio astronomy in their national policy alignments. We will trace the connection between the international conditions and processes which drove these governments to change, create, or modify policy to better position them for international developments in astronomy. In the case of Kenya, it will also be useful to trace some of her connections with Italy as the primary sources are well documented and are in public record.

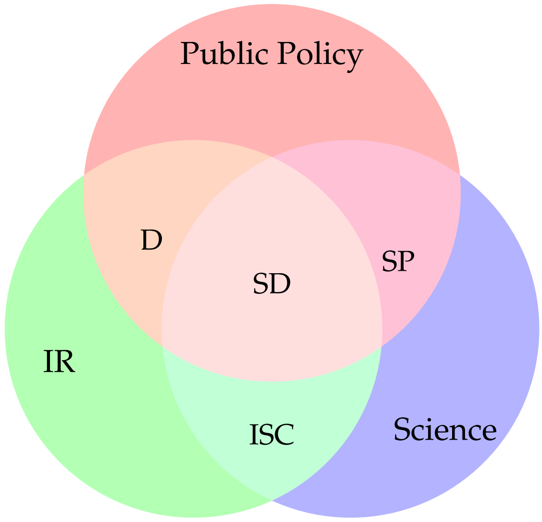

Figure 4.1: Venn Diagram of the Intersection of Public Policy, International Relations (IR) and Science. Science Diplomacy (SD) encompasses all three of these aspects. The interaction between public policy with science and international relations are best understood under Science Poicy(SP) and Diplomacy(D) respectively. Unstructured International Scientific Collaborations (ISC) exists at the interface of international relations and science

From the work described in chapter three, it can be concluded that South Africa has secured a strong position in radio astronomy not just locally, but also globally. South Africa has done this systematically and deliberately, positioning herself as central to African technoscientific progress[163]. This chapter further confirms the dominance of South Africa and studies the policy interventions that South Africa developed in connection with the world. This is specifically for radio astronomy, especially in the SKA. Thus Kenya like most African countries, is attached to the international radio astronomy node through South Africa. These relations can be traced quantitatively, through the methods explored in the previous chapter. We begin by exploring the evolution of various ministerial conferences that have been held between 2006 and 2019.

The SKA Africa meetings have been held annually from 2006. The first ministerial meeting of the African partner countries of the SKA was held in 2014 [164]. This was

[163](Pandor, 2012)-*South African science diplomacy: Fostering global partnerships and advancing the African agenda*

[164]Obtained from https://cordis.europa.eu/article/id/137828-outcomes-of-the-

the outcome of a process initiated by South Africa in approaching African partner countries for cooperation in hosting the SKA project. The hope was that South Africa and the partner countries would place a competitive bid comparable to the bids of Australia together with New Zealand, and of other competitors like China. After the successful edging out of other competitors, there was a split site decision made with South Africa and African partner countries sharing the hosting of the project with Australia[165].

The talks were held in response to this positive outcome in 2006. The main objective was to finalise discussions on policies and strategies which the countries held to prepare the African host countries for hosting and benefiting from the project. The major points of discussion were discussed in the meeting were included in the press release and are discussed below.

A priority objective discussed was "Meeting all the minimum regulatory and legal requirements for the successful construction and operation of the AVN and SKA telescopes."[166] The building of the core Phase I project in South Africa and the arms in the SKA partner countries required certain policies to protect and also alleviate any logistical challenges that were met in the implementation. For example, South Africa enacted the Astronomy Geographic Advantage Act [167], meant to protect an astronomy research area from technological, economic or social interference. Also , South Africa suspended import duty on astronomy related research tools. Kenya had before then developed astronomy and Space science as a scheduled science in the Science Technology and Innovation Act [168]. There was a need for "developing a vibrant community of researchers and scientists to undertake radio astronomy studies across Africa". Before focusing on how collaboration took place, it is important to underscore that both the and Kenya administration committed through the project

first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

165(Cherry, 2012)-*Square Kilometre Array decision bodes well for South Africa*

166Obtained from https://cordis.europa.eu/article/id/137828-outcomes -of-the-first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

167(A. G. A. Government Act, 2007)-*Astronomy Geographic Advantage Act*

168(S. T. I. Government Act, 2013)-*Science Technology and Innovation Act*

to a massive investment in providing trained personnel.
In the initial leaked report in which the committee of experts recommended the building of the entire project in South Africa, one of the main challenges which was pointed out was the lack of enough trained human capital in the continent [169]. This was a significant challenge in two ways.
The lifetime of the SKA is 50 years. It was not going to be tenable for the project to keep importing expat labour in order for it to run in the continent.
There was a need to avoid the "Chile Configuration". Chile has sophisticated research base in astronomy. It has been referred to by various parties as the "Astronomy Capital" of the world. However, Barandrian has argued that the presence of these astronomical tools has had little or no socioeconomic impact on the country[170]. This is because the telescopes are largely operated by international consortia. In some cases, Chile is a member of the consortia as the host country. However, the telescopes are largely operated by international expats. The development of local expertise in the technical and scientific aspects has been given little or no priority. Chile has not capitalized from a science diplomacy perspective either. Barandrian documents how the needs of the local scientific community have been subsumed to foreign scientific interests.
It was important to resolve this challenge because South Africa had invested money in building the precursor arrays, and was going to invest further in the development of the telescope. There was need to develop local expertise in the country and in the continent to benefit from the project.
The SKA South Africa office instituted a human capital development office which trained 136 students as of 2018 [171]. The Kenya Government instituted a publicly subsidised Astronomy and Astrophysics research programmes in 2010[172]. The third point of discussion was "Developing a pool of engineers, technicians and people with other associated skills to support the design, construction, operation and maintenance of

[169] (Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media*
[170] (Barandiaran, 2015)-*Reaching for the stars? Astronomy and growth in Chile*
[171] from University News-https://www.universityworldnews.com/post.php?story=20181101135238811. Obtained on 6thJune, 2020
[172] From University of Nairobi Website-https://sps.uonbi.ac.ke/admission-content-type/bsc-astronomy-and-astrophy

radio astronomy telescopes and related platforms."[173]

As depicted by local media in South Africa, the SKA is seen first and foremost as technological infrastructure rather than scientific [174]. As discussed in the introduction, the SKA poses significant technological challenges especially in the question of data storage and transfer[175]. It thus needs a human support infrastructure of engineers and technicians to keep the scientific superstructure operational. While both Kenya and South Africa have invested in the public education of engineers and technicians for decades, the interministerial conference recognised that there was a need for further investment in relevant fields to further accentuate the project.

The Government of Kenya had been significantly subsidising the education of engineers and technicians by paying 80% of the fees since its independence in 1963 [176]. South Africa also undertook the development of scholarships. In the first and second chapter, we have discussed how the strength of technoscientific networks are strengthened by exchanges of information and people. This is the basis for both these governments investing finances in the education of personnel who would then build, improve and permeate these technoscientific networks. Both countries have chosen to thus subsidised the education their students. Thus, this explains the policy decisions taken by these governments.

An important factor to the development of a locally beneficial radio astronomy facilities was the "Building (of) institutional capacity in universities, research institutions and government departments that promote the development of radio astronomy programmes and initiatives."[177]

It was recognised that to achieve the second and third objectives, there was a need to develop capacity "at the source". This meant training PhD and Master students who

[173]Obtained from https://cordis.europa.eu/article/id/137828-outcomes -of-the-first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

[174](Gastrow, 2015)-The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media, pg 90

[175](Jones, 2010)-*Technology challenges for the square kilometer array*

[176](Oketch, 2003)-*Affording the unaffordable: Cost sharing in higher education in sub-Saharan Africa*

[177]Obtained from https://cordis.europa.eu/article/id/137828-outcomes-of-the -first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

could go back to their respective universities as staff and to help develop capacity in the various countries. Through mutual collaboration, South Africa has been able to train various specialists in radio astronomy and in related fields. SKA in collaboration with DARA, runs short training programmes in data science[178].

Kenya herself has developed the Astronomy and Astrophysics program in the University of Nairobi. Similar programmes are being developed in the Technical University of Kenya and Kenyatta University. All these programmes are or will be publicly subsidised.

There was a discussion on financing the project. This was done under "Mobilising and leveraging both the funding and technical resources needed to realise Africa's vision for radio astronomy"[179]. The SKA and the related AVN project are resource intensive projects, and this was recognised by the SKA African countries. South Africa had already invested heavily into the project and continues to do so[180]. SKA countries had agreed to donate land, contribute in terms of education subsidies in the case of Kenya.

Another objective was "Facilitating strategic partnerships and collaborative efforts, both regionally and globally."[181]. All this was done in response to the development of the SKA, which was an international project. Ties between the SKA African partner countries and the member states of the SKA international organisation were to be strengthened in this regard. Seven out of the eight African partner countries are Commonwealth countries. This can be understood as the use of diplomacy for science [182] where pre-established diplomatic structures are used for scientific objectives. The ministers made observation of positive progress that had been made in the achieving of the named objectives. These are summarised below: Since the placing of the bid by South Africa in the early 2000s, there had been annual meetings held by bureaucrats

[178]Square Kilometre Array Big Data Africa Summer School 2017-https://www.sarao.ac.za/students/big-data-africa-summer-school/?s=, Obtained 76*th* June, 2020

[179]Obtained from https://cordis.europa.eu/article/id/137828-outcomes-of-the-first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

[180](Gastrow & Oppelt, 2019)-*The Square Kilometre Array and Local Development Mandates in the Karoo*

[181]Obtained from https://cordis.europa.eu/article/id/137828-outcomes-of-the-first-ministerial-meeting-of-the-square-kilometre-array-african-partner-count/pl on 6th June, 2020

[182](Grimes & McNulty, 2016)-*The Newton Fund: Science and innovation for development and diplomacy*

and academics from South Africa and the African partner countries. The hope was to help develop and sustain a strong African bid which was to compete with the strongest bid, placed by Australia and New Zealand. The contest between the two bids is an interesting example in which science and politics mixed, as is explored by Gastrow [183].

When it was leaked that the recommendations panel had settled on South Africa and the African partner countries, there was a rise in Afro-pessimist sentiment in Australian technocratic and bureaucratic circles. Sharkdam Wapmuk and Oluwatooni Akinkwotu define Afro-pessimists as " those who have completely lost hope in the continent", and on the other end Afro-Optimists, " those who hope for a better future for Africa"[184]. There are two important points to add here, Afro-pessimist and Afro-optimist camps draw their conclusions from the current state of the continent. For example, earlier in global SKA conferences, there was significant "talking down" to Africa's infrastructural and human capacity in science. The second point is that given the current life expectancy of the SKA project (50 years), the position that the African host countries of the SKA will remain stable for the next 50 years is Afro-optimist. The reverse position can be thought of as Afro-pessimist. The response of the South African party was to stay above the muddy political waters and to position the nation and the continent as technically capable and scalable.

The meetings were held to present a coherent African position with regards to the SKA project, and also with regards to other radio astronomy projects in the field. Agency must be ascribed to South Africa in this regard. It is South Africa, using existing diplomatic structures in the African Union and in the Commonwealth, who approached the prospective African countries for participation in the SKA project [185]. The meetings held from 2006 were a direct result of this.

The Inter-Ministerial conference congratulated South Africa for significant investments

[183] (Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media*

[184] (Wapmuk & Akinkwotu, 2017)-*The Dynamics of Africa in World Affairs: from Afro-pessimism to Afro-optimism?*

[185] (Pandor, 2012)-*South African science diplomacy: Fostering global partnerships and advancing the African agenda*

made by South Africa in two areas: Infrastructure development and Human capital development. South Africa had just finished completion of the completion of MeerKAT, a 64 dish extension of Karoo Array Telescope (KAT)[186]. These, as discussed in the introduction, are precursor telescopes to the SKA. The dish was constructed in the Northern Cape province, near Canarvon in South Africa. The inter-ministerial conference noted progress made in this regard.

The interministerial government noted progress made in the international funding for the project. The member states of the SKA project had contributed a total of 107 million pounds to the development of the project. The money was meant to carry out activities for the pre-construction phase of the SKA project. The funding commitments of 120 million Euros by the international SKA Member Countries for the pre-construction phase of the SKA project – currently underway – to finalise the detailed design and specifications of the project. The recent funding announcement by the United Kingdom (UK) science minister of 100 million pounds for the first phase of the SKA project, whose construction has been cost-capped at around 500 million pounds.

The achievements of the AVN project, particularly the work being undertaken on the conversion of the 32-metre dish in Kuntunse, Ghana were noted. A team of seven trainees from the Ghana Space Science and Technology Institute have been on a six-month training programme in South Africa since October 2013 [187]. The funding support of R120 million to the AVN project by the African Renaissance Fund of the Department of International Relations and Cooperation in South Africa complemented by an additional R20 million from the Department of Science and Technology.

The Sixth Ministerial Meeting of the African partner countries of the SKA was held in 2019 [188]. The press release documents followed the same format as other press release documents. We can notice a change in the attendance of the meeting. The meetings have transitioned from the high level inter-ministerial meeting to lower

[186](Goedhart, 2019)-*Early Science with MeerKAT*

[187](Asabere, Gaylard, Horellou, Winkler, & Jarrett, 2015)-*Radio astronomy in Africa: the case of Ghana*

[188]Joint media statement on the outcomes of the 6th SKA Africa partner countries Meeting-https://www.dst.gov.za/index.php/media-room/latest-news/2933-joint-media-statement-on-the-outcomes-of-the-6th-ska-africa-partner-countries-meeting , Obtained on 10^{th} June, 2020

level. However, the attendees of the meeting are still senior officials of various bureaucracies in their respective governments. This may denote a normalisation of affairs in the running of the SKA project in the continent.

The aim of the meeting was to review progress made and to suggest new initiatives. First, the activities of United Kingdom and South Africa were noted with regards to the human capital development. With support from the Newton Fund [189], DARA and DARA Big Data have been able to fund basic and advanced training for hundreds of students in and out of the continent. The SKA in conjunction with DARA big data, runs annual training workshops and hackathons in support of the development initiatives in South Africa and in the African partner countries.

The attendants of the meeting agreed that SKA, DARA and DARA Big Data teams would explore opportunities in the employment and internship positions for trained students in the programmes.

Other initiatives were noted specifically in the development of capacity for radio astronomy in the African partner countries. These include two dish interferometry and co-location.

This involves the development of small and affordable interferometer dishes for pedagogical purposes[190]. This is useful for outreach and training purposes. Funding for the project would be supplied by the SKA South Africa DARA projects. In the case of radio astronomy, the co-location of deep space receivers and data processing centres might be particularly helpful[191]. The panel noted that this might be helpful in terms of cost sharing. The holder of the site, which is typically the research institution, could generate revenue from this. Progress was noted in this, in which a pilot colocation project is underway in the Ghana Radio Astronomy Observatory (GRAO).

Other objectives which were discussed were the strengthening of relevant institutional capacities, the formulation of new academic programmes around physics and astronomy, and the roll-out of high-performance computing capability and big data training

[189](Grimes & McNulty, 2016)-*The Newton Fund: Science and innovation for development and diplomacy*

[190](Parthasarathy et al., 1998)-*A rooftop radio observatory: An undergraduate telescope system at the University of California at Berkeley*

[191](Michel, Roesch, & Long, 2005)-*Hartebeesthoek co-location survey*

interventions.
Computing and big data received particular attention in the meeting of 2019. As the world evolves into a period where making sense of large data sets quickly and efficiently is critical, it becomes important for Africa to have capability and capacity in this regard. The representatives paid attention to progress made.
First was the Centre for High Performance Computing (CHPC)[192] which has been instrumental in the setting up of computational resources in South Africa and around the continent. It has also developed capacity in the field in partnership with the SKA. Other African partner countries have access to CHPC resources.
The representatives agreed that the CHPC would explore the possibility of formalising training in the field of Big Data to build suitable structures in the field to hopefully build local capacity in this area. Formalisation could possibly take the form of courses and degrees from universities in the African partner countries of the SKA. The conference also agreed that to encourage collaboration, there would be CHPC research groups in the continent could hold a workshop to bring together the various research groups in the continent.
The financial commitment to the SKA project comes from public funds from the republic of South Africa. It is thus a necessity that the various astronomy institutions are engaged with radio astronomy in the continent engage with the public. This is not out only out of a "good heart", out of benevolence. It serves two purposes [193]: Accountability, and the growing and maintaining public support for the SKA and related astronomy projects.
As a branch of physics, astronomy relies almost on public support for its growth and development. Radio astronomy relies, especially today, on the building of expensive infrastructure which cannot be completed without the intervention of central governments (often -as in the case of SKA- in a collaborative framework)'. The support of the local communities in which the telescopes are embedded is critical to the progress and

[192](Gazendam, Eksteen, & Jones, 2007)-*On the establishment of infrastructure for the South African national Centre for High Performance Computing*
[193](Chapman, Catala, Mauduit, Govender, & Louw-Potgieter, 2015)-*Monitoring and evaluating astronomy outreach programmes: Challenges and solutions*

sustainability of the project. A stark example of this is the Mauna Kea observatory in Hawaii.
Years of neglect for the concern of the community has led to hostile relations between the local community and the astronomy community in the island. The presence of astronomy in the island is seen as a hold over of mainland American imperialism. This is typified as a lack of regard for local culture and practices, which has led to a degeneration of relationship between the two communities[194].
The crisis came to ahead in 2019 with month long protests against the construction of the Thirty meter telescope in the island[195]. According to the SKA South Africa office, community engagement is a priority. It has carried out community development projects in the area and engaged stake holders in outreach events stating: " At these events a strong SKA presence will be facilitated and information will be informally distributed. The main aim of these activities will be to establish trust and engrain the SKA as part of the community"[196].
Still, there are parties in the local community who object to the presence of the SKA in the community, leveling economic, social and environmental concerns. These will be explored in the next section The ministers also noted that progress had been made nationally in the SKA member countries. The committee noted the development of the co-location study being explored in the GRAO in Kuntunse, Ghana. They noted that the telescope itself was running nominally since its launch in 2017[197].

[194](Naylor, 2017)-textitMauna Kea–Construction Site or Sacred Land? A Look at the Long-lasting Effects of the Hawaiian Annexation
[195](Crane, 2019)-*Telescope Protests*
[196]*The Square Kilometre Array Integrated Environmental Management Plan*, page 229, retrieved from https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP on 10/05/2020
[197](Asabere et al., 2015)-*Radio astronomy in Africa: the case of Ghana*

Figure 4.2: Ghana Radio Astronomy Observatory from researchgate.net

Kenya was still in talks with telecommunication companies in the country for the hand over of two satellite dishes in Longonot. Although this was not mentioned in the report, it seems that progress on this end has been slow. The talks were initiated in 2006 as is reflected in the first inter-ministerial conference in 2014. 5 years later, no progress seems to have been made in this regard.

In the same period, Kenya has made significant strides in other aspects of space science and astronomy, with government support. The lack of progress in this regard is thus anomalous.

However, there have been private interventions by Kenyatta University in the country. The university runs a scaled down demonstration of interferometers in the physics department. This is for demonstration purposes [198]. Kenya's investment in radio astronomy has been less focused on one large-scale project and funding instead a variety of smaller endevours some of which can be seen as complementing the SKA. Another example of a complementary project was being undertaken in Zambia. The

[198]http://ku.ac.ke/schools/spas/index.php/component/content/article/89-faculty/11-dr-nadir-omar-hashim.

government of Zambia was in negotiations for the relocation of a mast at Mwembeshi, near Lusaka at the Southern part of the country. Madagascar is in the final stages of completion of the refurbishment of their radio astronomy project. The observatory's bureaucratic structure has been formed. Rooms to provide accommodation to the various scientists and engineers is almost complete.

Mauritius has an African scholarship scheme, which she has been running since 2015. Radio astronomy has been embedded in the scholarship scheme and African students in radio astronomy are currently in training in Mauritius. Mozambique is in partnership with Portugal in running a programmes analogous to DARA. Apart from radio astronomy, it runs other projects in Big Data and Earth Observations. Namibia and Botswana had also made progress in the field and in astronomy in general. Namibia had laid policy groundwork for Space science. There were also discussions ongoing for the construction of the Africa Milimetre Telescope(AMT)[199]. Botswana had also made progress in policy and was then appointing a project manager for the AVN project.

South Africa was noted for her continued running of the MeerKAT telescope. It had already began producing science results. It had produced the clearest image of the centre of the galaxy to date [200].

4.2 Interpretation and Emergent Issues

We have now given a description of the collaboration structures of radio astronomy in the continent. We can now look at these structures from the point of view of networks. We can also expound on the radio astronomy relationships between South Africa and Kenya in the context of diplomatic history. Just like the fact that there has to be a science for there to be science for diplomacy, there has to be a diplomacy for there to be a "diplomacy for science". This necessitates our discussion of the diplomacy context of these scientific relations between Kenya and South Africa. We will also

[199](Backes et al., 2017)-*The African Millimetre Telescope*

[200]https://apod.nasa.gov/apod/ap190708.html

look at the at the mutual assistance between South Africa and Ghana, which has been particularly productive for the two. From the point of view of science diplomacy, there are certain features from the developments highlighted above which can be inferred.

As far as the radio astronomy network is concerned, South Africa is the most important node in Africa. All the meetings mentioned above happened in South Africa. South Africa as we have demonstrated in chapter three, is highly productive in the field of radio astronomy. We measured this productivity through the number of papers published by researchers in South Africa and by the links South Africa has with the international radio astronomy network.

South Africa is the only African Member state of the SKA[201]. This means that South Africa is the only African country directly contributing finances to the construction of SKA. South Africa's intelligentsia and polity have over the last two decades directed national spending and policy towards the development of science and technology capacity in the country[202].

As such, South Africa has systematically strengthened its already strong position with regard to the scientific production of the African continent. It then used this strong position to seek partnerships with other African member states in the bidding for the SKA. In the spirit of "many hands make light work", South Africa approached and successfully established agreements with other African partner countries. It used already established diplomatic structures in the African Union and the Commonwealth to achieve its objectives [203]. This can be regarded as a case of "diplomacy for science"[204]. Significant ideological underpinnings of the scientists and bureaucrats who participated in this bid can be understood from Gastrow[205]. They sought to portray the present of the continent rather than the past, the capabilities of the continent rather than

[201] Retreived from https://www.skatelescope.org/

[202] As we have discussed from (Department of Arts & Technology, 1996) and (of Science & Technology, 2018)

[203] (Pandor, 2012)-*South African science diplomacy: Fostering global partnerships and advancing the African agenda*

[204] (Society, 2010)-*New frontiers in science diplomacy: Navigating the changing balance of power*

[205] (Gastrow, 2015)-*The stars in our eyes: representations of the Square Kilometre Array telescope in the South African media*

the incapacities, the successes of the continent rather than the failures, and the hope rather than the despair. In other words, they were "Afro-optimists".

We have seen the long path of association with astronomy in South Africa. From a long cultural association with the night sky dating thousands of years, and the development of the Cape Town observatory in the period of the British Empire [206].

We have also seen how the post Apartheid regime was keen to use astronomy as part of its tools for projecting the image of a new and modern South Africa. It is this work that has culminated in the relative strength of the position of South Africa in radio astronomy.

However, not everyone in the international SKA community, especially Australia, bought this narrative. There were significant attacks on the capability of the continent to run such sophisticated equipment with the view of learning such arcane science. These attacks were leveled on the continent by Australian media and polity. The official strategy of the South African bureaucrats and scientists was not to respond to mud-slinging, a thing uncharacteristic of African politicians:

> South Africans took the higher ground. We were in close communication with the government and the minister, and she actually gave us a clear indication that it was not South Africa's job to respond to the mud-slinging coming from Australia.
>
> ... I am glad that sanity prevailed and that we didn't release any public statement attacking Australia in any way.
>
> SKA Manager, Interviewed by Michael Gastrow(pg 124)

South Africa's policy of "sticking to the facts" and staying above muddy ideological waters, paid off.

South Africa has since then actively engaged with the rest of the continent in a bid to actively develop radio astronomy. The most productive relationship has been with Ghana, resulting in the construction of the Ghana Radio Astronomy Observatory in

[206](Dubow, 2019)-*200 Years of Astronomy in South Africa: From the Royal Observatory to the 'Big Bang'of the Square Kilometre Array*

Kuntunse, Ghana [207]. Ghana and South Africa have had strong diplomatic ties since the relationships built by the ANC with the Government of post independent Ghana during the Apartheid Regime [208]. These relationships were further strengthened by the ANC government and were relied upon by South Africa when developing a scientific partnership with Ghana in radio astronomy. We have already explored how science is critical to South Africa post-apartheid regime in terms of re-opening international relations and collaborations.

The decision by the SKA to have South Africa and the African partner countries to host most of the SKA phase I and II facilities led to the high level decision by South Africa to assist in the conversion of the telecommunication dish in Kuntunse into a radio astronomy facility. This was successfully conducted and resulted in the launching of the Ghana radio astronomy facility in 2017. The launch was presided over by the Ghanaian President, Nana Akufo-Addo.

Figure 4.3: The President of the Republic Of Ghana launching GRAO. Beside him is Naledi Pandor, the then South African Minister of Science and Technology from Graphic.com

We have studied the development of radio astronomy in the Republics of South Africa and Kenya. We have considered in the context of the political economy of the two countries, outlined in the first chapter. We have measured the development of the

[207](Asabere et al., 2015)-*Radio astronomy in Africa: the case of Ghana*
[208](Ahlman, 2011)-*Road to Ghana: Nkrumah, Southern Africa and the eclipse of a decolonizing Africa*

field in the two countries in terms of scientometrics. We have used scientometrics and social network analysis in measuring the production and collaborations of the two countries in the context of global and continental development of the two fields. We have seen that South Africa has an accelerated development in the field, being the most productive in the continent. Kenya has a small research group in the country. Both countries are seeing a rise in radio astronomy and astronomy related activities. These developments are not without their associated challenges or risks. These risks and challenges can be classified in two ways, exogenous and endogenous risks.
In this work, we have surrendered the notion that the development of radio astronomy can be considered in isolation to the context of its development. This is the reason we began by considering the socioeconomic developments of the two states. Thus exogenous and endogenous factors can feed into each other, producing non-linear risk factors to and from the project. We study these risk factors here in attempt to understand their context, implications for the project, and possible amelioration policies to these projects.
Land is a sensitive socioeconomic issue both for South Africa[209] and Kenya[210]. Most of Sub Saharan countries still associate a significant amount of their economic output to agricultural produce. This means that the more the amount of land one has, the greater the chances of socio-economic production, and hence of advantage[211]. In both these countries, there are significant economic inequalities which arise from inequities in land distribution. Both countries have a fraught history with land alienation by immigrant European populations, coupled with inefficient and corrupt schemes for the redress of historical injustices. This has led to spasms of violence in both countries, with the most pronounced occurring in Kenya in 2007/2008[212].
In South Africa, the inequality is further exacerbated by the fact that the distribution of land and wealth is on the basis of a racial divide[213]. While there exists poor and

[209](Moyo, 2007)-*The land question in southern Africa: a comparative review*
[210](Boone, 2012)-*Land conflict and distributive politics in Kenya*
[211](Moyo, 2007)-*The land question in southern africa: a comparative review.*
[212](Bicknell, 2010)-*The meaning of violence: a journey of understanding through the Rift Valley of Kenya*
[213](Moyo, 2007)-*The land question in southern Africa: a comparative review*

landless whites and wealthy and landed black elite, the owners of productive land in South Africa are overwhelmingly white, while the poor and landless are overwhelmingly black.

This situation has become a tinderbox of politics and policy in the country. The initial policy of the ANC was to allow exchange on the basis of a free market. This was coupled to a economic scheme of black economic empowerment. The hope was that as black South Africans accumulate resources, they would be able to buy productive land in the country. While there have been successes in the redress of injustices, this process has been slow, and in the view of Tangri and Southall[214] and Andrews[215], has further exacerbated the levels of inequality in the country.

The lack of progress in this regard has led to the formation of leftist organisations in the country. Chief among this is the Economic Freedom Fighters [216]. It was formed from a group of ANC-Youth League members who were expelled from the party. The group proposed the expropriation of land without compensation. This forced the centre-left ANC to shift further to the left to support expropriation of land without compensation. The EFF has developed into a sophisticated political party, enjoying broad based support among the young black South Africans in the country. However, the ANC still maintains a dominating control of the country. This domination however, is in decline. The second most popular party is the Democratic Alliance. This is a centre-right party. This sets the context for the presence of the SKA in the country, and the implications this holds for land use in the country. The implications are both positive and negative, as will be seen.

The SKA Integrated Environmental Management Plan (IEMP) states that SARAO has access to around 600,000 hectares of land in the Northern Cape province of South Africa[217]. This is organised in three layers according to the Astronomy Geographic Advantage act[218]. The first is the core astronomy area. This is the area where the

[214](Tangri & Southall, 2008)-*The politics of black economic empowerment in South Africa*
[215](Andrews, 2008)-*Is black economic empowerment a South African growth catalyst?(Or could it be...)*
[216](Mbete, 2015)-*The Economic Freedom Fighters-South Africa's turn towards populism?*
[217]Retrieved from SKA South Africa website-https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP-Chapter-0.pdf
[218](A. G. A. Government Act, 2007)-*Astronomy Geographic Advantage No. 21 of 2007*

telescopes are located, or will be located. The area is protected because of the telescope. Secondly is the Central Astronomy Area. This area is protected to ensure the protection of the core Third is the Coordinated Astronomy Area. This is a further buffer zone added for protection. By protection, we mean the placing of restrictions on technological and economic development in the area. These include restrictions from light pollution, aircraft communication and radio interference.

The region in the Northern Cape is mostly arid or semi-arid. It is not heavily populated, with a population of around 1.26 Million, compared to the Western Cape, with a population of 6.8 Million[219]. The economic activities in the region consist mostly of sheep farming[220]. The SKA IEMP was conducted to assess the effect of the construction and operation of the instruments on the area, in accordance with South Africa's laws and regulations. Several impact assessments were carried out, including biodiversity studies, environmental impact assessments, socioeconomic structures within the land, and impact on the people's livelihoods near and within the area of operation of the telescope.

We will present a summary of the findings and to compare them with the position taken by *Save The Karoo*, a group that opposes the construction of the SKA in the region.

There were two general impact assessment studies made in the region. Studies were carried out to assess the presence of species resident in the region. This includes invasive and noninvasive species of both flora and fauna. There are two biomes in the region, the Nama-Karoo biome, and the Azonal Vegetation Biome.[221] They have a few resident wild animals including the black jack jackals and caracals. For the case of vegetation, there are a few species native to the region such as the African Sheepbrush, and the Large Bushman Grass.

All of the vegetation in the region was found to be of least threatened status. However,

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[219](South, n.d.)-*Africa: Statistical release P0302 Mid-year estimates*

[220](Chinigò, 2019)-*From the 'Merino Revolution'to the 'Astronomy Revolution': Land Alienation and Identity in Carnarvon, South Africa*

[221]*The Square Kilometre Array Integrated Environmental Management Plan*, page 229, retrieved from https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP on 10/05/2020

there were endangered species native to the Area, including the Black Harrier, Martial Eagle and the Kori Bustard. Some risk factors were pointed out in the construction of the array. These activities include the development of hardened surfaces such as roads, concrete surfaces. These could complicate or hamper the motion of wild animals in the area. The clearance of vegetation which the wild herbivores depend on could place vegetative stress on the area. This being said, it may not be possible to know the extent of this stress. Because of construction activities, there might be a change of drainage patterns in rainy seasons. These among other factors, were identified as possible threats which may arise from construction of the array in the region.

However it was also pointed out that there might be salutary effects from the construction of the telescope array in the region. There is evidence that the local sheep farming activities of resident of the region has put stress on the vegetation. This has in turn led to a reduction of population of the region. It is thus hoped that the sealing off of the area under consideration will lead to a recovery of the vegetation and to the recovery of the population of endangered species in the region[222] .

Economic Impact assessments were carried out in the towns surrounding the area of study. Most of the economic activities are carried in agricultural and tourism towns of Carnarvon, Brandvlei, Copperton among others. The impact assessment developed a classification scheme of these towns on the basis of their closeness and effects from the SKA.

Carnarvon was classified as a hub town. This is the town most closely associated to the SKA in the region. The SKA has made direct social and economic investments in the region. These include investing in education and training. The organisation has developed modern computer laboratories in the region and invested in the training of artisans and technicians in the region. Carnarvon has seen significant positive change since the beginning of the presence of the SKA in the region.

[222] *The Square Kilometre Array Integrated Environmental Management Plan*, page 229, retrieved from https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP on 10/05/2020

Figure 4.4: SKA computer lab in the Northern Cape from the South African Agency for Science and Technology Advancement

Second classification was thematically related towns. These include Sutherland, which is the host of the South African Large Telescope Array. They may benefit from science tourism in South Africa. Third were gateway towns. These are towns which can take advantage of the presence of the SKA in South Africa by building on trade and investments in the region. The last category are threatened towns. These are towns facing economic downturn due to the presence of the SKA in the region. This is mostly due to the requirement of non-interference when carrying out radio astronomy activities. This places restrictions on the communication capacity in the region.
Save the Karoo[223] is a minority group in the Karoo region of the Northern Cape who oppose the building of the SKA core in the Karoo. It mostly consists of farmers who are resident near and in the proposed site for the construction of the SKA. In the preamble of their website they state that:

> Many South Africans have been keen and excited about the radio astronomy, Square Kilometer Array (SKA) project. SKA marketing strategies and the SKA website present a convincing and impressive picture of SKA South Africa. There is no need to argue the scientific merits of the project.
>
> The 'other side' of the project is less convincing. It is the socioeconomic impact and the Ecocide which will affect communities and the environment due to SKA phase 1, and the later phase 2.

[223]See their website https://savethekaroo.com/ retreived on 10/06/2020

They object to the presence and development of the SKA on the basis of a series of ecological and socioeconomic arguments. These arguments are partially supported by the environmental impact assessment, and the environmental management plan. Their objections to the project are many and varied. We discuss some of them below. The group states that there will be stresses on the water resources of the region. The construction phase of the SKA will need water from nearby sources. The group states that the daily amount of water needed during the construction of the SKA will be around 10 to 20 times the amount needed for daily agricultural activities in the region. This, they argue, places significant stresses on the water resources of the Karoo [224].
The group points out that the restrictions implied by the Astronomy Geographic Advantage Area act includes the airspace above the Karoo. It is argued that a rerouting of flights to and fro Cape Town might be needed, which they argue might carry cost and carbon footprint implications. They also point out some farms in the region have airstrips, and this may lead to restrictions on these farms.
The group argues that the introduction and enforcement of the radio quiet zone has implications for the ability of the population to have effective communication. This is in concurrence with the IEMP[225] report which identifies that certain towns within the core area are at risk of decline. Communication mitigation measures have been introduced by the SKA South Africa office. This include the introduction of special mobile devices and a subsidised VSAT network. They dismiss this as a " A 'souped-up' walkie-talkie with a vastly limited sms function and without internet connection... "[226]

Save the Karoo disagrees with the estimated loss that was calculated for the presence of the SKA in the region[227]. The estimated contraction in the region is 31 million Rands, with 15 million Rands ascribed to direct agricultural loss, and 16 million Rands

[224] *The Square Kilometre Array Integrated Environmental Management Plan*, page 229, retrieved from https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP on 10/05/2020
[225] *The Square Kilometre Array Integrated Environmental Management Plan*, page 229, retrieved from https://www.sarao.ac.za/wp-content/uploads/2019/03/SKA-IEMP on 10/05/2020
[226] website https://savethekaroo.com/ retreived on 10/06/2020
[227] (Kirsten, 2016)-*An estimation of the agricultural economic and local economic impact of phase 1 of the SKA*

from the processing industry. They estimate the annual loss to be at 20 to 30 million Rands. They also argue that this will result in an estimated loss of 263 million Rands to the South African economy. No models are provided for either of these estimates. Other social impacts include possible impacts on the culture of the region which may suffer significant emigration because of the lack of opportunities. While recognising that the SKA has brought some benefits to the region, they point out that these benefits: "seem to be aimed at uplifting Carnarvon's community rather than providing sustainable economic growth over the next half-a-century or more".[228]

The group states that the construction of the SKA in the region will lead to disturbance of the top soil. This will accelerate the desertification of the Karoo, possibly leading to an ecological crisis. The IEMP agrees that erosion is one possible negative impact from the construction of the SKA. However, the IEMP has proposed mitigation measures. It has also proposed the continuous monitoring of the region for any signs of erosion.

The group argues that the wild animals have developed a symbiotic relationship with the farms in the region. They depend on the farm boreholes in the region for their water supply. Save the Karoo states that it has been the practice of the SKA to close up boreholes in farms which they have acquired. They argue that this will lead to animal dehydration and death.

The group ends their objections to the presence of the SKA by asking for clarity on the environmental management plan ensuring that it satisfies the Environmental Management Act. They further ask for consistency with international law, suggesting that the presence of the SKA is a violation of their rights. They then claim that some concerns by the public were not answered, reiterating their position on the communication technology.

Other concerns were noted in the external response to the IEMP by parties other than the group[229]. There were points of concern raised by De Waal. These were mostly to do with predator control in the region. The parties asked for clarity regarding

[228]website https://savethekaroo.com/ retreived on 10/06/2020

[229]Comments and Responses Trail for the public review of the Draft Integrated Environmental Management Plan(IEMP) -https://www.sarao.ac.za/wp-content/uploads/2019/03/Appendix-B-External-Comments-Responses-Trail-of-the-IEMP.pdf

the fences to be put up in the area, protecting the local farmers from the recovering predator population from the park. Officially, the region in which the SKA is to be located is a public park run by the South African National Parks service. Thus, the recovery of the region as a wildlife park may lead to the return of a significant predator population in the area. These concerns were responded to in the meeting with the SKA. These concerns were also shared by Agri-SA an agricultural lobby group in South Africa. De Waal states that

> It is widely perceived that the Furthermore the – SKA Project is the "invader" in a traditional sheep farming community, therefore having good neighbourly relations should have been a very high priority...

On the whole, it seems clear that while some take for granted the benefits to be derived to South Africa from an investment in radio astronomy, others (Karoo, etc) see it as problematic in light of their potential to exacerbate already existing inequalities in the distribution of land.

We can understand the developments of contestations over land as a tension or break down over social contracts between principal-agent relations. If we understand the government of the republic of South Africa as an agent of the public, we argue that in the opinion of Save the Karoo, the government of South Africa has neglected its duties in the interest of international scientific collaboration. From the point of view of government, it is the principal and the SKA organisation in the country is the agent. We can see that the government is building a social contract between the SKA and the public it represents. The Government is, and will, give out land and resources to the SKA which should, in principle, provide educational and technological development to the country. The SKA portrays itself primarily as a technological and educational facility addressing a need that the country, and the continent at large is prioritising. This can be seen in Gastrow.

We can also understand these tensions using the Colebatch picture. We have attempted, in this short excursion to trace government engagement with the public and with the SKA. These can be seen as a series of horizontal and vertical communications between various government agencies and the public. These can be understood as a series of horizontal communications encouraged vertically by government. The government is then seen responding to organic pressure from the public and to more organised action from pressure groups. This has however not yet led to a change of policy by the government. As this is an evolving situation, the impact of these horizontal and vertical communication flows as the SKA is built and commissioned.

If we integrate the nascent radio astronomy network into the wider social network of the nation, we can understand the tension over land as a contestation over resources from different fragments of a network . This can be understood as an instability of the network, which can lead to significant further fragmentation. This will be manifested possibly as a civil strife and tensions within the regions. Tensions over resources are baked into the very nature of social networks. For example, we have seen how the distribution of collaborators is unevenly matched in the network. However, when there is an active struggle between two nodes or fragments in the network could cause signigicant fragmentation in the network.

We must also consider the role played by land in South Africa and Kenya. This plays into the notion of path dependency. Land is a constraint on the scientific technological and educational development which the government and the SKA Organisation promises the two republics. Land plays an important economic, cultural and political role in societies from both Kenya and South Africa. The government of South Africa seems to have taken this into consideration in the planning of the Integrated Environmental Management Plan and in subsequent consultations with the public and the farmers in the horizontal flows we have discussed. This is however not to the satisfaction of some parties, for example 'Save the Karoo'.

Kenya, by contrast, has played a peripheral role in the radio astronomy network, yielding control to the financial, bureaucratic and technical muscle of South Africa. Relationships between Kenya and Post Apartheid South Africa have been historically frosty [230]. Kenya was perceived as not participating in the struggle for freedom in

[230] See "Zuma awakens a dormant relationship with Kenya" by Peter Fabricius for a summary of the difficult relations between Kenya and South Africa. Retreived from

South Africa [231]. There were a system of Sub-Saharan organisations who had the aim of dismantling the Apartheid State. Kenya stepped back from any direct engagement with liberation movements in South Africa. While the ANC under Mandela was arguing for the non-recognition of the South African apartheid state, Kenya hosted the then president Frederik Willem De Klerk. Mandela would later come to avoid engagement with Kenya. The reason for this as documented by Phathutshedzo Mabude is on the account of the then President Moi's dictatorial regime.

After the retirement of both Mandela and Moi, there was active engagement by their successors, Thabo Mbeki and Mwai Kibaki. The two attempted to repair relations and enhance trade between the two countries. This was described by Mabuda as a qualified success. There was an attempted reset of relations by the South African president Jacob Zuma. The current president of Kenya has established good relationships with the country.

We cannot speculate whether the historically difficult relationships between Kenya and South Africa has been the main obstacle to the development of radio astronomy in Kenya. In fact, it seems to be the case that the causes for the relative retardation of the development of radio astronomy in the country is the result of local actors rather than continental or global actors. This is because Kenya has quite sophisticated scientific relationships with other countries in other aspects of astronomy research. Examples include cooperation with Italy in the building and running of the Broglio Space Center[232]. The Broglio Space Center is a series of platforms and telemetry centers at the Kenyan Coast. It consists of the now defunct San Marco launch platform together with two other launch platforms in the area. The main telemetry centre is located at the coast and is still in operation

Recently there has been cooperation with the Japanese Space Agency (JAXA) and the United Nations Office for Outer Space Affairs (UNOOSA) in the building of 1KUNS[233]. 1KUNS stands for the First Kenya University Nanosatellite. This shows that Kenya

https://issafrica.org/iss-today/zuma-awakens-a-dormant-relationship-with-kenya on 12/06/2020

[231](Mabude, 2008)-*South Africa's foreign relations towards Kenya: the political and economic dynamics*

[232](De Maria, Pigliacelli, & Orlando, 2003)-*Italy in Space*

[233](Mbuthia & Ouma, 2016)-

maintains interest in other aspects of astronomy and space science.
Kenyan polity has been historically reluctant in the accepting of large science projects. Since her independence, the country has had to deliberate all of her major international agreements through the parliament, since it is a parliamentary democracy. This means that the members of parliament can ask any question of the executive, unless this carries security implications for the state. Thus at several points in the history of the country we can trace out the relations between executive and legislative arms of government. For example, there were tensions on the occasion of the set of deliberations leading to the construction of the San Marco Project.
The executive arm seems particularly keen on collaboration with the West. The legislative arm seems skeptical, at times even derisive of international scientific agreements which the executive is party to. We used the Kenya Hansard to trace these relations from 1963 to the present. A desktop search for public records related to San Marco was carried out. The activities of the Italian Space Programme in Kenya has been studied, and problematised by Siddiqi [234]. Siddiqi traces the development of the project while attempting to see this from as many frames as possible. He makes the argument that the San Marco project was a scientific success in the framing of the Italians and Americans while also tracing the interactions between local Kenyan government and the local communities which are hosting the project. Siddiqi shows from this perspective the project may not be unqualified success.
The earliest interaction we can trace by a desktop search is in 1973[235]. The Assistant Minister for Power and Communications introduced the San Marco Station in response to a question asked. After that there was set aside some time for further questions and deliberations. The Member of Parliament for Nyeri raised concerns about the specific benefits that the country was going to get from the project. The Member of Parliament was worried that the country would be swept away in the parapet of the international storm of the cold war. Instead, the member proposed the focusing on

[234] Asif Siddiqi, "Dispersed Sites: San Marco and the Launch From Kenya" in *How Knowledge Moves: Writing the Transnational History of Science and Technology* by John Krige
[235] (Assembly, 1973)-Kenya National Assembly Official Record(Hansard)

social problems on trying to "settle things on Earth". To which the assistant minister responded: "Mr. Speaker Sir, Kenya cannot be isolated from other countries. It must be a part of this world and we have to face it."

With a historical understanding of the period, we can construct a narrative from this exchange. The member of Parliament seems to be rejecting the then polarization of the world along the two Soviet and Western blocs. This is consistent with contemporary thought, coupled with the Government of Kenya's position. Much of the African continent was, and still is, party to the non aligned movement[236]. There is also a pragmatic bent, challenging the resources being put into space exploration. The Assistant minister's curt response is also pragmatically aligned in its diplomatic goals. While Kenya was officially non aligned, she aligned herself with the West. In fact, the debate over ideological alignments later evolved into an internal political crisis in the young country, as discussed in Chapter 2[237].

Other concerns, were raised in this session. Including whether there were Kenyans trained to benefit from the project. There were also concerns raised about the possibility of using satellites for spying instead of telecommunications. This was responded to by the assistant minister. He said that there were still studies going on, and Kenya would benefit later on. He said that there was no possibility that the satellites launched on the platform would be used for spying.

There was evolution in concerns from the legislative arm and in the response of the executive when the agreement was overdue for review in 2012[238]. Siddiqi discusses how Kenya had been elbowed out of participation and benefit from the project. This led to a change of the general attitude. Siddiqi states: "The Kenyan Government, once sympathetic to the San Marco project, has also begun to weigh in with censure." A reading of the source document shows a much more contested atmosphere within the Kenya government itself. The executive, which comprises of the president, various

[236](Shaw, 1989)-*The Non-Aligned Movement and the new international division of labour*

[237](Cullen, 2018)-*'Playing Cold War politics': the cold war in Anglo-Kenyan relations in the 1960s*

[238](Assembly, 2012)-*Kenya National Assembly Official Record(Hansard)* also cited in (Krige, 2019)-*How Knowledge Moves: Writing the Transnational History of Science and Technology*-Chapter 6-*Dispersed Sites: San Marco and the Launch From Kenya* by Asif Siddiqi

ministers and the armed forces, remained sympathetic to the project. The legislature, comprising of the members of parliament, had lost good faith with the project. It was the arm of government doing the censuring.

The members of parliament were more strident, skeptical and sarcastic in the framing of concerns against the research facility. We show below some of these concerns, which can be interpreted as attacks. An initial challenge was leveled on the finances of the project by the Member of parliament for Garsen. He was deeply suspicious of the government position that the project was not a profitable concern. He pointed out the cost of launching a rocket was US$ 100 million. He voiced intense frustration with the fact that the project only contributed 2.5 million dollars for community projects over 60 years. He urged that "this thing to be taken seriously by the Ministry of State of Defence."

The Member of Parliament for the then Gwassi constituency suggested that the review of the agreement should go through parliament:

> I would ask that the Assistant Minister assures to this House that this agreement before it is signed, because it ended in 2011, this Parliament will be involved in improving it. This country should not be committed to agreements whose effects on us and benefits to us we do not know.

There are two things of note here. First is the significant expansion of democratic space within the country[239]. This space allowed the members of Parliament to robustly challenge the executive. This includes particularly sensitive departments such as that of the Ministry of Defence.

Relevant to science diplomacy, there is movement away from the ideological considerations of the mid 20^{th} century to a much more neoliberal paradigms. The members of parliament insist on understanding of what benefit the agreement is to the state and the local community neighboring it. There is a suspicion towards financial considerations of the project.

This is an example of how Kenya's various arms of government respond to international

[239](Nyinguro & Otenyo, 2007)-*Social movements and democratic transitions in Kenya*

scientific projects. The robust input by the members of parliament led to an agreement which is more sensitive to the needs of Kenya and Kenya's communities [240]. We still do not have sufficient evidence to make conclusive claims about the executive position on SKA. We can however speculate that it may also be part of the explanation for the particularly slow response of the executive branch of the government to respond proactively to collaboration efforts in radio astronomy. Weary of the robust challenges introduced by members of parliament in an ever charged political atmosphere, the executive may be steering clear of flagship projects whose development mandate cannot be defended in a clear and simple manner. It seems that the executive is weighing an opportunity cost here and finding it difficult to defend invested interest in the project. Unlike South Africa, there is some skepticism within the executive about the foreign policy and economic advantages to be derived from big science projects.

How can we best understand these internal tensions within the Kenyan governmnent and its interaction and effect on Kenya's National Innovation System (NIS) ? In terms of the Colebatch model , we can see the new democratisation in Kenya as the levelling of the three arms of the Kenya government. This then caused a shift from vertical communication between the executive and the legislature to a more horizontal scheme. From a science policy perspective this means that there was a further constraint on the science system. The parliament can be seen as an internal pressuire group to which any international scientific collaborations in the country must be subjected to. If we understand the Parliamentarians as representing the public, the pressure group is actually external to the science policy system, which is a purvey of the executive. This can also be understood as a breakdown of the social contract between the principal and the agent. The Government of Kenya did not act to extract significant concessions from the Broglio Space Centre , the agent. As such, the government of Kenya which is the agent of the public can be interpreted to be violating its social contract with the public. Also, if we understand scientific agencies as implicitly coming into social

[240] See the full report of the revised agreement from:http://www.parliament.go.ke/sites/default/files/2019-07/REPORT %20OF%20THE%20DC%20DEFENCE%20ON%20THE%20AGREEMENT %20BETWEEN%20KENYA%20AND%20ITALY %20ON%20THE%20MALINDI%20SPACE%20CENTRE_compressed.pdf

contracts with the public by their very existence, we can infer that the social contract between the Italian Space Centre and the coastal public of Kenya had implicitly been violated. This informs the frustration apparent in the Hansard by the Members of Parliament. This also informs us of the more explicit social contract which was then accepted in Parliament later on.

We have earlier discussed how the executive was a strong node in the Kenya's technoscientific network. The pressures applied from Parliament could be understood as the development of a strong node in the network. This node can be seen as struggling for the distribution of resources within the network. This can be seen as overly bekneficial to the network since it strengthens links in the NIS, making it more stable. The resources are the concessions extracted from the Italian Government by the Governmenit of Kenya. These include scholarships, community development schemes and money payments to the Government. This is indicated in the new contract signed between the two governments. We can also infer that the Broglio Space centre was never really a part of Kenya's technoscientific network, it was a part of Italy's. Only with the renewal of the contract, has the space centre began integration into Kenya's NIS.

South Africa and Kenya have thus different approaches to the development of radio astronomy and astronomy in general. South Africa is at the forefront of radio astronomy development internationally, with astronomy deeply embedded into the structure of government policy. Although Kenya has space science as a priority area of development, it has preferred a much slower, deliberative process, mostly dependent on international partners. In radio astronomy, there has been very little government intervention to aid in the accelerated development of the field.

This may complicate international collaborations in the area. One country that has over the years tried to address these differences in approach and development is the United Kingdom. In the burgeoning radio astronomy network in the continent, the United Kingdom plays a central role. The United Kingdom has had a strong historical role to play in radio astronomy. This began with the pioneering work of Lovell as earlier discussed. There is evidence of Lovell and Jodrell Bank being having an interest in developing continental collaboration in radio astronomy[241]. This work began in the 1980s in the setting up of the European Consortium for VLBI which came to be known as the European VLBI network(EVN), headquartered in the Netherlands. The legacy of this work explains the centrality of Europe in the radio astronomy community, as seen in chapter 2.

The United Kingdom has also had a strong negative and positive presence in both South Africa and Kenya. Both countries were former colonies of the British Empire. South Africa regained her independence from the Empire in 1910 and slid into Apartheid. Kenya regained her independence in 1963, during the period of the dismantling of the British Empire. Both have retained membership in the Commonwealth of Nations. The United Kingdom is the headquarters of the SKA. Through the Newton Fund, the UK has developed and maintained strong ties with African countries, especially those of the commonwealth[242]. On the basis of these diplomatic structures, the United Kingdom has built scientific relationships with Kenya. [243] The United Kingdom thus maintains an active research and innovation interest in the country. The UK and Kenya have a research partnership called the Newton-Utafiti Fund[244]. The partnership provides funds for researchers from both countries to research questions that are of mutual benefit to both. These include: Food security, Sustainable and renewable energy, Health, Environment and climate change, Economic transition skills and jobs through manufacturing for SMEs, Governance, Conflict Resolution and Security, and other Cross cutting issues - including capacity building, big data, innovation and entrepreneurship.

The UK's partnership with South Africa is equally strong, if not stronger. It also runs the Newton research fund programme with the country [245]. The thematic concerns

[241] (Saward, 1984)-*Bernard Lovell. A biography*

[242] (Grimes & McNulty, 2016)-*The Newton Fund: Science and innovation for development and diplomacy*

[243] Retreived from the United Kingdom foreign office, "Kenya: Science and Innovation Network Snapshot " https://www.gov.uk/government/publications/kenya-science-and-innovation-network-snapshot on 15/06/2020

[244] See the Newton Utafiti fund page. Utafiti is Swahili for research. Retrieved from http://www.newtonfund.ac.uk/about/about-partner-countries/kenya/ on 15/06/2020

[245] Retreived from https://www.newtonfund.ac.uk/about/about-partner-countries/south-africa/ on15/06/2020

listed above are also included in the UK's partnership. Astronomy features as a priority area of concern in the UK and South Africa's scientific relations. This can be ascribed to the presence of the SKA in both countries. This is acknowledged by the Foreign and Commonwealth office [246].

The UK and South Africa seem to have developed close connections after the dismantling of Apartheid. This can be seen from the development of assistance programmes from the United Kingdom's Department for International Development (DFID). In the Apartheid state, the United Kingdom, specifically under Margaret Thatcher, adopted a "constructive engagement" approach towards South Africa. This is the strategy that instead of closing off relations with South Africa, an engagement would be had with the regime.

The engagement would be made in an attempt to push the South African Apartheid state towards democratization. This has come under significant criticism then[247].

After the dismantling of apartheid state, South Africa liberalised her economy and attracted development partners and donors. The DFID almost immediately began development programmes.

Because of this expansion and liberalisation of the South African Economy, the United Kingdom has moved away from seeing South Africa as a donor receiving state to a developmental partner. These diplomatic connections have led to the development of collaboration networks between the countries. South Africa is an anchor country for the UK's developmental, security and business activities in the continent. This could be the basis under which the UK's investments in South Africa could be much more than in Kenya.

We have been able to isolate these collaborations specifically in radio astronomy from our sample size of 5000 papers. South Africa's third most active collaborator is the United Kingdom. 65% of the South Africa's top 10 collaboration links are with European countries.

[246] From the Foreign Office, "UK Science and Innovation Network Country Snapshot – South Africa" https://www.gov.uk/government/publications/uk-science-and-innovation-network-country-snapshot-south-africa

[247] (Ungar & Vale, 1985)-*South Africa: why constructive engagement failed*

Thus, we can see that the United Kingdom plays a central role in the development of radio astronomy in the continent. Through direct partnerships with the individual countries the UK is building capacity in research. We have also verified that diplomacy for science has been productive for radio astronomy in South Africa.
An emergent issue that may require the attention of the United Kingdom and other SKA member states is the emergence of technologies which may be problematic for the development of the SKA is constellation satellites.

4.3 Conclusion

We have looked at the collaboration structures which have underwritten the development of radio astronomy in Kenya and South Africa. We have done this by a reading of the press releases of inter ministerial meetings, contextualised by external information.
We have then proceeded to analyse these developments from the point of view of actors in science diplomacy. Particularly instructive is the activity of Ghana and South Africa. We have also contextualised the slow development of Kenya within internal tensions between arms of government. We have also situated this development within the cool relations between South Africa and Kenya. We have also explored the importance of South Africa to the network and analysed the local consideration of land in South Africa.
In the next section we will conclude and summarise the work presented.

5 Conclusion

We have studied the development of radio astronomy in South Africa and Kenya. This has been done by using different methods including primary and secondary sources, data collection and analysis using algorithmic methods. We have also studied and contextualized the development of radio astronomy in the countries within the general socieconomic context of development of Africa, and of radio astronomy in the global context.

In Chapter 2, we have studied the social, economic and political development of the two countries. We have seen that the two countries underwent somewhat different political evolution. Kenya got her independence from the United Kingdom together with majority rule in 1963. South Africa on the other hand, got her independence in 1912 but only obtain majority rule in 1994. This difference determined the different political and social evolution of the two countries.

Self governance allowed Kenya to rapidly Africanise its academic and therefore scientific systems while South Africa retained a mostly white academia as an artifact of the policy of apartheid. The differential social development in South Africa had a negative effect on the National Innovation System (NIS) of the country. Kenya on the other hand followed the general trajectory of one party dictatorial rule, entrenching the development of a politically connected elite in the country. Although progress was made in the social Africanisation programmes in the country, rapid increases in population caused significant strains on local scientific programmes. This caused the retarded growth of Kenya's NIS.

The position was further worsened in the 1970s and 1980s when the country hit economic doldrums as the oil shocks and a bloated public service led to the World Bank and the International Monetary Fund to force the country into economic structural advancement programmes. From the data obtained, we have seen that South Africa on the other hand showed a bit more resilience to the economic oil shocks. This was partially because of a racially skewed economic system, which allowed the country to effectively drive down export prices by tightly controlling the wages of labourers. Essentially, the black population in the country could absorb the economic shocks. The local industries were also significantly subsidised and protected from international competition by government banking institutions.

However in the late 80s and early 90s, we see a marked change in the political configurations of the two countries. Analogies can be drawn in this time period. We saw that there was significant local, regional, continental and global push for the dismantling of Apartheid in South Africa. There was a change in political policy in South Africa as the then governing National Party attempted the orderly removal of apartheid structures in the country. This was in response to significant economic pressures leveled on the country by the West.

In Kenya, there was similar political development in which one party rule came under significant local and international challenge. International donors essentially dictated fiats to the government of Kenya, demanding a liberalisation of economic and political space in the country. This led to the removal of one party rule in the country and led to the collapse of the independence party in the country in 2002. South Africa conducted her first universal suffrage in 1994, leading to the election of Nelson Mandela of the African National Congress (ANC). The ANC formed a government of national unity with the National Party.

We have seen how the two governments took stock of their National innovation systems. There is a difference in development here too. South Africa did this through the development of a White Paper on science and technology in 1996, two years after the election.

From our reading of the white paper, we see that the government recognises the unique challenges it faced in restructuring the NIS because of apartheid. The academic sector of the NIS was skewed alongside racial and gender lines, which needed urgent attention. It was also primarily concerned with the propping up of a military industrial complex, with a security system comparable to those of Europe. It was misaligned to the social and economic needs of the new South African state. The National Innovation system was also underfunded.

The 1996 white Paper on science and technology proposed solutions to these problems.

Chief among them was a significant increase in public investment in R& D. Policies were also proposed to improve the enrollment of blacks in the country's universities. The hope here was that this would improve the racial skew in South Africa's research ecosystem.

Our reading of the White Paper also identifies a "non-utilitarian" bent of government science policy, almost unique amongst African governments in this period. The drafters of the White Paper were intensely interested in the maintenance and further development of flagship sciences or "blue skies research". They sought to escape the mentality of African governments typically concerned with the "clothing and feeding" of their population. We can thus see a strong aspirational bent to the white paper. We posit that this attitude sets the stage for significantly strong funding we see in astronomy and radio astronomy in particular in the country.

Kenya on the other hand developed an analogue to the White Paper in the National Science Policy Framework. This was done in 2011 as the country sought to restructure herself politically, economically and socially. The drafters of the policy framework identify certain challenges that Kenya's NIS faced. This primarily included an underfunded NIS, weak links with government which resulted weak regulation of the NIS. This also resulted in the development of poor relationships between academics and technocrats. The NIS also recognised that there was a gender imbalance in Academia. It also noted poor links with industry in the knowledge systems.

The drafters of the Policy Framework sought institutional redresses to these challenges. Funding was to be addressed through the National Research Fund (NRF). To ensure the presence of strong links between government and the NIS, the National Commission on Science, Technology and Innovation (NACOSTI) was constituted. It was to serve as an interface between the NIS and the government. It was to advise government on the needs of the NIS, while at the same time regulating the NIS. To prioritise innovation in the country, the Kenya National Innovation Agency (KENIA) was also constituted.

This set the context for the mapping of the development of radio astronomy in Kenya and South Africa in Chapter 3. We began by obtaining data regarding scientific productivity in Africa from worldmapper.org. The data sets obtained were the growth of numbers of papers published in 2015 with 2005 as a baseline. The second database was the number of papers published in 2016. We saw that South Africa dominates both production and growth in production. South Africa published upwards of 12000 papers in 2016. It also experienced a growth of 6000 papers between 2005 and 2015, a growth only compared to that of Egypt. Kenya, while not as dominant as South Africa, had a relatively decent improvement of between 500 to 1000 more papers published between 2005 and 2015. Most African countries saw either modest improvements, no improvements or in some extreme cases, a reduction in the number of papers published.

We then moved to the specific case of radio astronomy, and the SKA. The process of acquiring the data in this case was a bit more involved than the worldmapper database.

We acquired the data from the *Scopus* database using the *Scopus* API. The API was itself embedded in a wrapper called Pyscopus which helped in further simplification of the data acquisition process. We first ran a query of the search term "radio astronomy" and were able to obtain a result of 5000 papers. We then began the process of data reduction which allowed us to zero in on our interest, which was the country in which the authors publishing the papers lived. This would give us an indication of the national productivity of the countries.

After doing a statistical compilation using the Python library Pandas we piped the data to a visualisation algorithms to help us further understand the data. We followed the same process in the acquisition and representation of collaboration networks.

It is clear from our studies that South Africa is the hegemon of radio astronomy in the continent. It dominates scientific production in the field in Africa. It also plays a central role in the collaboration networks in the continent and the world. From our qualitative work on radio astronomy diplomacy, we have seen that the country drives radio astronomy development in the continent, in collaboration with the United Kingdom. The reasons, as we have seen, are historical and also contemporary. The investment in astronomy over centuries has led to a sustained build up in scholarly activity in the country. The new post-apartheid state has topped this off with massive investments in the field of radio astronomy. This has seen a massive expansion in scholarship in the field over the past ten years. The diagrams in chapter 3 show that South Africa is most productive in the field. It is one of the major nodes of the radio astronomy networks in the world.

Kenya is also active in the field of radio astronomy, though not as actively or powerfully as the South Africa. Kenya has built on its historically utilitarian policy to partner with international organisations and other nation states to build on space science capacities and capabilities which it deems more aligned to her developmental mandates. However it is also interested in radio astronomy, having instituted programmes in its public universities for this purpose. It is also an SKA African partner country.

For the final chapter, we concentrated our efforts on understanding the processes South Africa and Kenya have engaged in to develop astronomy and radio astronomy in their countries. We concentrated on qualitative aspects of the development, by following policy documents. This included various press statements summarising the outcomes of the meetings of the ministers of the African partner countries. A second class of document is various laws, an example of which is the astronomy Geographic Advantage Area Act. Proceedings of the Parliament of the Republic Kenya also served as source documents for the tracing out of the development of science diplomacy. We also used secondary documents to situate our understanding of these developments.

As can be inferred from the first three chapters, South Africa is aggressive in this regard. From our reading of the policy documents, the country is effectively underwriting the development of radio astronomy in the country and continent. It has organised and hosted the African partner meetings. From the reading, we noted several social, diplomatic and infrastructural developments in radio astronomy. On the social sphere, the country has invested heavily in human capital development. This is in the training of students, especially in postgraduate training. Training has also been carried out in technical fields, especially in the areas neighbouring the development of the SKA.

The South African government has also invested significant financial resources in the construction of SKA precursor instruments: KAT and MeerKAT. The diplomatic resources expended by South Africa to develop the SKA are also considerable.
The country joined the SKA as a member state. It also applied to be a host country. It successfully edged out competition to host the telescope, in concert with Australia.
It also approached the African partner countries for the co hosting of the telescope.
Together with the United Kingdom it has engaged in activities developing radio astronomy in the continent, especially in the SKA partner countries.
Kenya has in contrast taken a back seat to the development of radio astronomy in the continent. It has depended on its close relationship with the United Kingdom to develop most of its radio astronomy. It has however also made investments in the public education of scientists and engineers in the country. Our reading of proceedings of the National Assembly we can infer the science diplomacy prerogatives of the country. We have seen tensions between arms of government in their attitudes towards international scientific development.
In summary, because of historical and cultural reasons, militated by a strong economic and financial position, South Africa has developed as a powerhouse of radio astronomy.
It sees astronomy and radio astronomy as practical tools of socioeconomic development.
There are also diplomatic reasons for this. The country seems to be interested in projecting itself as a modern, technologically sophisticated state, not the usual trope of an African country "primarily concerned with feeding and clothing" itself.
Kenya has a much more restricted interaction with astronomy and radio astronomy.
This is partly because of the restricted financial muscle of the country. Kenya has however made targeted investments and depended on international partnerships primarily with South Africa and the United Kingdom. The country is also primarily invested with projecting itself as a rapidly industrialising state. It maintains interest in supporting astronomy and radio astronomy activities, although not as significantly as South Africa.
The rise of South Africa in radio astronomy has certain interesting implications. South

Africa is currently seen as the centre of astronomy and scientific development in the continent. For example, the International Astronomical Union has selected Cape Town to hold the International Astronomical Union General Assembly in 2024 [248].
The science diplomacy structures that have been built by the country in the continent and beyond have tended to emphasise on collaboration rather than competition.
South Africa has underwritten much of the structure, building active scientific relationships with the rest of the African partner countries. It is of interest to us that "Maghreb" Africa has little to no participation in the burgeoning collaboration network in Radio Astronomy. This is despite the relatively good numbers in scientific production. Especially in Egypt, Tunisia, Algeria and Morocco. Egypt stands out amongst these group of countries in the Maghreb. It is the third largest economy in the continent, third after Nigeria and South Africa. It was the second largest scientific producer after South Africa.
Of equal interest for further investigation in science diplomacy is the absence of Nigeria in the collaboration network. Nigeria is the largest economy in West Africa. It is the sixth largest scientific producer in the continent, and has a relatively sophisticated astronomy and space science ecosystem. SKA and South Africa have chosen to instead collaborate with Ghana. We speculate that this might be because Ghana is a more historically stable country.
The data and documents collected here have a constraint of volume and time. For example, for our scientometric work, we obtained a sample of 5000 papers for the case of radio astronomy. This is for the period between 2013 and 2020. This thus carries a limit on whatever long term trends we can draw on the data. The volume of the data also places limitations on permanent conclusions on the state and development of radio astronomy in the two countries.

[248] See the website of the organising committee: https://astronomy2024capetown.org/

5.1 Analysis

We have considered the theoretical frameworks of principal agent relations, National Innovation Systems and the horizontal and vertical policy model suggested by Colebatch. Which -model is most predictive of the developments in radio astronomy which we have described? To what extent are these models useful tools in understanding the development of radio astronomy in Kenya and South Africa? How can we best model this development?

Principal-agent relations helps us understand how deeply the technoscientific networks are dependent on government. In the case of Kenya where the national science policy framework was explicitly constructed to aid in in the technological development of the country, we have a technoscientific network which is aligned to supporting and enhancing innovation in the country. In the case of South Africa which takes a different view on the space and purpose of science, we have a much more cultural support for the basic sciences in the country, evidenced in this work by the strong presence demonstrated through scientometric and qualitative methods. These networks are "created in the image" of government policy.

We can also use Colebatch's horizontal and vertical communication models in various government communications. The science white paper can be seen as an example of upwards and downwards communication between government and various stakeholders. We can trace similar structures in the national science policy framework of Kenya. The communication between governments in the continent regarding progress made in radio astronomy and allied sciences like computation, we can understand this as horizontal communication. Since we have deployed the theoretical framework in the restricted sense of national science policy, there is opportunity for expansion of our description to international networks of communication. This can then allow us to understand the government to government communications in the SKA African Partner countries.

The social network model of national innovation systems or Pickstone's technoscientific networks, is particularly descriptive of the designed innovation systems we have discussed. The framers of the Kenyan policy framework seem to concur in describing the systems they are setting up as National Innovation Systems. It is understood implicitly that the interactions between members of these systems can best be understood as a network. This lends qualitative support to the fact that we can use the NIS model usefully here. Quantitative support comes from technoscientific networks in the form of the international scientific collaboration networks traced in section three of chapter Three. There was space to demonstrate that the international radio astronomy network was a social network. This was done by using the methods of social network analysis. From our establishment of Barabasi Albert behaviour, we could infer quantitative support for the social network model.

Which model is most effective in describing this development? We hold that this may not be a useful question to ask. The reason is the ontological overlap in the models under considerations. For example, the social contract relations between the principle and agent can be understood to be emergent from a series of vertical and horizontal communication between the principal and various agents. The principal agent relations can themselves be thought of to be embedded in larger social networks. We can understand these networks to be larger innovation systems. Examples of larger innovation systems are continental innovation systems and global innovation systems. In the case of Africa, Muchie proposes a continental innovation system which is Emergent from National Inovation Systems of member countries in the continent. Starting at the largest case, we can describe a "global innovation system" in radio astronomy, or which consists of international scientific collaborations in radio astronomy research. We have seen that there is a small subnetwork of this collaboration network is the SKA. We have also concluded that these networks are described quantitatively using Barabasi-Albert scale invariance. We can thus safely conclude that the technoscientific network model is descriptive of this system. Zooming into the South African network, we can see that South African radio astronomy academia is embedded in a National Innovation System as a node. While it is possible to describe specific relations between these nodes a series of directed communications with the representations of digraphs, we find the description of principal-agent relations and horizontal-vertical communications between government and academia. This allows us to flesh out the detailed structure of exchange of information between the networks.

We thus must commit to the notion that different on the formation of science policy are effective at different levels of analysis and that all the theories discussed are effective descriptions of our case study at different scales.

Further important areas of research can be obtained from an expanded access to the *Scopus* database. This will allow a much clearer picture of the development of radio astronomy in the two countries, the continent, and the world in general. Also, periodic scientometric measures can be taken to monitor the development of radio astronomy in the two countries. This will be important as it will form a robust basis for impact measurement of radio astronomy project in the countries and continent.

South Africa and Kenya are the most powerful economies in Southern and East Africa respectively. Over the last two decades, both countries have seen significant expansion in their GDPs. South Africa has tripled its GDP from US$ 136.4 billion to US$358.3 billion. Kenya on the other hand has nearly octupled its GDP from US $12.7 billion to US $ 99.246 billion. This is indicative of the general economic expansion in Sub-Saharan Africa, which has had its GDP grow by nearly 5 times in the last 20 years [249].

Despite these massive expansions in the economy of the two countries, there are persistent problems that the countries face. We have discussed the destabilizing inequality of the two countries, with South Africa being the most unequal state in the world.

Both countries have high youth unemployment and underemployment. This has necessitated the interest of both countries in industrialization and innovation.

In the eyes of both Kenya and South Africa, science plays a role here. The governments seem to recognise that the flow from scientific research to economic expansion is not universally linear or deterministic. They however believe that science is critical for the building of a knowledge base on which to trigger an “African Scientific Revolution”. They view it as central to the tools with which Africa can take control of her own

[249] World Bank https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=ZG

future. Indeed, as was stated by Mohamed Hassan two decades ago: “Science alone cannot save Africa. But without science, Africa cannot be saved.” [250].

[250](Hassan, 2001)-*Can science save Africa?*

6 Appendix A

6.1 Economic Indicators

This is a Python script written to help us obtain, extract, and graphically represent various economic indicators of Kenya and South Africa. We first begin by importing the useful Python modules. Pandas is a python module used for robust manipulation of data. Matplotlib is a module used for the graphic representation of data. The data for chapter two was obtained from:

1. The Organisation for Economic Cooperation and Development(OECD) website: https://www.oecd.org/africa/ on the 27th of January, 2020.
2. The World Bank-Open Data Portal: https://data.worldbank.org/ on the 28th of January, 2020.

```
import matplotlib.pyplot as plt
import pandas as pd
path1='/home/carringtone/Desktop/general.xls'
GDPGPC_Raw=pd.read_excel(path1)
GDPGPC_Raw.head()
GDPGPC_Clean=GDPGPC_Raw.drop(GDPGPC_Raw.index[[0,1]])
GDPGPC_Clean2=GDPGPC_Clean.rename(columns=GDPGPC_Clean.iloc[0]).drop(GDPGPC_Clean.ind
GDPGPC_Clean2.head()
GDPGPC_Kenya=GDPGPC_Clean2.loc[GDPGPC_Clean2['Country Name']=='Kenya']
GDPGPC_Kenya
GDPGPC_Kenya2=GDPGPC_Kenya.dropna(axis=1)
GDPGPC_Kenya3=GDPGPC_Kenya2.transpose()
GDPGPC_Kenya3
GDPGPC_KenyaP=GDPGPC_Kenya3.drop(GDPGPC_Kenya3.index[[0,1,2]])
GDPGPC_KenyaP2=GDPGPC_KenyaP.rename(columns=GDPGPC_KenyaP.iloc[0]).drop(GDPGPC_KenyaP
GDPGPC_KenyaP2.rename(columns = {'NY.GDP.PCAP.KD.ZG':'Kenya GDP Growth Per Capita'},
```

```
GDPGPC_KenyaP3=GDPGPC_KenyaP2.plot().set_xlabel('Years')
plt.savefig('Kenya_GDP.png')
GDPGPC_SA=GDPGPC_Clean2.loc[GDPGPC_Clean2['Country Name']=='South Africa']
GDPGPC_SA2=GDPGPC_SA.dropna(axis=1)
GDPGPC_SA3=GDPGPC_SA2.transpose()
GDPGPC_SAP=GDPGPC_SA3.drop(GDPGPC_SA3.index[[0,1,2]])
GDPGPC_SAP2=GDPGPC_SAP.rename(columns=GDPGPC_SAP.iloc[0]).drop(GDPGPC_SAP.index[0])
GDPGPC_SAP2.rename(columns = {'NY.GDP.PCAP.KD.ZG':'South Africa GDP Growth Per Capita
GDPGPC_SAP2.plot().set_xlabel("Years")
plt.savefig('SA_GDP.png')
ax=GDPGPC_KenyaP2.plot()
GDPGPC_SAP2.plot(ax=ax).set_xlabel("Years")
plt.savefig('comparison.png')
```

Gross Expenditure on Research and Development (GERD)

```
path4='/home/carringtone/Desktop/gerd.csv'
GERD=pd.read_csv(path4)
GERD.head()
GERD_SA=GERD.loc[GERD['LOCATION']=='ZAF']
GERD_SA2=GERD_SA.loc[GERD_SA['MEASURE']=='PC_GDP']
GERD_SA3=GERD_SA2.rename(columns={'Value':'South Africa GERD'}, inplace=True)
GERD_SA_Plot=GERD_SA2.plot(kind='line', x='TIME',y='South Africa GERD')
plt.savefig('South_Africa_GERD.png')
path2='/home/carringtone/Desktop/kenya3.xls'
GERD2=pd.read_excel(path2)
GERD_Clean=GERD2.drop(GERD.index[[0,1]])
GERD_Clean2=GERD_Clean.rename(columns=GERD_Clean.iloc[0]).drop(GERD_Clean.index[0])
GERD_Clean2
GERD_Kenya=GERD_Clean2.loc[GERD_Clean2['Country Name']=='Kenya']
GERD_Kenya
```

```
GERD_Kenya.dropna(axis=1)
```

7 Appendix B

This section contains all the code that was used to generate all images and plots in chapter three. We show the raw code. The fully commented, interactive programme is available on request We begin with importing all the libraries and modules needed for our work.

```
import configparser
import json
import requests
import pandas
import urllib
import numpy as np
from geopy.geocoders import Nominatim
from geopy.geocoders import GoogleV3
import matplotlib.pyplot as plt
plt.rcParams['figure.figsize'] = [15, 10]
import geoplot as gp
import csv
import pandas as pd
import geopandas as gpd
from pyscopus import Scopus
from PIL import Image
import io
from io import StringIO
from gcmap import GCMapper, Gradient
import pycountry
import itertools as it
```

```
import cv2
import numpy as np
from mpl_toolkits.basemap import Basemap
import matplotlib.pyplot as plt
from matplotlib.colors import Normalize, LinearSegmentedColormap, PowerNorm
import networkx as nx
```

7.1 Code for the Mapping of National Production

7.1.1 Downloading the Data

```
key='0344de2a473cb05a35c2d523e7b60690'
scopus=Scopus(key)
df= scopus.search("KEY(radio astronomy)", count=5000)
df.to_csv(radio.csv)
```

7.1.2 Data Reduction

```
df2=df['affiliation'].str.get(0)
df3=pd.DataFrame(df2)
df4=df3['affiliation'].apply(str)
df5=pd.DataFrame(df4)
df6=df5['affiliation'].apply(lambda x: pd.Series(x.split(':')))
del df6[0]
del df6[1]
del df6[2]
del df6[4]
df6=df6[3].apply(lambda x: pd.Series(x.strip('}')))
df7=pd.DataFrame(df6[0].value_counts())
df8=df7.reset_index()
df8.columns=['Country', 'Papers Published']
```

```
df8["Coordinates"]=df8["Country"].apply(nom.geocode)
```

7.1.3 Generating Coordinates

```
df8["Latitude"]=df8["Coordinates"].apply(lambda x: x.latitude)
df8["Longitude"]=df8["Coordinates"].apply(lambda x: x.longitude)
```

7.1.4 Mapping

```
gdf = gpd.GeoDataFrame(
df8, geometry=gpd.points_from_xy(df8.Longitude, df8.Latitude))
world = gpd.read_file(gpd.datasets.get_path('naturalearth_lowres'))
ax = world.plot(color='white', edgecolor='black')
gdf.plot(ax=ax, color='red')
ax = world.plot()
gdf.plot(ax=ax,column='Papers Published',legend='True',  legend_kwds={'label': "Colou
'orientation': "horizontal"})
gdf.to_crs(world.crs,inplace=True)
world_and_points=gpd.sjoin(world,gdf)
world_and_points.plot(column='Papers Published',legend='True')
ax = world.plot()
world_and_points.plot(ax=ax,column='Papers Published',legend='True', legend_kwds={'la
'orientation': "horizontal"})
Africa=world.query('continent == "Africa"')
Africa_points=world_and_points.query('continent == "Africa"')
ax = Africa.plot()
Africa_points.plot(ax=ax,column='Papers Published',legend='True', legend_kwds={'label
'orientation': "horizontal"})
ax3 = gp.cartogram(
world_and_points, scale='Papers Published', limits=(0.2, 1),
edgecolor='None', figsize=(10, 7),
```

```
)
gp.polyplot(world, edgecolor='gray', ax=ax3)


ax3 = gp.cartogram(
Africa_points, scale='Papers Published', limits=(0.2, 1),
edgecolor='None', figsize=(10, 7),
)
gp.polyplot(Africa, edgecolor='gray', ax=ax3)
```

7.2 Code for The Mapping of Connections

7.3 Code for the Clustering of Abstracts using Machine Learning

This is the code for the clustering of abstracts. The model used is the K means clustering model. The model is an off-the-shelf model obtained from Samet Girgin [251] but adapted for our purposes here.

```
import matplotlib.pyplot as plt
import pandas as pd
import nltk
from google.colab import files
import numpy as np
import matplotlib.pyplot as plt
from nltk.corpus import stopwords
from nltk.stem import PorterStemmer
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.cluster import KMeans
import io

uploaded=files.upload()
df1 = pd.read_csv(io.BytesIO(uploaded['ska_lens_export.csv']))
```

[251] Samet Girgin-"K-Means Clustering Model in 6 Steps with Python"-https://medium.com/pursuitnotes/k-means-c

```
df2=df1['Abstract']
df3=df2.dropna()
df3=df2.dropna()
vectorizer = TfidfVectorizer(stop_words='english')
X1 = vectorizer.fit_transform(df3)
true_k = 3
model = KMeans(n_clusters=true_k, init='k-means++', max_iter=100, n_init=1)
model.fit(X1)
order_centroids = model.cluster_centers_.argsort()[:, ::-1]
terms = vectorizer.get_feature_names()

for i in range(true_k):
print('Cluster %d:' % i),
for ind in order_centroids[i, :10]:
print(' %s' % terms[ind])
y_clf=model.fit_predict(X1)
df5=pd.DataFrame(y_clf)
df6=df5.groupby([0]).size().reset_index(name="number")
del(df6[0])
df6.plot(kind="bar")
```

7.3.1 Downloading the Data

```
key='0344de2a473cb05a35c2d523e7b60690'
scopus=Scopus(key)
df= scopus.search("KEY(radio astronomy)", count=5000)
df.to_csv(radio.csv)
```

7.3.2 Generating Pairs

```
df1=pd.read_csv("/home/carringtone/radio.csv")
df2=df1['affiliation']
df3=pd.DataFrame(df2)
countries=[]
for i in range(0,4999):
text = df3['affiliation'].iloc[i]
try:
for country in pycountry.countries:
if country.name in text:
countries.append(country.name)
countries.append(":")
except TypeError:
print('NaN')
s=":"
s=s.join(countries)
data = io.StringIO(s)
df4 = pd.read_csv(data, sep=":::",header=None)
df5=df4.transpose()
df6=df5[0].apply(lambda x: pd.Series(str(x)))
df7=df6[0].apply(lambda x: pd.Series(x.split(':')))
df8=df7.dropna(thresh=2)
df9=df8.reset_index(drop=True)
df9
pairs=[]
for i in range(0,5000):
try:
for a,b in it.combinations(df9.loc[i], 2):
```

```
pairs.append(str(a)+":"+str(b))
except:
pass
df10=pd.DataFrame(pairs)
df11=df10[0].apply(lambda x: pd.Series(x.split(':')))
df11
```

7.3.3 Generating Coordinates

```
df11.to_csv("radio2.csv")
df12=pd.read_csv('/home/carringtone/radio2.csv')
df13=df12.dropna()
del df13["Unnamed: 0"]
df14=df13.reset_index(drop=True)
df14.columns=['start','stop']
df15=df14.groupby(['start','stop']).size().reset_index(name="number")
nom=Nominatim(timeout=10)
df15["start Coordinates"]=df15["start"].apply(nom.geocode)
df15["stop Coordinates"]=df15["stop"].apply(nom.geocode)
```

7.3.4 Generating Images

The code for this section was adapted from Hugo Larcher [252] obtained on 5^{th} April, 2020 :

```
df15["start Latitude"]=df15["start Coordinates"].apply(lambda x: x.latitude)
df15["start Longitude"]=df15["start Coordinates"].apply(lambda x: x.longitude)
df15["stop Latitude"]=df15["stop Coordinates"].apply(lambda x: x.latitude)
df15["stop Longitude"]=df15["stop Coordinates"].apply(lambda x: x.longitude)
del df15["stop Coordinates"]
```

[252] *Flight data visualisation with Pandas and Matplotlib*-https://blog.hugo-larcher.com/flight-data-visualisation-with-pandas-and-matplotlib-ebbd13038647

```
del df15["start Coordinates"]
grad = Gradient(((0, 70, 50,0), (0.5, 200,170, 0), (1, 255, 204, 230)))
gcm = GCMapper(cols=grad, height=2000, width=4000)
gcm.set_data(df15['start Longitude'], df15['start Latitude'], df15['stop Longitude'],
df15['stop Latitude'],df15['number'])
image = gcm.draw()
image.save('radio_connections.png')
image
df15.to_csv("radio_data.csv")
def plot_map(in_filename, color_mode='screen',
out_filename='nuclear_connections2.png', absolute=False):
if color_mode == 'screen':
bg_color = (0.0, 0.0, 0, 1.0)
coast_color = (204/255.0, 0, 153/255.0, 0.7)
color_list = [(0.0, 0.0, 0.0, 0.0),
(204/255.0, 0, 153/255.0, 0.6),
(255/255.0, 204/255.0, 230/255.0, 1.0)]
else:
bg_color = (1.0, 1.0, 1.0, 1.0)
coast_color = (10.0/255.0, 10.0/255.0, 10/255.0, 0.8)
color_list = [(1.0, 1.0, 1.0, 0.0),
(255/255.0, 204/255.0, 230/255.0, 1.0),
(204/255.0, 0, 153/255.0, 0.6)
]
CSV_COLS = ('useless','start', 'stop','number', 'start Latitude', 'start Longitude',
'stop Latitude', 'stop Longitude')
routes = pd.read_csv(in_filename, names=CSV_COLS, na_values=['\\N'],
sep=',', skiprows=1)
num_routes = len(routes.index)
```

```
norm = PowerNorm(0.3, routes['number'].min(),
routes['number'].max())
if absolute:
n = routes['number'].max()
else:
n = num_routes
cmap = LinearSegmentedColormap.from_list('cmap_connections', color_list,
N=n)
plt.figure(figsize=(27, 20))
m = Basemap(projection='mill', lon_0=0)
m.drawcoastlines(color=coast_color, linewidth=1.0)
m.fillcontinents(color=bg_color, lake_color=bg_color)
m.drawmapboundary(fill_color=bg_color)
for i, route in enumerate(routes.sort_values(by='number',
ascending=True).iterrows()):
route = route[1]
if absolute:
color = cmap(norm(int(route['number'])))
else:
color = cmap(i * 1.0 / num_routes)
line, = m.drawgreatcircle(route['start Longitude'], route['start Latitude'],
route['stop Longitude'], route['stop Latitude'],
linewidth=1.5, color=color)
plt.savefig(out_filename, format='png', bbox_inches='tight')
if __name__ == '__main__':
plot_map('/home/carringtone/radio_data.csv', 'print', absolute=False)
```

7.3.5 Network Analysis

```
Graphtype = nx.Graph()
```

```
G = nx.from_pandas_edgelist(df16, source='start',target="stop", create_using=Graphtyp
nx.draw(G, with_labels=True)
plt.savefig("radio_network.pdf")
df18=pd.DataFrame(nx.degree(G))
df19=df18.sort_values(1, ascending=False)
df19.columns=['Country', 'Degree']
df20=df19.reset_index(drop=True)
df19.plot(kind='bar',x='Country', y='Degree')
def func(x, a, c, d):
return a*np.exp(-c*x)
params,cov=curve_fit(func, df20['Unnamed: 0'],df20['Degree'],p0=(1, 1e-6, 1))
plt.scatter(df20['Unnamed: 0'],df20['Degree'] , label='Data')
plt.plot(df20['Unnamed: 0'], func(df20['Unnamed: 0'], params[0],params[1],params[2]),
label='exponential fit')
plt.legend(loc='best')
plt.show()
list1=nx.eigenvector_centrality(G)
list2=str(list1)
data2 = io.StringIO(list2)
df5 = pd.read_csv(data2, sep=",",header=None)
df6=df5.transpose()
df6[0]=df6[0].astype('str')
df6[0]=df6[0].apply(lambda x: pd.Series(x.strip('{')))
df6[0]=df6[0].apply(lambda x: pd.Series(x.strip('}')))
df7=df6[0].apply(lambda x: pd.Series(x.split(':')))
df8=df7.sort_values(1, ascending=False)
df8.columns=['Country', 'Eigenvector Centrality']
df8['Eigenvector Centrality']=df8['Eigenvector Centrality'].astype('float')
df8.head(10)
```

```
df8.plot(x='Country',y='Eigenvector Centrality',kind='bar')
```

7.4 Code for Reference Bar Graph Plots

```
path='/home/carringtone/Desktop/2016_papers.xlsx'
data=pd.read_excel(path)
data1=data.loc[67:126]
data1.columns=['Country Code','Country','Papers Published']
data2=data1.sort_values('Papers Published')
data2.plot(x='Country',y='Papers Published', kind='bar' )
plt.savefig("science_in_africa.png")
path2='/home/carringtone/Desktop/Science_growth.xlsx'
data2=pd.read_excel(path2)
data3=data2.loc[67:126]
data3.columns=['Country Code','Country','Growth In Papers Published']
data4=data3.sort_values('Growth In Papers Published')
data4.plot(x='Country',y='Growth In Papers Published', kind='bar' )
```

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