AFRICALICS THEMATIC CHAIR REPORT

Towards a research and theoretical agenda for STI measurement in Africa

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A. INTRODUCTION

This AfricaLics Thematic Report considers the state of the art of science, technology and innovation (STI) measurement in Africa, to inform a research agenda for AfricaLics members. The aim is to set a shared research agenda for conceptual and empirical frameworks, indicators, and measurement appropriate to African country contexts. The main argument is that if we are to develop STI indicators that are appropriate to our African contexts and of value to policy actors to assess progress towards development outcomes, then we need to better contextualise measurement. Measurement programmes in Africa need to be built on a strong base of literature on the nature, forms, and drivers of innovation in the economic growth and development pathways of low- and middle-income countries in Africa.

A concern is that the research literature on STI measurement in Africa, and the Global South, is sparse. While the body of literature on innovation in African contexts is growing, it is not extensive. What exists tends to display a high degree of conceptual borrowing (Muchie et al., 2003), an often uncritical emulation of analytical frameworks and provides insufficient strong empirical evidence as a foundation to inform new conceptual development.

To ensure that innovation measurement can inform policy and transformation in the African context in a theoretically sound manner, building on existing institutional arrangements and capabilities, it is necessary to strengthen the literature, informed by a shared research agenda, using local expertise, and building local networks. The AfricaLics network recognised the importance of building expertise in Africa-focussed innovation measurement, by appointing a thematic chair to contribute to developing its innovation and development knowledge base.

This report is an output of the work of the AfricaLics thematic chair on Africa-focused innovation measurement led by teams at CeSTII in South Africa and NACETEM in Nigeria. The first section considers why it is important to build an African STI measurement knowledge base at this conjuncture. The second section steps back to consider the state of STI measurement in Africa as it has evolved over the past few decades. The third section reports on a bibliometric study of the existing literature, to identify key topics, under-researched topics and the geographical structure of the research networks contributing to this field. The fourth section focuses on four areas for new research to underpin the design of contextualised African STI indicators and measures. Finally, we conclude by proposing a draft research agenda, as the foundation for wider consultation with STI measurement experts and innovation systems researchers across the continent.

B. WHY IT IS IMPORTANT TO BUILD AN AFRICAN STI MEASUREMENT KNOWLEDGE BASE NOW

Measuring innovation is considered important for every country (Charmes et al., 2016; Borras and Edquist, 2019; Godin et al., 2021; Gault, 2020). It provides, "critical policy evidence to inform strategies for technological upgrading and innovation that can drive the distinctive economic growth paths of middle- or low-income countries" (Kruss, 2018: 348). In the current post-pandemic and environmentally challenged context, the need to orient STI policy to inclusive human development and sustainable growth is ever more acute and urgent (OECD, 2021). The evidence and indicators used to leverage and influence government resource allocations to STI, need to be relevant and suitable for the task.

Over fifteen years ago, innovation measurement using the Oslo Manual global standard (OECD/Eurostat, 1992; 2018) was introduced (Gault, 2008; NEPAD, 2006) and supported in African countries. The African Union and its partners have been driving national efforts to promote STI, and continental efforts to produce internationally comparable indicators (AU-NEPAD, 2010; 2019; Gault, 2014; Gault et al., 2016; UNU-INTECH, 2004). From the outset, there was extensive debate on how the standard instruments could be adapted (Bartels and Koria, 2014; Blankely et al., 2006; Manzini, 2015) to contexts with low levels of technological capability and industrialisation, and major human development challenges (Lorentzen, 2011).

In recent years, there is mounting evidence globally that current measurement standards do not sufficiently capture how STI contributes to social and human development goals (Boon and Edler, 2018; Dzilias and Blind, 2019; Charmes et al., 2016; Gault, 2020; Godin, 2015; 2021; Kruss, 2018; OECD, 2012; 2015) or to sustainable development (Bordt et al., 2006). There is growing recognition that new indicators and measures are required, and much experimentation with the existing theoretical and methodological frameworks that underpin innovation measurement globally (Archibugi and Coco, 2004; Castro-Martinez et al., 2009; Iizuka & Hollanders, 2017).

Indeed, the field of innovation studies in general has undergone major changes over the past decade, accelerating over the past five years in response to grand societal challenges and a growing environmental crisis.

The emphasis is shifting, from trying to understand the contribution of innovation to economic growth, to interrogate how innovation drives development, and now, to consider how innovation can be harnessed for inclusive and sustainable development (Pansera and Owen, 2018a; Park et al., 2017; Rodriguez et al., 2020). A number of new conceptual frameworks to understand innovation have emerged from different

country contexts. The European Union has driven research around "responsible innovation" (see Rafols, 2019 for example). Pansera and Fressoli (2021) in contrast, question the basic assumptions about innovation normalised in current measurement systems, that innovation is always positive and through economic growth, can deliver prosperity for all (see also Pansera and Owen, 2018b). They call for a new model of "innovation without growth" and attempt to design alternative frameworks that foreground the socially constructed character of technology development, politics, and capabilities. In the Chinese context, Chen et al. (2018) posit a new "holistic innovation" paradigm, that draws on and is informed by Chinese and eastern cultures. Borras and Edquist (2019) make a powerful case for the "holistic innovation" approach, arguing that most approaches are "partial", in that they occlude critical societal problems that require greater innovation policy attention. The volume and creativity of such research is so great that Godin et al. (2021) were able to compile a substantial handbook on "alternative innovation", based on the challenge that we need new and different imaginaries.

In the innovation measurement space specifically, there are accompanying major shifts globally, reflected in a change to a more expanded definition of the "innovation" that can be applied to actors other than firms (Gault, 2020; OECD, 2018). Research is growing to problematise how to assess innovation in a range of formal and informal settings, as enacted by a broader range of actors (Sutz, 2012): in households (De Jong, 2016; Von Hippel, 2016), communities in informal settings (Cozzens and Sutz, 2014), public sector agencies (Arundel et al., 2015; Arundel and Huber, 2013) or informal enterprises (Charmes et al., 2016; Kraemer-Mbula and Wunsch-Vincent, 2016). Innovation measurement is catching up, as evident by experimental efforts to measure innovation in informal enterprises in South Africa and Nigeria, for example (Mustapha et al., 2021).

Much research is undertaken to review and refine innovation indicators, to be of value to policy makers in high-income countries (Alhusen et al., 2021; Janger et al., 2017; Klarin, 2019). There is a growing case that simple aggregated indicators are of limited value, and that frameworks for more advanced indicators should be designed through differentiating and profiling modes of innovation. There is also a growing body of new indicators research focused on and emanating from developing countries of the Global South (Cirera and Muzi, 2020). One stream in this work stretches and adapts standard approaches to measure how, and to what extent, research and innovation outcomes are oriented to promote the Sustainable Development Goals, or address societal grand challenges (Ciarli et al., 2022; Iizuka and Hane, 2021; Kahn and Koc, 2016; Rafols et al., 2021).

Few of these alternative perspectives on innovation, and new critical approaches to indicator development emerge from Africa. The literature on African innovation measurement tends to reflect conceptual frameworks of innovation systems characterised in terms of 'absence', of what does not exist, when

measured against high-income countries. This is evident for instance, in attempts to explain "the failure to compete" (Lall et al., 2002), or expressed in a call to understand the nature of "innovation under the radar" in African systems (Fu, 2020).

The structure of post-colonial African economies differ markedly from the high- and middle-income countries on which most of the innovation theory and literature is based, and their insertion into global value chains is constrained. They are highly dependent on resource extraction to the benefit of multi-national corporations and local elites, and large proportions of their populations remain dependent on informal livelihoods, whether in agriculture, manufacturing, trade, or services. Strong systems of political patronage and elite capture constrain transformation. While African economies have not built strong national technological capabilities over time, some countries are positioning themselves to create opportunities through digital transformation, and the potential of the African Free Trade Continental Agreement is being explored.

From this brief overview, we can distil three key reasons for growing a knowledge base to inform the design of STI measurement and indicators in Africa. First, for indicators to be of value and use to policy actors, they need to be informed by research that links the theorisation of the attributes and determinants of innovation, through an iterative process, with empirical testing (Borras and Edquist, 2019). Second, and closely related, is the need for a stronger research base on the science, technological and innovation capabilities of African countries. If policy mixes and instruments are borrowed from high-income countries into innovation system contexts with low capabilities, they are unlikely to succeed. Third, it is vital to identify and understand the societal grand challenges experienced in African countries, to which STI policy and practice will need to be oriented. To elaborate, we use the example of a recent AU-EU innovation strategy, which proposes to direct strategic efforts to strengthen innovation capabilities, competences, and eco-systems of member states. The focus of interventions is on five dimensions: to grow innovation ecosystems; innovation management; knowledge exchange; access to finance; and human capacity development. There are four focus fields: public health; the green transition; capacities for science; and innovation and technology. To monitor progress and measure the impact of these policy goals requires a conceptual framework based on understanding not only the science system, or the outputs of science and innovation activity or the practice of formal sector firms. It requires an understanding of current systems, competences and capabilities, and flows of resources, and how they can be transformed, across a range of actors.

In short, this requires very different STI indicators to the ones that governments typically prioritise. A measure of GERD/GDP at the national level, for instance, provides a sense of transition towards a knowledge economy, but will not enable policy actors to assess how STI is supporting the green transition,

or how the science system is oriented to address human development challenges. Typically used proxy indicators for innovation competences, such as patents, will be of limited value to inform understanding of existing capabilities, as a basis for designing policy interventions that support desired future capabilities. Data that is routinely collected, such as bibliometrics, will need to be analysed in different ways, for instance, to assess how the knowledge production system is oriented to provide research evidence to enable the achievement of key SDGs (Ciarli et al., 2022; Rafols et al., 2021).

C. THE STATE OF STI MEASUREMENT IN AFRICA

As a foundation for this reorientation, it is necessary to assess the current state of STI measurement across African countries with a broad range of statistical capabilities.

Monitoring the SDGs has highlighted the need for better statistical measurement capacity globally, and more so, in Africa. The focus over the past twenty years has primarily been to establish STI measurement capacity. Significant funding by European development agencies supported the application of the OECD standard STI frameworks and methodologies, based on the Frascati and Oslo manuals. On the continent, agencies like the African Observatory on STI, AOSTI, and African Union's AUDA-NEPAD (NEPAD Office of Science and Technology, 2006; AU NEPAD, 2010; Gault, 2008; UNU-INTECH, 2004) drive training and capacity building. Through the Department of Science and Innovation, South African research groups have been encouraged and funded to support these cross-continental efforts.

The main outcome to date has been R&D surveys that largely provide internationally comparable data on key indicators of investment, as well as insights into R&D expenditure, primarily in the science system, focused on the higher education, government and/or non-profit sectors. Few countries have included the business sector in their R&D surveys. Fewer countries have the competence to run innovation surveys, to identify patterns of formal business innovation activity.

Take the example of the 16 member countries of the Southern African Development Community (SADC). R&D and innovation are highlighted as central to the achievement of the SADC Industrialisation Strategy, and in 2008, countries affirmed the SADC Science and Technology Protocol target of spending one percent of GDP on R&D (GERD/GDP). STI measurement is largely focused on updating and monitoring progress towards this indicator. The main usage of the indicators has been benchmarking with SADC and other African peers, coordinated by AUDA-NEPAD, and global comparators as reflected in the UNESCO Institute of Statistics and OECD scoreboards. This requires reliable longitudinal STI datasets, maintained over time.

Table 1 reviews the status in 2022 of the R&D survey datasets on which the GERD/GDP indicators for the SADC countries are based. Data constraints are immediately evident: there is limited sectoral coverage in some countries, and the most recently available data is typically very out of date, with some surveys last produced fifteen years ago.

Table 1. R&D datasets as the basis for indicators

Country	GERD / GDP target	Target	Performance	Latest data year	Sectors
Angola	1%	Not indicated	0.04%	2013/14	Gov, HE
Botswana	2%	2016	0.54%	2013/14	All sectors
DR Congo	1%.	Not indicated	0.43%	2015	Gov, HE, NPO
Eswatini	3%	2030	0.26%	2015/16	All sectors
Lesotho	1%	Not indicated	0.01%	2011	Gov, HE
Madagascar	N/S	N/S	0.11%	2011	N/S
Malawi	No target	Not indicated	1.7%	2007/08	Gov, HE, NPO
Mauritius	N/S	N/S	N/S	N/S	N/S
Mozambique	No target	Not indicated	0.36%	2016	All sectors
Namibia	2%	2030	0.34%	2013/14	All sectors
Seychelles	1% 2%	2020 2025	0.04%	AIO, 2018	All sectors
South Africa	1.5%	2030	0.82%	2016/17	All sectors
Tanzania	None	Not indicated	1.10%	2007 (AIO, 2010)	Gov, HE
Zambia	None	Not indicated	0.37	2008 (AIO, 2010)	
Zimbabwe	1%	Not indicated	N/S	2012 (AIO, 2014)	Gov, HE

Notes: Gov = Government; HE = Higher education; NPO = Non-profit organisation; and All sectors = Government, higher education, non-profit organisation, science councils and business. AIO = African Innovation Outlook.

Increasingly, African states recognise how useful more extensive STI measurement would be, to assess progress towards achieving SDG 9, and their STI Strategy for Africa (STISA) targets, as well as monitoring and reporting national STI policy achievements to Parliament and Cabinet. This requires coordinating datasets from multiple sources on STI, key priority sectors and national development.

The foundation is laid for national agencies to prioritise measurement of STI for development, to strengthen capacities that have been built, and to develop capacities to design and implement new kinds of measures and indicators, appropriate to current African contexts and global challenges. How can the available literature on STI measurement in Africa provide an empirical and conceptual research base to inform these objectives?

D. WHAT DOES THE EXISTING LITERATURE CONTRIBUTE?

This section reviews the recent literature on STI measurement in Africa, to highlight key focal issues, key analytical trends, and potential research gaps.

The discussion is based on a bibliographic analysis[1] of published scholarly outputs on innovation and measurement in Africa and the Global South. The bibliometric analysis used the Scopus database to identify and extract papers, and VOSviewer software to identify and visualise key trends. The value of such an analysis is to understand, "the current state of the academic conversation" (Park et al., 2020: 141) on STI measurement in Africa, as a foundation to highlight key areas for further research and indicator development.

The analysis focused on two main aspects. First, it assessed the topics covered in the research field, based on an analysis of keywords, complemented by an analysis of subject terms. Second, it analysed the geographical scope of the papers, based on the institutional affiliation of the authors and citation analysis.

Search terms with wider and broader degrees of specificity were used to identify relevant literature:

1. Science, technology, innovation measurement in Africa/developing countries/Global South (31 scholarly outputs)
2. Science, technology, innovation indicators (in general and in Africa) (11 scholarly outputs)

After screening the paper titles and abstracts, a total of 42 papers were identified as relevant for analysis, the majority being journal articles. The earliest date of publication found was 2008. A team of researchers at CeSTII and NACETEM read the papers and recorded key information on an Excel spreadsheet template.

[1] A bibliographic analysis is a systematic literature review that analyses bibliographic data – including, amongst others, author names, journal names and article titles, keywords, abstracts and publication years – using bibliometric methods (Block and Fisch, 2020). The bibliographic and citation data analysed was sourced through Scopus, the main bibliographic database available to researchers at the HSRC and analysed using the free software tool, VOSviewer. This analysis is limited to data available through Scopus and published in English. The analysis of geographical coverage only applies to peer-reviewed outputs as the country affiliation of authors is not available for outputs that were not available in Scopus. The advantages and limitations of VOSviewer are discussed by Park et al. (2020).

This dataset was analysed using bibliometrics, complemented by a thematic analysis. The bibliometric analysis included the following commonly used techniques (see Park et al., 2020: 151):

1. "Co-occurrence analysis: the greater the number of documents in which two keywords occur together, the higher the relatedness of these keywords"
2. "Citation analysis: the greater the number of times authors, journals, and papers cite each other, the higher the relatedness of these items"
3. Analysis by publication year and geographical location of the authors' institutional affiliations.

The following sections present and discuss the results of this analysis, stepwise.

D.1 Which topics are covered most in the STI measurement in Africa/Global South literature?

D.1.1 What an analysis of the co-occurrence of key terms reveals

Co-occurrence analysis involves assessing the number of papers in which the author keywords and all other keywords co-occur, showing their frequency and relatedness (Park et al., 2020). For the keyword visualisations, a minimum co-occurrence of words of two, with a selection of 29 of the most frequently occurring terms, was used out of a total of 164 keywords. The occurrence of these keywords ranged from two to 18, with most of the keywords occurring between two and three times. Figure 1 shows the co-occurrence of the keywords that occurred four or more times.

Table 2 lists the most commonly occurring keywords. The top five most common keywords, besides innovation, ranked by number of occurrences include: 'South Africa', 'research and development', 'Africa', 'developing countries' and 'expenditure'.

Table 2. Most commonly occurring key words

Keyword	*Occurrences*	*Total link strength*
Innovation	**18**	**54**
South Africa	**6**	**21**
Research and Development	**4**	**20**
Africa	3	9
Developing countries	3	7
Expenditure	**3**	**18**
Indicators	**3**	**11**
Literature review	**3**	**13**
Science	3	8
Science and technology	**3**	**15**

Developing world	2	7
Economic development	2	9
Economics	2	9
Entrepreneurship	2	5
Experimental study	**2**	**15**
Fourth Industrial Revolution	2	7
Innovation indicators	2	2
Innovation metrics	2	6
Innovation systems	2	8
Patents and inventions	2	9
Policy	**2**	**11**
Policy approach	**2**	**13**
Social development	2	6
STI indicators	**2**	**13**
Technological change	**2**	**10**
Technological development	**2**	**10**
Technology	2	5
Technology and innovation	**2**	**10**
Technology policy	2	7

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

The keyword co-occurrence analysis depicted in Figure 1 reveals four major keyword clusters: 1) Innovation, focusing on indicators and metrics (green), 2) South Africa (red), 3) Africa (yellow), and 4) science and technology in developing countries (blue). The clusters are illustrated in Figure 1. We also analysed the occurrence of keywords against publication year, to get a sense of change over time (Figure 2).

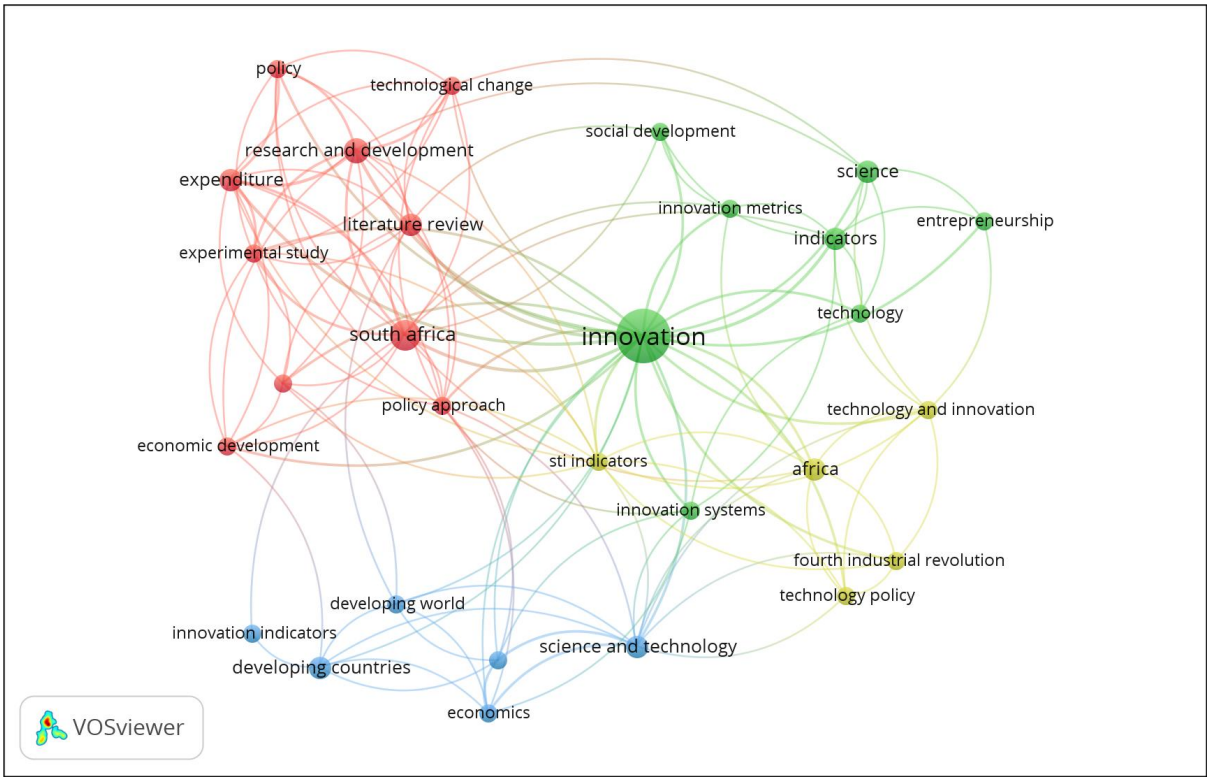

Figure 1. Map of co-occurrence of indexed and author keywords

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

The largest cluster, in **green**, focuses on 'indicators' and 'metrics' of 'science', 'technology' and 'innovation'. This finding is expected considering that the main literature search terms included 'STI measurement' and 'STI indicators'. Co-occurring with these topics is the 'innovation systems' approach. When we analysed the publication year, we found that papers on these topics were mainly published prior to 2017 (Figure 2). More recent topics not as well linked into this cluster include metrics of innovation and 'social development' and 'entrepreneurship'. These are relatively new areas of interest.

A second, considerably smaller cluster, in **blue**, reflects an older trend with most papers published prior to 2017. It focuses on approaches to innovation measurement, and a more general focus on STI and developing countries as a broad category. Here African countries may be covered under the broad categories of 'developing countries' and 'developing world'. The specific topics covered in this cluster include 'developing countries' and 'innovation indicators', and 'science and technology' linked to 'innovation systems'. This cluster appears more distant or weakly linked to the central cluster of key words in the middle of the network.

When it comes to Africa, South Africa appears in the top three occurrences, indicating that STI measurement in South Africa is well researched, more so than any other African country. No other country is identified in the list of frequently occurring keywords. The trend can be seen in the second largest cluster, in **red**, which centres on innovation measurement in 'South Africa' highlighting research on 'research and development', 'expenditure' and 'experimental study'. Also identified are 'policy' and 'technological change' and 'economic development'. In South Africa, measurement of R&D is well established, in comparison with innovation measurement. It is therefore not surprising that R&D measurement is well researched as a policy focus and linked with technological change. Whereas the focus on R&D appears more strongly in 2017 and 2018, interest in the link between innovation measurement and economic development and expenditure as a policy focus, and experimental research is more recent, from 2019 and 2020 onwards. Innovation measurement and technological change in South Africa is an older area of interest, mainly prior to 2017.

The focus of research on innovation measurement in 'Africa' as a region of interest is relatively more recent, from 2019 onwards. The smaller cluster in **yellow** shows that, in relation to Africa, the growing trend has been research on STI indicators and the 4IR, as one focus for technology policy (Figures 1 and 2). Research on innovation systems and Africa appears to be an older focus, from prior to 2017.

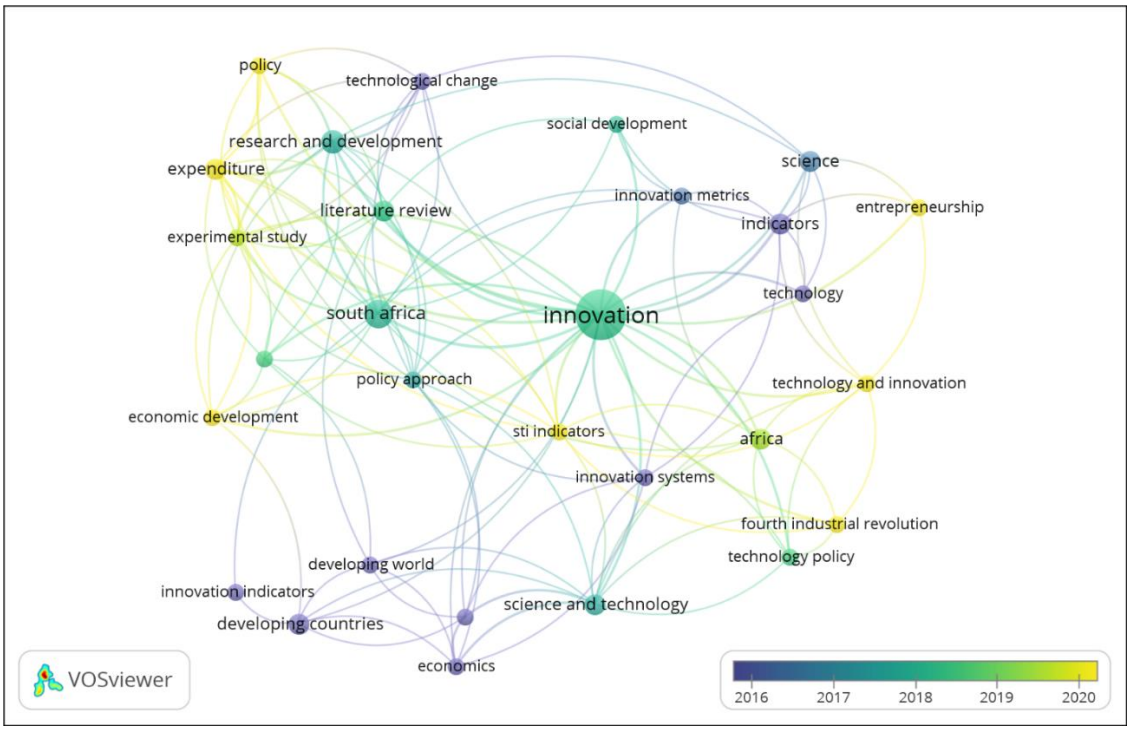

Figure 2. Map of co-occurrence of indexed and author keywords by average publication year

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

When we analysed the occurrence of the keywords against citations, these were the topics of interest: 'indicators', 'technology', 'innovation systems' and the 'developing world' (Figure 3). Given that research on these topics tended to be in earlier publications, it is expected that there will be more citations on these topics. The *conversion* is more well established. Interestingly, although South Africa and R&D-related research in South Africa was also well researched, this research did not appear to be frequently cited. The *conversation* seems to be limited in reach.

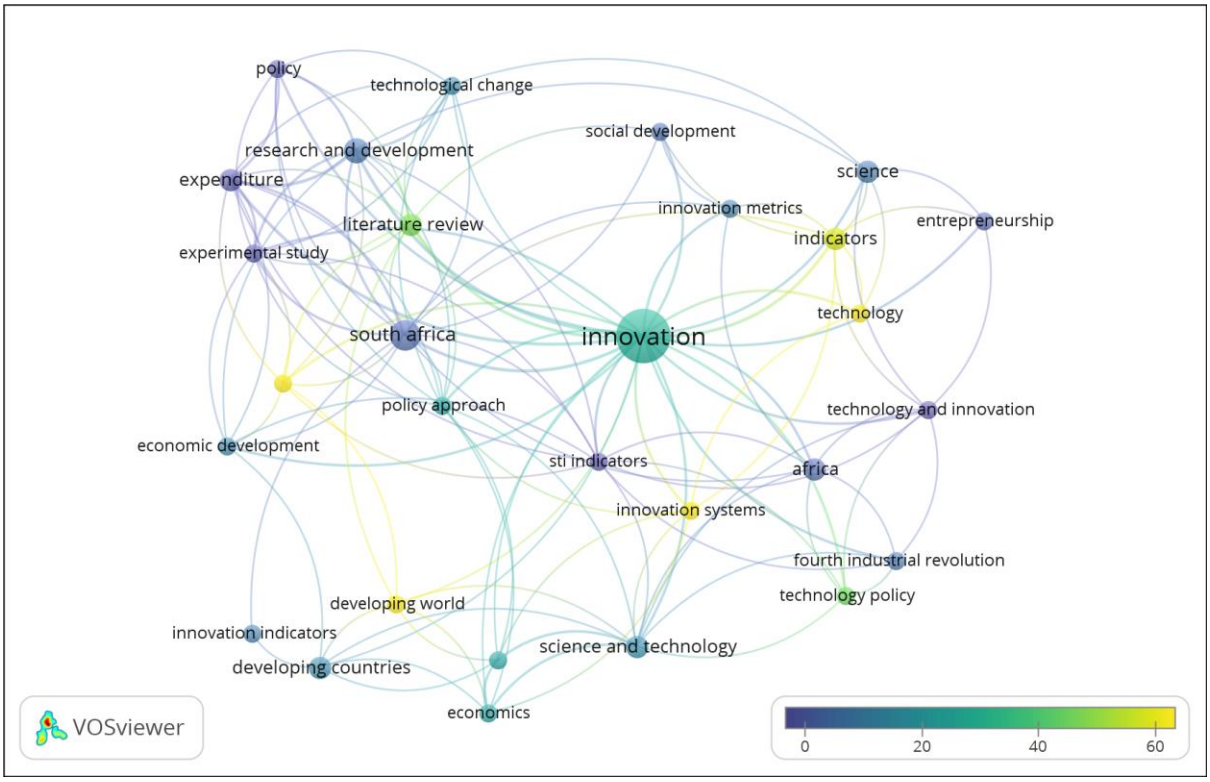

Figure 3. Map of co-occurrence of indexed and author keywords by average citation count

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

D.1.2 What an analysis of co-occurrence of subject terms in title and abstract fields reveals

The analysis described in Figures 1 to 3 focused on the keywords linked to the 42 papers identified as relevant. To complement this exercise, we analysed the subject terms, extracted from the abstracts and titles of these papers. Such analysis allows for a broader understanding of topics than from the keywords

as indexed and identified by the authors of the papers. The subject terms were analysed across 36 of the outputs that were either primarily indexed (27) or indexed as secondary documents.[2]

For the keyword visualisations, the minimum number of occurrences of the term was three and included a total of 872 terms. A relevance score was calculated and used to identify the most relevant terms. The default choice was to select 60% of the most relevant terms. When we broaden the analysis in this way, the picture includes a wider array of topics. As shown in Figure 4, four main clusters are visible:

1. 'Impact', 'economy' and 'GDP'; 'R&D expenditure' and 'research fields' and 'creation'. A more recent focus in this cluster is 'institutional quality' with 'entrepreneurship' and 'academic promotion' more recent and less related.
2. 'Policy', 'STI', 'policy making' and 'process'. A more recent focus in this cluster of topics is 'social innovation'.
3. 'Knowledge', with a more recent focus on 'capability', 'mediating role', and 'questionnaire'.
4. 'Innovation policy', 'agenda', 'survey', and 'Africa'. 'Production' and 'use' is part of this cluster, but not as closely related. The 'informal economy' has been on the innovation measurement agenda for a while, but innovation measurement in the 'informal sector' is an emerging area of research, reflecting new efforts to measure innovation in informal enterprises rather than innovation in the informal economy more broadly.

[2] This excludes structured abstract labels (consisting of multiple labels) and copyright statements.

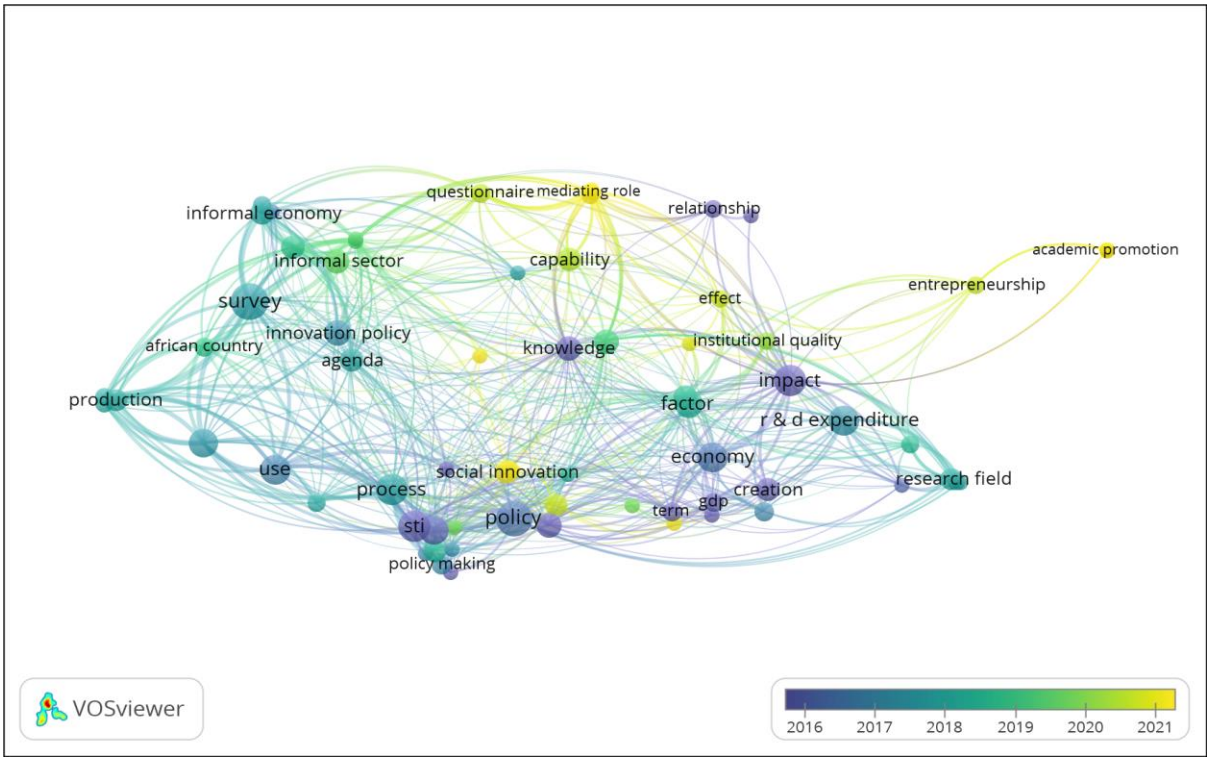

Figure 4. Map of co-occurrence of subject terms in the titles and abstracts, by publication date

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

We analysed citations based on the subject terms in abstracts and titles, focusing on terms with at least three citations. Based on the citation analysis, the most researched and cited topics include 'STI policy' and 'innovation policy', innovation 'creation' and 'use', and 'capability' and 'knowledge'. Topics related to 'impact', 'social innovation', 'policy making', 'institutional quality', 'R&D expenditure', and 'research fields' were least cited.

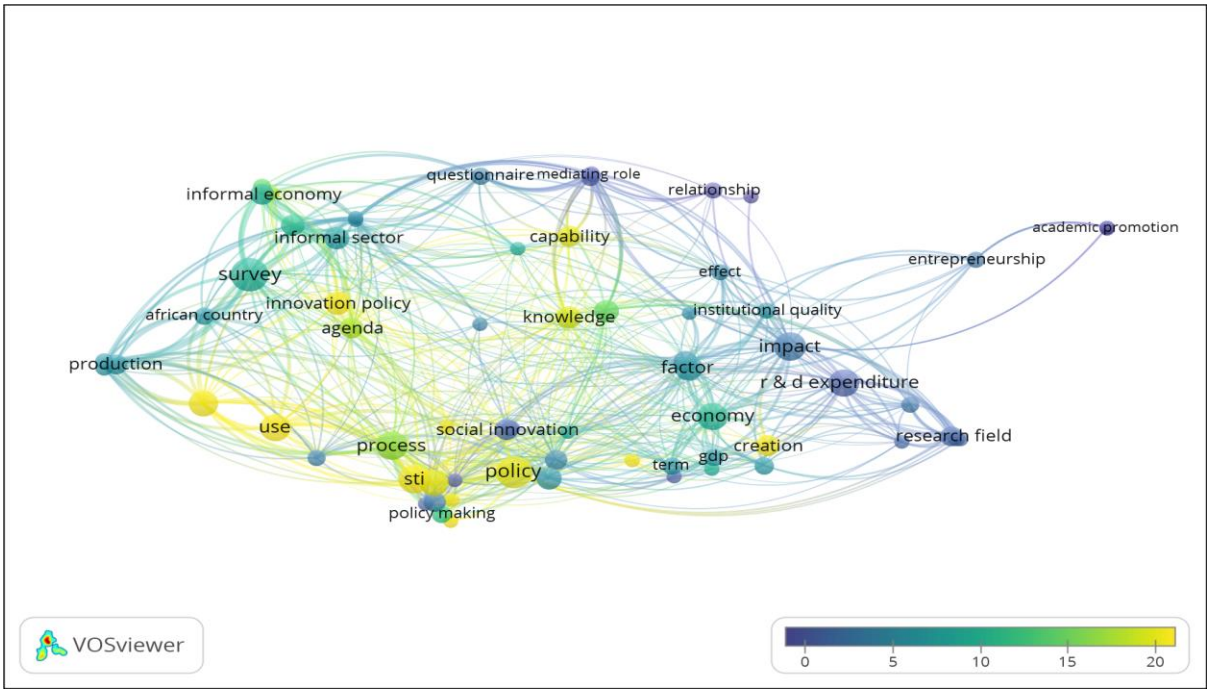

Figure 5. Map of co-occurrence of subject terms in the titles and abstracts, by citation count

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

D.1.3 The main topics covered by papers citing the literature on STI measurement in Africa/Global South

What are the main academic conversations that draw on the literature on STI measurement in Africa/Global South? We now broaden the analysis of keywords to analyse the co-occurrence of keywords used in papers citing the papers in our sample. The citation analysis identified 527 papers that cited 27 of the papers in our sample. These are the 27 papers covered by Scopus, for which the necessary information was available. The analysis includes keywords that occurred at least five times and ranged from five to 165 occurrences. A total of 144 were identified as the most frequently occurring terms, out of 3026 keywords.

What were the main topics covered by papers citing our sample of papers on STI measurement in Africa/developing countries/Global South? Based on the citation analysis, the following topics were most highly cited: a trend related to 'sustainability' and included 'sustainable development' and the 'green economy'; a trend related to 'technological innovation' and 'technology adoption', with some relation to 'manufacturing' and 'SMEs'; and a third strand related to 'innovation policy', 'industry" and 'engineering'.

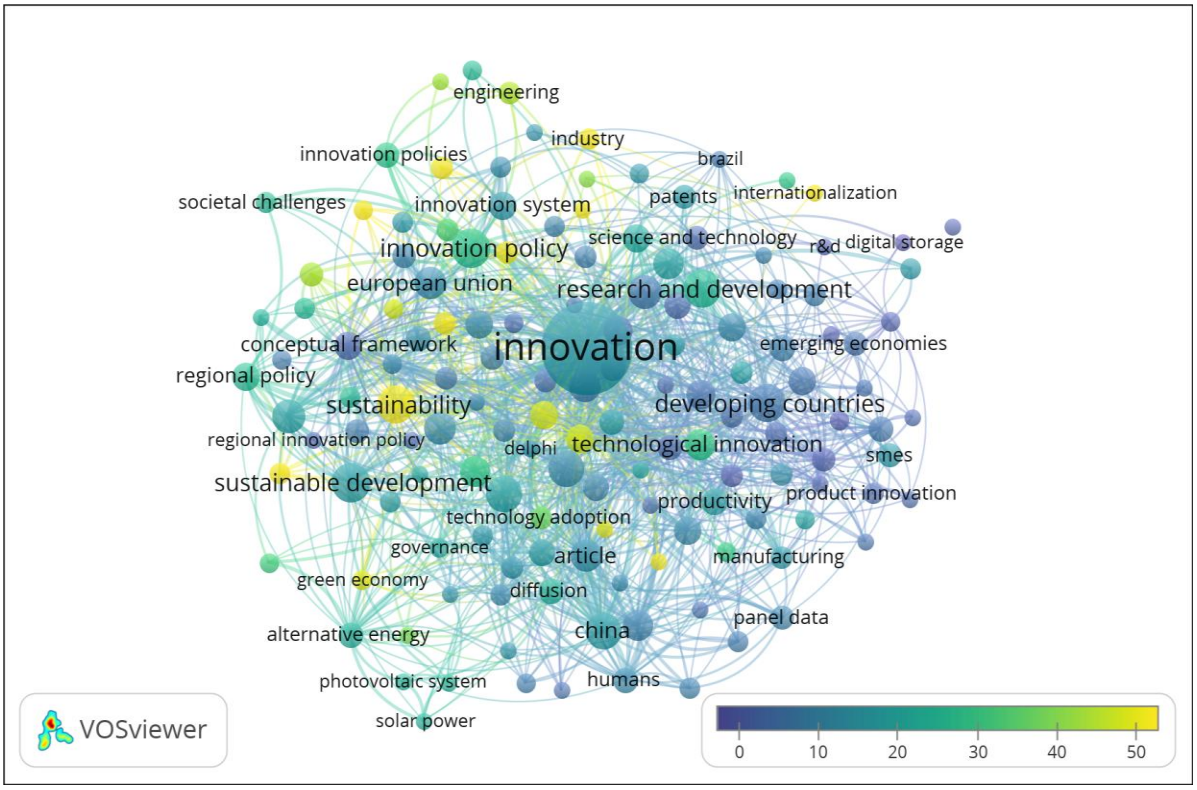

Figure 6. Map of citations

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

A citation analysis by publication year shows that the focus on sustainable development and sustainability, specifically in relation to alternative energy sources is relatively recent. Also recent, but not receiving as much attention is research on innovation measurement in Africa/developing countries and 'social challenges', as well as 'product innovation'. Research on China also appears prominently as interest in the country has grown in recent years. Africa and countries in Africa do not appear as frequently in the academic conversation.

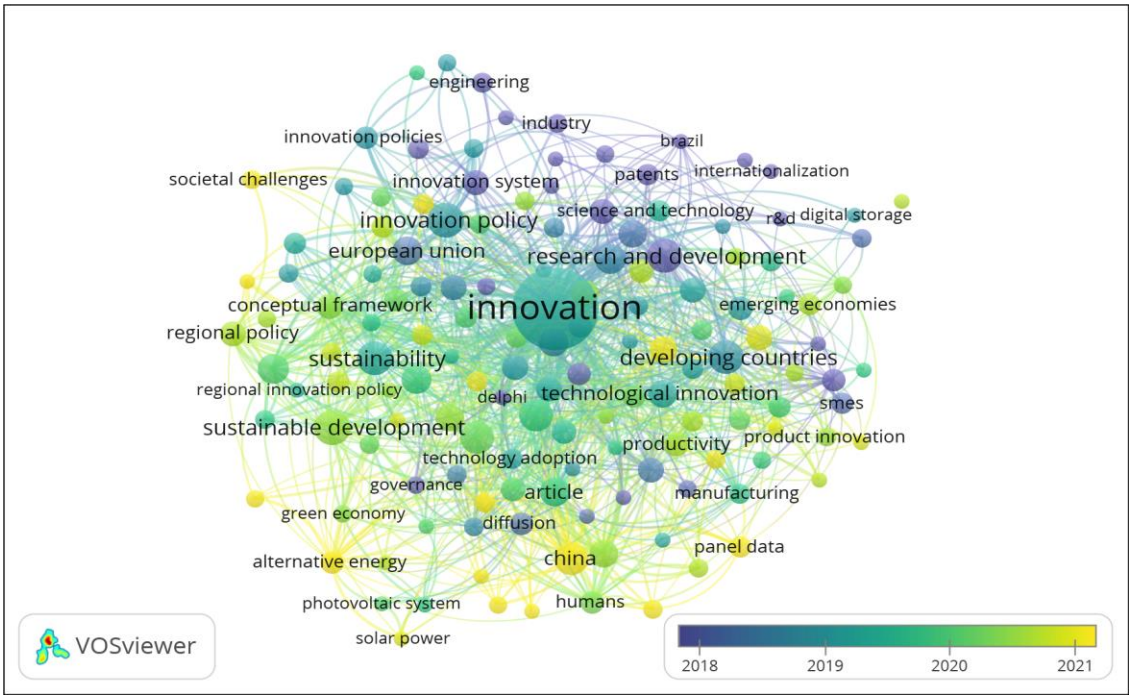

Figure 7. Map of citations by publication year

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

D.2 What does the geographical structure of STI measurement in the Africa/Global South research network look like?

The geographical location of the authors, based on their institutional affiliations, were analysed and related to the average citations and publication year. The analysis shows that researchers in South Africa are most prolific in this area of research. Interestingly though, the South African research is cited far less than research by authors in the Netherlands and United Kingdom (Table 3). The South African research is thus not as influential. The top 10 cited papers in Table 4 indicates that the most cited papers tend to be seminal papers and reviews of the literature.

Table 3. The top six countries that produced a minimum of two papers

Country	Documents	Citations	Total link strength
South Africa	13	72	4
Netherlands	4	300	3
United Kingdom	4	333	3
Uruguay	2	20	2
Iran	2	7	1

Weight: Citations **Scores:** Average Publication Years

Source: Created in VOSviewer, by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

Table 4. Top 10 cited papers

Citation count (Scopus)	Author/s	Title	Year	Journal reference	Institutional affiliation
156	Christopher Freeman, Luc Soete	Developing science, technology and innovation indicators: What we can learn from the past	2009	Research Policy	SPRU, Sussex University UK; UNU-MERIT, University of Maastricht, Netherlands
132	Giacomo Zanello, Xiaolan Fu, Pierre Mohnen, Marc Ventresca	The creation and diffusion of innovation in developing countries: a systematic literature review	2015	Journal of Economic Surveys	School of Agriculture, Policy and Development University of Reading; Department of International Development, University of Oxford; Saıd Business School, University of Oxford
86	Lars Coenen, Teis Hansen and Josephine V. Rekers	Innovation Policy for Grand Challenges. An Economic Geography Perspective	2015	Geography Compass	Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Lund University; Nordic Institute for Studies in Innovation, Research and Education (NIFU)
44	Sorin M.S. Kramme	Science, technology, and innovation for economic competitiveness: the role of smart specialization in less-developed countries	2017	Technological Forecasting & Social Change	Centre for International Business, Leeds University Business School, Leeds LS29JT, United Kingdom
26	Jorge Niosi	Rethinking Science, Technology and Innovation (STI) Institutions in Developing Countries	2010	Innovation	Department of Management and Technology, Université du Québec à Montréal, Canada Research Chair on the Management of Technology, Montréal, Québec, Canada
26	Xavier Cireraa SilviaMuzib	Measuring innovation using firm-level surveys: evidence from developing countries	2020	Research Policy	Firms, Innovation and Entrepreneurship Unit, Finance, Competitiveness and Innovation Global Practice, The World Bank Group, Washington, DC, Unites States; and Enterprise Analysis Unit, Development Economics Vice Presidency, The World Bank Group, Washington, DC, Unites States

20	Willie Siyanbola, Adedamola Adeyeye, Olawale Olaopa, and Omowumi Hassan	Science, technology and innovation indicators in policy-making: the Nigerian experience	2016	Palgrave Communications	Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria; National Centre for Technology Management, Obafemi Awolowo University, Ile-Ife, Nigeria; Department of Political Science, Osun State University, Osogbo, Nigeria; Department of Politics and International Relations, North-West University, Potchefstroom, South Africa; High Tech Centre for Nigerian Women and Youths, Abuja, Nigeria
16	Danielle Nel and Lucia Masilela	Open Governance for improved service delivery innovation in South Africa	2020	International Journal of eBusiness and Government Studies	School of Public Management, Governance and Public Policy, University of Johannesburg; School of Public Management, Governance and Public Policy, University of Johannesburg
16	Judith Sutz	Measuring innovation in developing countries: some suggestions to achieve more accurate and useful indicators	2012	International Journal of Technological Learning, Innovation and Development	Universidad de la República de Uruguay, Uruguay
13	Fred Gault	Science, Technology and Innovation Indicators: opportunities for Africa	2008	The African Statistical Journal	Science, Innovation and Electronic Information Division at Statistics Canada
11	Sibusiso T. Manzini	Measurement of innovation in South Africa: an analysis of survey metrics and recommendations	2015	South African Journal of Science	Green Matter, Johannesburg, South Africa

We took this analysis further by analysing the geographical locations of the 527 papers that cited 27 of the papers in our sample. Only countries with at least five papers were included in the analysis. The network diagram reflects the dominance of European countries, as well as Australia and the United States in the academic conversation (Figure 8). The same analysis by publication date shows an emerging trend growing around the influence of emerging economies in Asia, and Latin American countries to a lesser extent (Figure 9). In Africa, Nigeria and South Africa are the only two countries with at least five papers on STI measurement in Africa/Global South. Considering that the small body of literature from these countries appears to be more recent, it suggests an upward trend in publications from these countries.

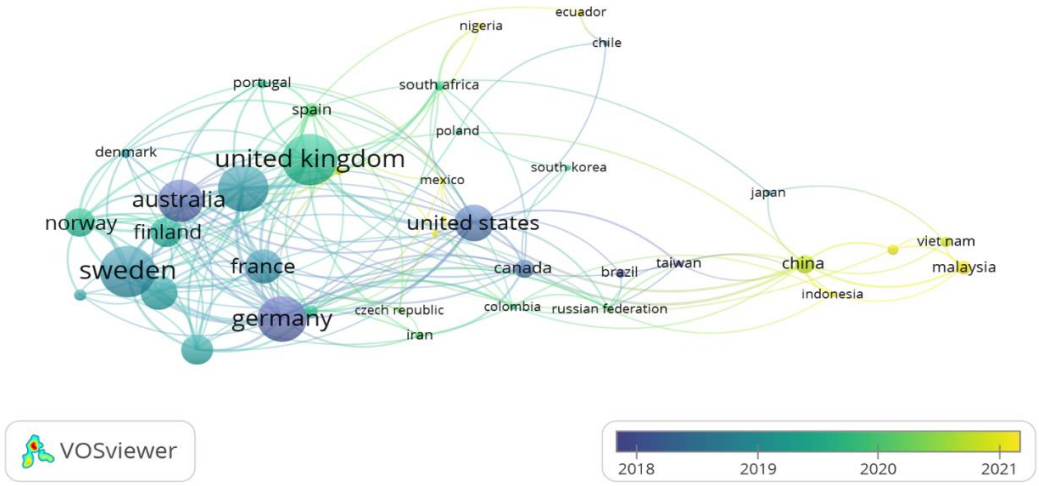

Figure 8. Map highlighting the geographical locations of authors citing papers on STI measurement in Africa/Global South

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

A strong but perhaps expected trend, therefore, is that citations and the academic conversation are still dominated by countries in the Global North. It will take time and effort for this picture to change, even with the emerging research networks from Nigeria and South Africa (see Figure 9).

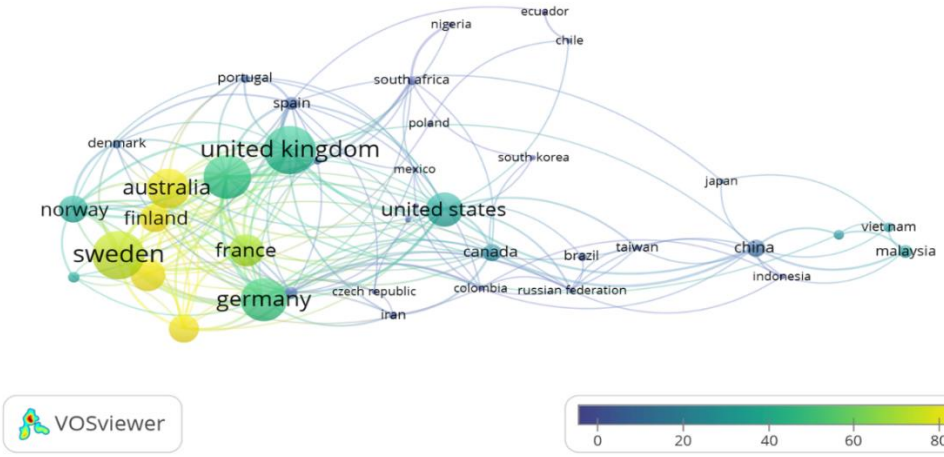

Figure 9. Map highlighting the geographical locations of authors citing papers on STI measurement in Africa/Global South, by publication date

Source: Created in VOSviewer by Frieda Billson and Shingirirai Muzondo (eRKC, HSRC)

D.3 What does the bibliometric analysis tell us about the main topics covered and geographical structure of the academic conversations related to STI measurement in Africa/Global South?

To sum up the bibliometric analysis. It highlights well-researched topics, including 'STI measurement' and 'developing countries' more broadly, and approaches, including 'economics' and 'innovation systems. As discussed in Section C, the focus is on how international standards and existing approaches can be adopted by and extended for developing country contexts. A few papers by leading international scholars, including from the Global South (for example, Judith Sutz from Uruguay), dominate the academic conversation. 'STI indicators' has been on the research agenda for several years and continues to be an area of interest in the Global South, including Africa. This may be linked to research on 'STI measurement' and 'STI policy', another well-researched topic.

A more recent area of interest that is growing rapidly is STI measurement and 'sustainable development'. A growing focus has been on 'sustainability' and 'alternative energy' sources, in recent years. The 'impact' of STI, 'social innovation' and 'social challenges' have appeared in recent years but received less attention.

Emerging areas of research in Africa centre around measurement in relation to digital technologies and the 'Fourth Industrial Revolution', and innovation in the 'informal sector'. In general, research on STI measurement in African countries and Africa, as a region of interest, is under-researched. The bibliometric analysis points to an *emerging* trend with 'Africa' as a region of interest, with research growing since 2019.

The emerging body of literature on Africa appears to be led by South African and Nigerian researchers, but relative to other regions in the Global South, the research base is nascent, and growing at a slower pace. Historically, research and academic conversation on STI measurement in Africa and the Global South has been led by researchers in the global north. In recent years, there has been rapid growth of research on the topic led by researchers in Asia, particularly China, and Latin America. Considering that measurement tends to lag behind research, this trend suggests it will take quite some time for African countries to develop measurement programmes underpinned by contextually informed conceptual frameworks, instruments and methodologies.

E. AREAS FOR NEW RESEARCH TO UNDERPIN THE DESIGN OF STI INDICATORS AND MEASURES

The bibliometric analysis identified emergent trends and gaps. This section hones in on four potentially fruitful areas to strengthen the research base as a foundation for contextualised STI measurement and indicators. The analysis in this section maps out key issues, conceptual frameworks and emerging empirical research, as a means to recommend lines of academic research within the AfricaLics network.

E.1 Identifying African modes of innovation capabilities

The conceptual models underpinning current measurement paradigms, based on innovation patterns in high-income contexts, may steer STI policy in the wrong directions. Many African firms in low- and middle-income contexts are more likely to reflect modes of innovation activities that take the form of adoption, imitation or adaptation of new technologies acquired from elsewhere, rather than R&D or STI driven, or may not have the required capabilities to access and absorb new technologies. Or, there may be contextually important emergent forms of innovation that are not typically measured nor supported in high-income countries, but which should be grown and nurtured in low and middle-income contexts.

Appropriate and relevant indicators therefore need to be informed by context-specific evidence on the determinants and nature of technological learning and upgrading in local firms (Edler, 2009; Lall, 1993; Lorentzen, 2009). Unfortunately, as Section D suggests, there is only a small evidence base of the relative spread, importance, and intensity of innovation capabilities in specific clusters of firms in African economies. We thus propose research to map and profile the modes of innovation found across local firms.

Initially, in the late 1990s and early 2000s in the innovation research and policy literature, the definitions of innovation modes were simple, based on binary distinctions between degrees of novelty (radical or incremental) or high-level types of activity (product or process). Disaggregated analysis could examine the drivers, outcomes and barriers of types of innovation, across and between industrial sectors. These indicators are used for benchmarking progress over time, and to compare national progress relative to other countries, as discussed in Section B. They have limited value in providing policy evidence to understand distinctive national, sectoral or regional patterns that reflect local innovation capabilities

Over time, more nuanced and complex distinctions have emerged in the literature, as understanding of innovation activity in different sectors, types of firms, and regional and national systems has grown (Arundel and Hollanders, 2008; Roud, 2018; Vargas, 2022). Much of the research used the taxonomical principles elaborated by Peneder (2003), to define modes in one or more of three ways:

a "cut-off" approach using a single variable, yielding the typical binary indicators; data-driven taxonomies using a range of dimensions; top-down mixed classifications using multiple variables. Researchers in a range of countries now critically interrogate the application and value of different taxonomies and analytical models (Arundel and Hollanders, 2005; Bogliacino and Pianta, 2016; Huang et al., 2010). Some identify patterns of innovation by categorising firms in terms of science intensity – R&D, non-R&D and technological-driven innovation (Huang et al., 2010). Some focus on illuminating "hidden" forms of innovation that were under-studied, such as external innovation investments (O'Brien, 2016) or design-led innovation (Fillipetti, 2011; Townson et al., 2016).

Examples and models to define African modes can be drawn from a range of attempts to define contextually specific classifications of modes of innovation, both conceptually and empirically, to track changes over time (Gokhberg and Roud, 2016; Gokhberg, 2018) or in specific countries (Peneder, 2007; Hagen, 2014) or regions (EUROSTAT, 2020; Frenz and Lambert, 2012; Vargas, 2022). A potentially significant stream of research distinguishes STI and DUI modes of innovation particularly in SMMEs (Jensen et al., 2007; Parilli and Heras, 2016; Parrilli and Radicic, 2021; Alhusen et al., 2021), and is gaining traction as an analytical model in African contexts (Lukhele and Soumonni, 2020; Hooli et al., 2019; Hansen-Addy, 2021).

Modes of innovation that are typically unexplored in the literature may have great policy significance in low- and middle-income country contexts. Indicators for modes of innovation in low- and middle-income African countries should capture activity across the full spectrum of innovation capabilities, and be particularly fine-grained at the adoption, imitation, and modification end of the spectrum. As a starting point, researchers can critically interrogate, extend, and adapt the research literature on modes of innovation that improve upon simple binary indicators by classifying firms in a more fine-grained manner to capture complexity along multiple dimensions.

E.2 Defining innovation in informal enterprises

Whereas measuring innovation in formal enterprises has evolved over decades through the iterations of the Oslo Manual (OECD/Eurostat, 2018), there is little international precedent for measuring innovation in informal enterprises. A foundation has been laid with experimental African attempts, including sectoral studies such as that done in Senegal (Konte and Ndong, 2012); and a set of case studies and surveys of innovation in the informal economy (Kraemer-Mbula and Wunsch-Vincent, 2016). A gap in this emerging literature is innovation measurement that is not industry or sector specific.

An important starting point is to clearly define what is being measured. The emerging empirical literature on the informal sector in Africa has pointed to ways in which innovation differs from that in formal enterprises, including its mainly non-technological and necessity-driven nature (Petersen and

Kruss, 2021); the importance of local embeddedness and innovation as 'every day activities' in 'every day settings' (Hoffecker, 2018); and the prevalence of experiential forms of learning involving mainly imitative practice and learning by doing and using, rather than through interaction or R&D (Kraemer-Mbula et al., 2019). Some have questioned the significance of informal sector innovation, and whether the activities described in fact count as innovation. Others have pointed to the significance of informal sector innovation for building innovation ecosystems at the local level rather than for identifying and scaling up innovative products and solutions (Hoffecker, 2018).

Charmes et al (2018), among others, have suggested approaches for measuring and understanding innovation in the informal sector. In grappling with the problem of the suitability of the conceptual foundations of existing measurement frameworks, there is experimentation with novel analytical frameworks for understanding innovation at the local level, drawing on and extending international standards (De Beer et al., 2013; Mustapha et al., 2021). Some have attempted to leverage existing methodologies and surveys such as the Global Innovation Index and the Global Competitiveness Index to develop contextualised indicator frameworks but have found gaps (Hassouna, 2018; Rizk et al., 2018). In South Africa, researchers have adapted and contextualised the standardised formal business innovation questionnaire for informal businesses, informed by in-depth qualitative research and cognitive testing with informal business owners (CeSTII, 2020; Mustapha et al., 2021). The same questionnaire has been piloted by counterparts in Nigeria. The research methodology is participatory and involves a mix of methods to be able to build up a bottom-up understanding of innovation in the informal sector, and at the same time, use this understanding to inform and implement measurement.

This new approach may be beneficial, considering the slow growth of research in Africa. The experimentation with measurement in informal enterprises was presented and discussed at the 2022 AfricaLics conference during a special session on informal sector innovation. Also discussed was experimental work aimed at investigating the role of informal sector actors in R&D in Namibia, starting with including questions in the national R&D survey. The role of Africa-wide organisations such as AUDA-NEPAD in co-ordinating and supporting the measurement of innovation in the informal sector was emphasised.

The recent experimental work by African researchers raises important points for further research around Africa-focussed innovation measurement: How useful are such attempts at adapting and extending well-established analytical frameworks underpinning international measurement standards, for policy and stimulating local development? What lessons can be learnt from current efforts to put together a measurement framework that responds directly to the need to understand innovation activity in the informal sector on the continent, and how can these be linked to the existing measurement programmes of formal sector innovation?

E.3 The potential of digital technologies and the Fourth Industrial Revolution

In developing countries, digitalisation has proven to be an important driver of economic growth because of its potentially positive impact on raising capital and labour productivity, lowering transaction costs, and improving access to global markets (Dahlman, et. al., 2016). Smart technologies in sub-Saharan Africa are beginning to play important roles in economic activities, such as giving citizens access to modern communication systems, financial inclusion for the poor through mobile banking, and increased participation of small businesses through e-commerce (Myovella, et. al., 2020). Meanwhile, nations are currently confronting issues of technological advancement in digitalisation and automation (de Man and Strandhagen, 2017). The convergence, configuration, and application of principles such as digitalization, automation, interoperability, virtual applications, decentralised systems, real-time capabilities, orientation for service and modular production have been termed "Industry 4.0" (Ghobakhloo, 2018; Stock and Seliger, 2016; Lasi, et. al., 2014; Kagermann et. al., 2013). It has also been described as 'the products, the different stakeholders such as customers, workers or suppliers, and the manufacturing equipment that are embedded in a virtual network and are interchanging data in and between the different phases of a product life cycle' (Stock and Seliger, 2016).

Despite the deep interest of many governments, policy makers, captains of the industries, academic scholars and media in Industry 4.0 in Africa, adequate understanding of this phenomenon within the global economy, and particularly in Africa, is yet to be achieved (Castellani, et. al., 2022). Some scholars have made efforts to track progress and deepen understanding by collecting data through surveys in specific countries, or assessing specific technologies, or in-depth examination of innovation through case studies (Dachs et al., 2019; Delic and Eyers, 2020). The reason behind the inadequate knowledge in this field has been linked to weak theoretical and conceptual frameworks, as well as lack of reliable and accurate indicators to measure the development and utilization of digitalisation on a large scale across countries and over time.

In high-income economies, some indicators have been produced to measure the readiness of their countries towards Industry 4.0. For instance, Ronald Berger Strategy Consultants (2014) developed an Industry 4.0 Readiness Index with two sets of indicators, called industrial excellence indicators and value network indicators, and used it to rank countries in Europe. This index categorised industrial European countries into four: frontrunners, the traditionalists, the hesitators, and the potentialists. At the same time, Nick and Pongrácz (2016) proposed an indicator that can be used to measure city readiness through a Smart Collaboration Index, assessing two main dimensions. The first dimension consists of performance indicators versus enablement indicators, and the second dimension comprises indicators of actors and their performance, such as industry, regulatory and economic environment, and academy. Kuruczleki et al. (2016) also used eight indicators to create a Fourth Industrial Revolution readiness index for the European Union.

Given the socio-economic realities within Africa, the issue of conceptualising and developing reliable indicators for Industry 4.0 should become a priority. The process of digitalisation started much later in developing countries. While the main intent of digitalisation in high-income countries is marketing, that of the low- and middle-income countries is to make profit and to address societal grand challenges. Other differentiating factors to consider include barriers such as costs (lack of financial resources), infrastructural, institutional (lack of policy support), and a lack of skilled manpower (Bogoviz et al., 2019; Kamble et al., 2018).

Stronger research efforts are required to improve our understanding of the magnitude of production, adoption, and utilisation of Industry 4.0 in Africa and its evolution over time with appropriate theoretical and conceptual framings. From a methodological point of view, tracking the growth and evolution of Industry 4.0 technologies is particularly complicated without reliable data, especially when the evolution is still ongoing and the technology is not mature. It is important to track the geographical spread across the continent and the presence of specialised clusters, through reliable indicators. Being able to measure and track the development and evolution of digitalisation and Industry 4.0 in Africa would enable understanding of a relatively new phenomenon, to inform appropriate public policy and private sector interventions.

E.4 Orienting STI measurement and indicators to promote the Sustainable Development Goals

The report has discussed the impact of global sustainability challenges and inequality gaps on standard STI policy models and measurement frameworks. The simultaneous emergence of the new frame and approach, of transformative innovation policy, opens up new perspectives on indicators. These trends draw attention to the intended directions of policy change towards inclusive and sustainable development, and to the processes that are activated to enact a theory of change as articulated in policy intents. Significantly, it shifts the main unit of analysis from firms to other actors and beneficiaries in the national system of innovation.

The STI policy vision of most African countries is aligned with the commitment to contribute to achieving the United Nations' Sustainable Development Goals (SDGs), as a shared framework for transformation through innovation globally; and to the achievement of the African Union's *STI Strategy for Africa* (STISA) 2030, which focuses around six development priorities that prevail on the continent. To assess progress requires new STI measures and indicators oriented to societal challenges. The focus can be at a range of levels, from a very high-level development priority such as eradicating hunger and ensuring food security, to high-level societal grand challenges such as climate change and environmental sustainability, to a specific priority such as innovating and diffusing affordable, technologically appropriate and environmentally sustainable sanitation, energy or healthcare.

The existing frameworks and models of innovation measurement can serve as a core, but there is much conceptual and empirical research required to lay a foundation for these new kinds of indicators. For example, standard STI indicators are typically drawn from datasets that measure input dimensions, such as R&D expenditure or human resources. The major challenge is to conceptualise and define the outcome and impact measures of STI activity, such as strengthened technological capabilities, more effective utilisation of digitalisation, improved sustainability, or wider inclusion of citizens in the opportunities and benefits of innovation.

F. CONCLUSION: A RESEARCH AGENDA FOR AFRICALICS ON STI MEASUREMENT

What would a "holistic innovation" (Chen et al., 2018) paradigm based on African cultures look like? One that is underpinned by contextualised conceptualisation of innovation and methodologies and that addresses societal challenges prioritised in African countries? This report makes a start at developing a research agenda to build a knowledge base to help address this question.

This review of STI measurement practice and research in Africa points to areas that have been well researched, under researched and not given much attention. Also highlighted are trends that show who is playing a role in shaping the agenda. Based on this review, we describe a research agenda to develop conceptual and empirical frameworks, indicators, and measurement appropriate to African country contexts.

Contextualised STI indicator development

STI indicators should remain on the research agenda but with greater focus on their contextualisation. Designing STI indicators requires a stronger knowledge base of the structure, dynamics and path dependencies of specific African economies and innovation systems. In particular, the nature of 'enterprise' activity and organisation in informal settings is a major research gap to close.

New analysis of R&D survey data related to development priorities in Africa

Relative to business innovation surveys, R&D surveys are well established in many African countries. STI data is thus most complete for R&D. It is important to build on current experimental work analysing R&D survey data in new ways to address development priorities important for African countries. For example, mapping and tracking investment in health or green R&D, or R&D expenditure and collaboration related to indigenous knowledge. The extent and nature of collaboration between formal businesses, NPOs, higher education, science councils and informal sector actors such as indigenous knowledge holders and practitioners is worth exploring. The informal economy is significant and indigenous knowledge is highly valued in African countries. Taking this kind of R&D related research further may also contribute to research on STI measurement that contributes to monitoring and evaluating progress towards the sustainable development goals (SDGs).

STI measurement towards advancing the SDGs and understanding impact

The importance of STI and the measurement of STI to advance the SDGs is high on the international agenda. Clear measurement frameworks tracking STI in relation to the SDGs are not yet available anywhere. In general, measuring the impact of STI interventions is a more recent focus in the literature but has not yet received much traction. Our review of the literature shows that these topics are not yet well studied. Research centred around sustainable development, specifically environmental

sustainability appears to be a growing research trend in the Global South, but not in Africa specifically.

More priority for research on environmental sustainability

In Africa, in relation to sustainable development, research on poverty and inequalities tends to be prioritised more than climate change, alternative energy sources, and so on. Given the current energy, water, and climate crises in African countries, these should be raised as priorities. Research is needed to inform and track the progress of interventions on renewable energy, for example. It is important to assess the direction and impact of innovations.

Understanding innovation capabilities in both the formal and informal sectors

To better inform policy, we need to be able to profile businesses, both formal and informal, to understand existing innovation capabilities and track changes in innovation capabilities over time and across regional and national borders. Recent research on modes of innovation in formal enterprises should be extended to other contexts, and to informal enterprises. Comparative research is also needed to understand the differences in geographical contexts and share methodologies. Research on modes of innovation also provides a different approach to understanding technological capability building, which is well researched.

Empirically grounded research on innovation measurement in the informal sector

Measuring innovation in the informal sector is a recent focus in the literature. There is a growing body of research on innovation in informal settings and a small part of this literature focuses on measurement. This area of research is arguably one of the most important areas of research for Africa because of the significance of informal economic activity. Also, because the informal sector is not high on the measurement agenda at the international level, it is an area where African researchers need to take the lead. African researchers can contribute to extending measurement guidelines as these are contextualised for the informal enterprises in African countries.

Considering the limited funding available for innovation measurement in Africa, research collaboration and comparative analysis across countries and within country contexts is important. Current research on measuring innovation in informal enterprises uses mixed methods research and proceeds with measurement while building a bottom-up understanding of informal sector innovation that can be used to inform the research instruments and methodology. The value of this approach to conducting measurement alongside research needs to be explored as a way to fast-track advances in measurement.

Measuring progress and the impact of digital technologies and the Fourth Industrial Revolution

Lastly, there is growing interest in the potential of digital technologies and other emerging technologies for development in African countries. This area can be further explored with digital technologies

providing the potential for leapfrogging. It is important to assess and track progress to get a sense of the extent and direction of leapfrogging. Assessing the directionality of digital technologies can also help to avoid creating or deepening development problems such as widening inequalities.

In conclusion, this AfricaLics thematic report highlights key areas of future research for Africa-focused innovation measurement. The next step is to workshop these to inform the development of a research agenda for academics, researchers, policymakers, practitioners and STI measurement experts in Africa. This workshop is planned to take place later in 2023.

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H. APPENDICES

Appendix 1 Full report on the bibliometric analysis compiled by HSRC's eKRC

Centre for Science, Technology and Innovation Indicators (CeSTII)

Topical Coverage + Geographical Scope

Date: 24 May 2023

Compiled by Frieda Billson

INTRODUCTION

This report covers the topical coverage and geographical reach of the 42 research outputs identified related to the subject area around innovation measurement but also covers 567 outputs that cite or reference 27 of the 42 outputs. The 27 outputs are primarily indexed in Scopus.

The **topical coverage** is based on analysing **keywords** indexed in Scopus, Elsevier's abstract and citation database, and the keywords assigned by the author.

For the **geographical scope** of the outputs, the **country affiliation of the authors** was retrieved from Scopus. This analysis only applies to peer-reviewed outputs as the country affiliation of authors is not available for outputs that were not available in Scopus.

Not all outputs are indexed by Scopus, a limitation that must be considered when interpreting the assessment.

The report is divided into two sections, i.e., a description of the nature of outputs identified by CeSTII staff, followed by a description of the nature of resources that cited or referenced the outputs identified.

SECTION 1: THE 42 RELEVANT RESOURCES IDENTIFIED

1.1. Topical coverage (keywords – indexed and author keywords)

The keywords were analysed in VOSviewer, a software tool for constructing and visualising bibliometric networks. Through text mining and co-concurrence visualisation, a picture emerged using the topical coverage of these outputs. To investigate the relationships between highly occurring terms, co-occurrence maps were created. Polley (2016) explains that in these maps, terms are represented in a two-dimensional space, with terms that appear more often in combination with other terms being placed closer together. Frequently co-occurring terms are clustered together, and these clusters are interpreted as representing research areas present in this group of outputs.

1.1.1. A minimum co-occurrence of two words (keywords – indexed and author keywords)

For the keyword visualisations, a minimum co-occurrence of words of two, with a selection of 29 of the most frequently occurring terms, was used out of 164 keywords. The occurrence of these keywords ranged from two to 18, with most of the keywords occurring between two and three times. Table 1 shows the keyword occurrence of those keywords that occurred four or more times.

Table 1. Keyword occurrence

Keyword	Occurrences	Total link strength
innovation	18	54
South Africa	6	21
research and development	4	20
Africa	3	9
developing countries	3	7
expenditure	3	18
indicators	3	11
literature review	3	13
Science	3	8
science and technology	3	15
developing world	2	7
economic development	2	9
economics	2	9
entrepreneurship	2	5
experimental study	2	15
fourth industrial revolution	2	7
innovation indicators	2	2
innovation metrics	2	6
innovation systems	2	8
patents and inventions	2	9
policy	2	11
policy approach	2	13
social development	2	6
STI indicators	2	13
technological change	2	10
technological development	2	10
technology	2	5
technology and innovation	2	10
technology policy	2	7

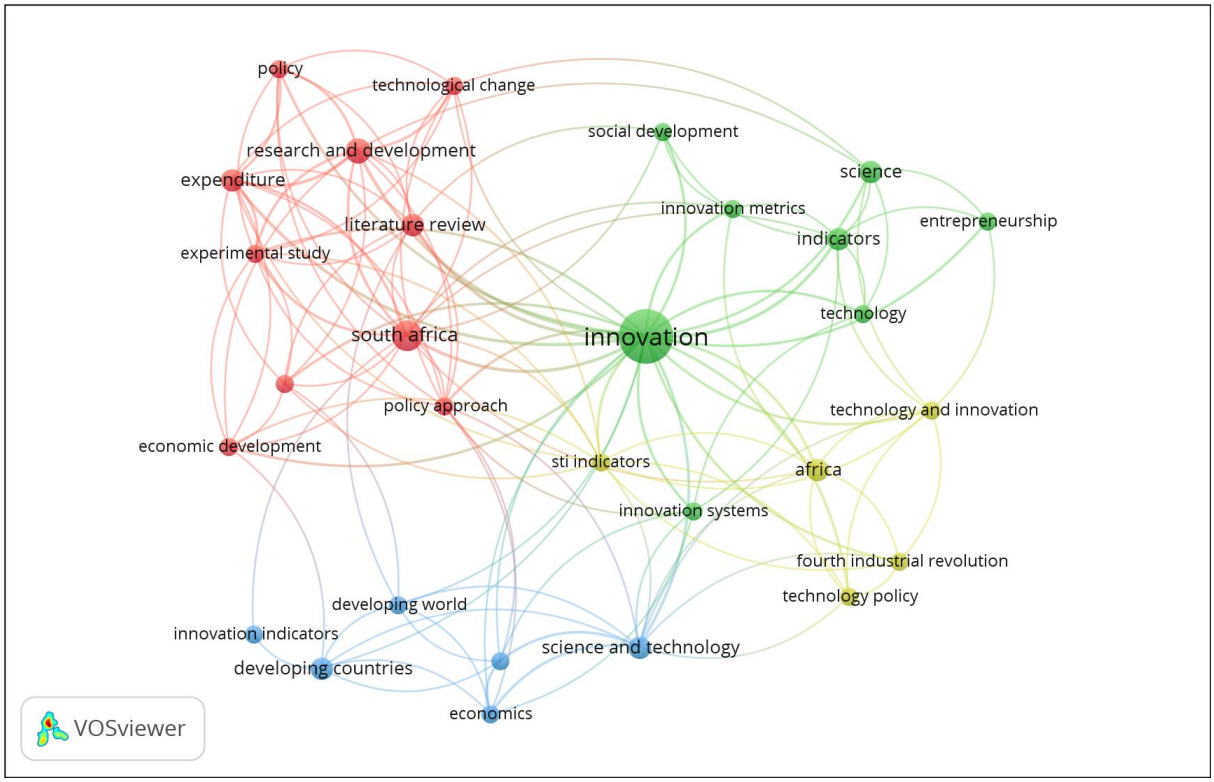

Figure 1. Network visualisation

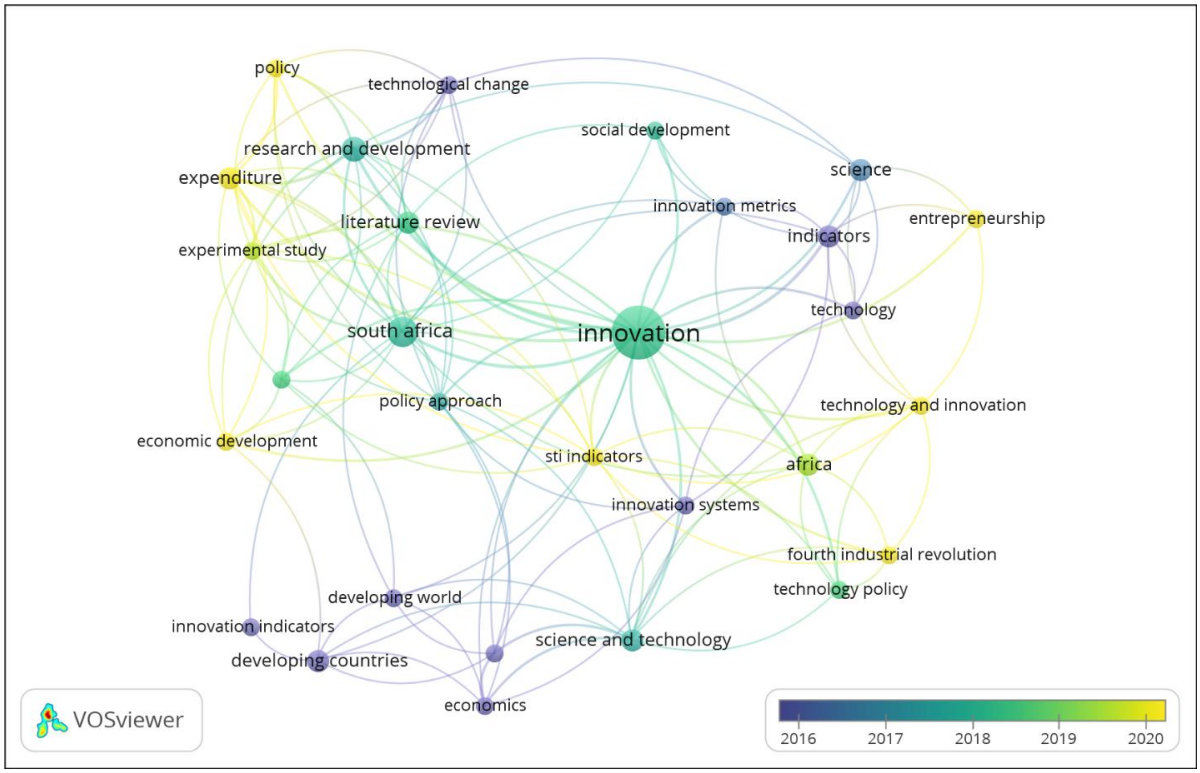

Figure 2. Network visualisation, occurrences (weight) by average publication year (score)

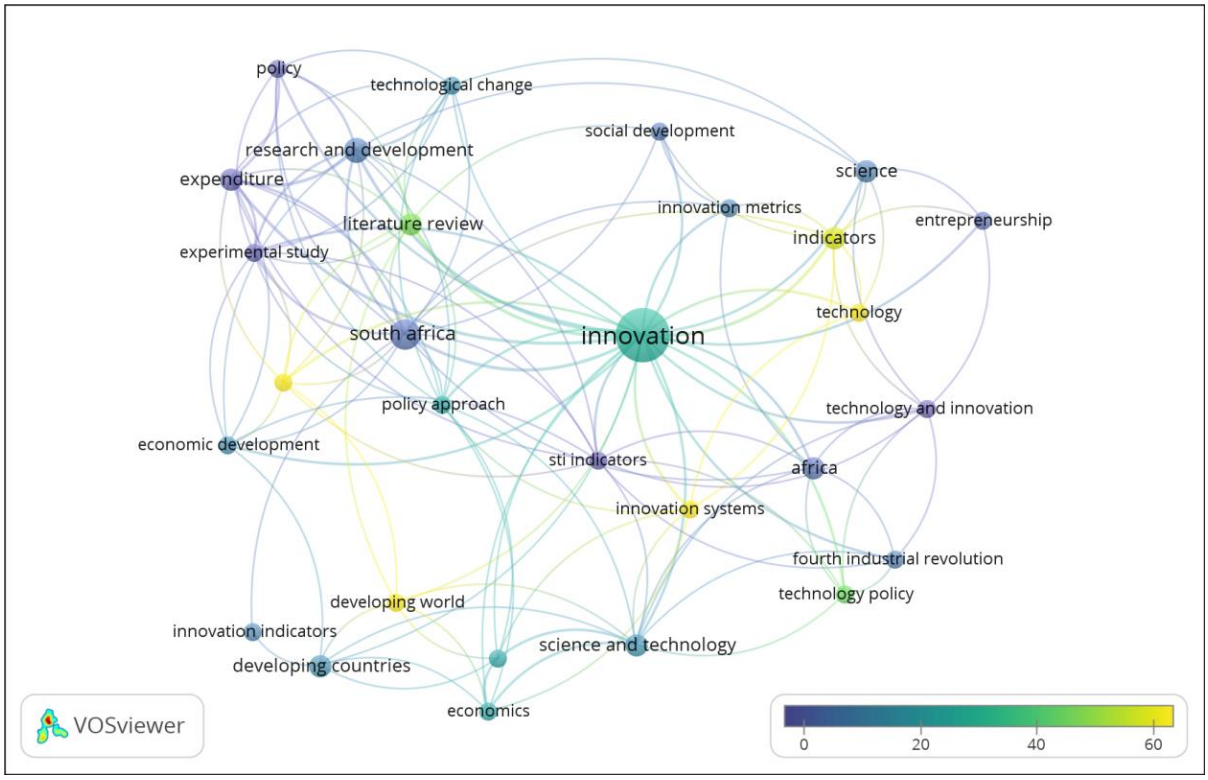

Figure 3. Network visualisation, occurrences (weight) by average citations (score)

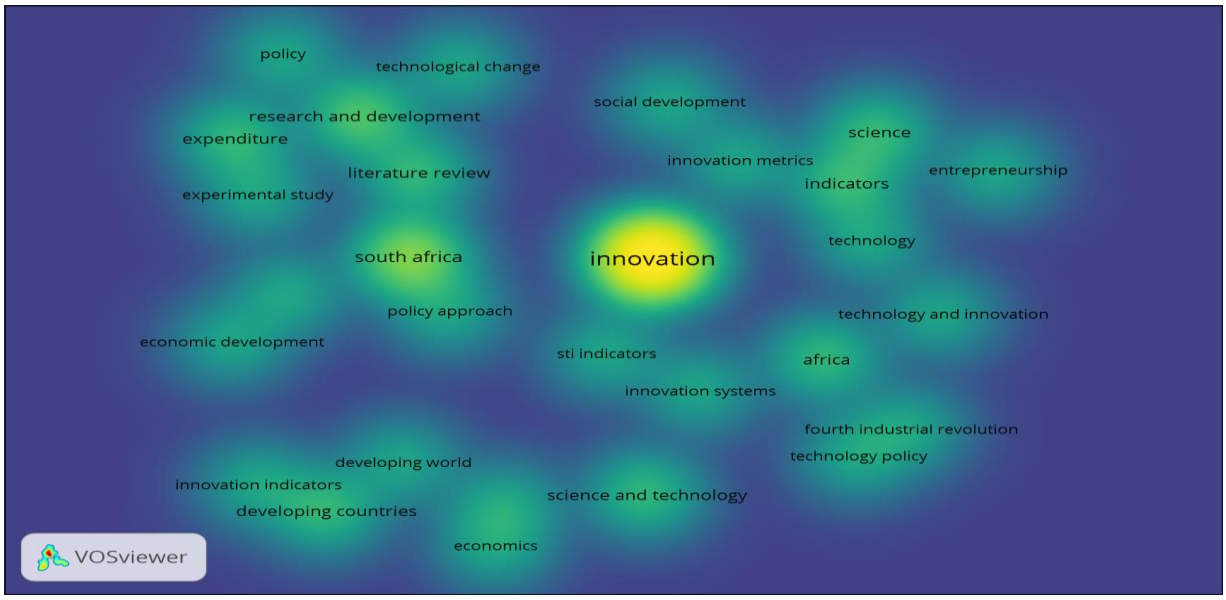

Figure 4. Density visualisation

1.1.2. A minimum co-occurrence of three words (keywords – indexed and author keywords)

For the keyword visualisations, a minimum co-occurrence of words of three, with a selection of ten of the most frequently occurring terms, was used out of 164 keywords. The occurrence of these keywords ranged from three to 10, with most of the keywords occurring between two and three times. Figure 5 shows the keyword occurrence of those keywords that occurred four or more times.

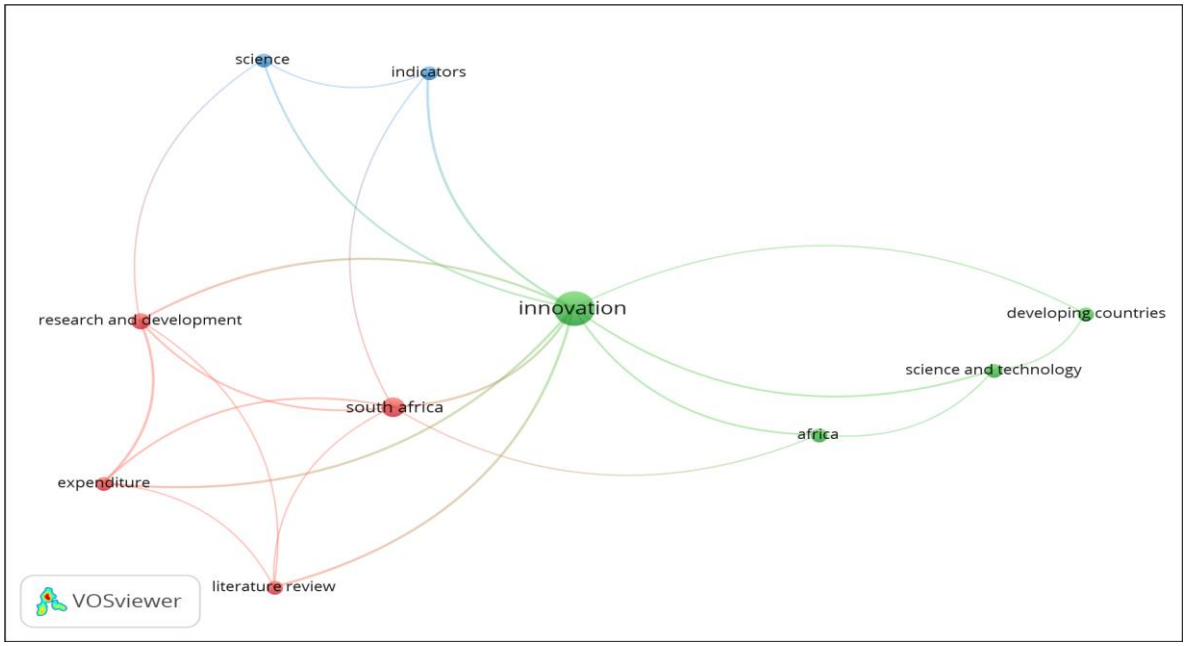

Figure 5. Network visualisation

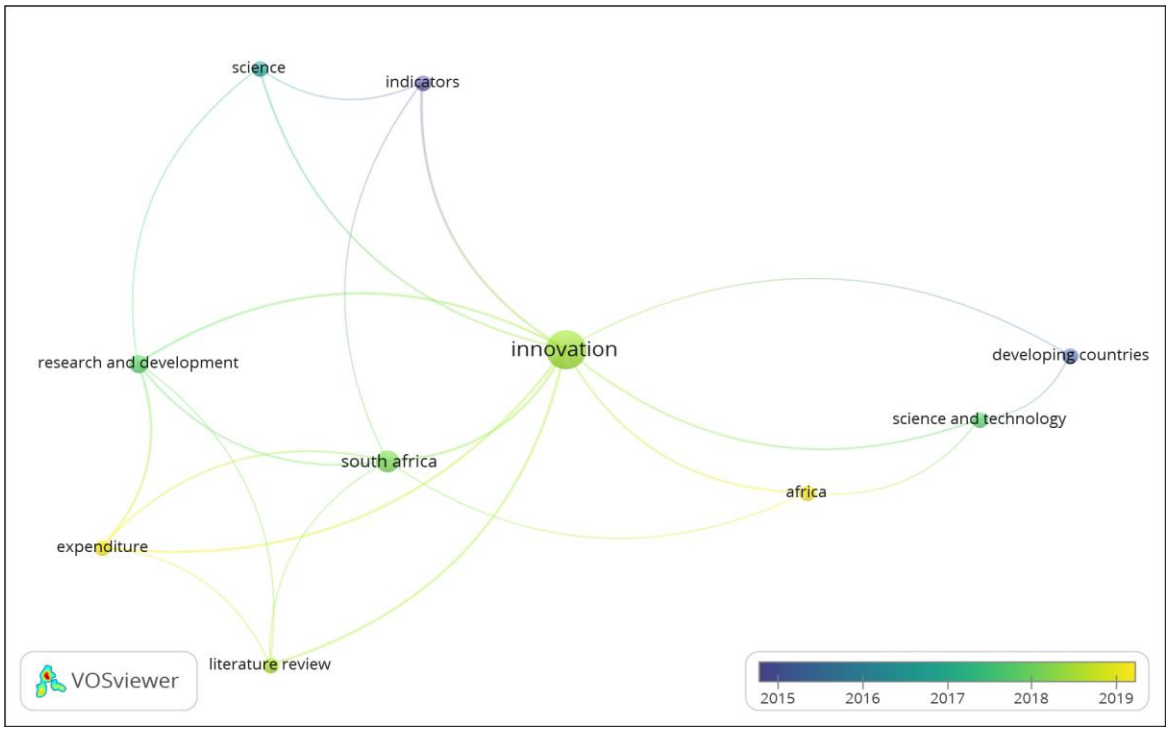

Figure 6. Network visualisation, occurrences (weight) by average publication (score)

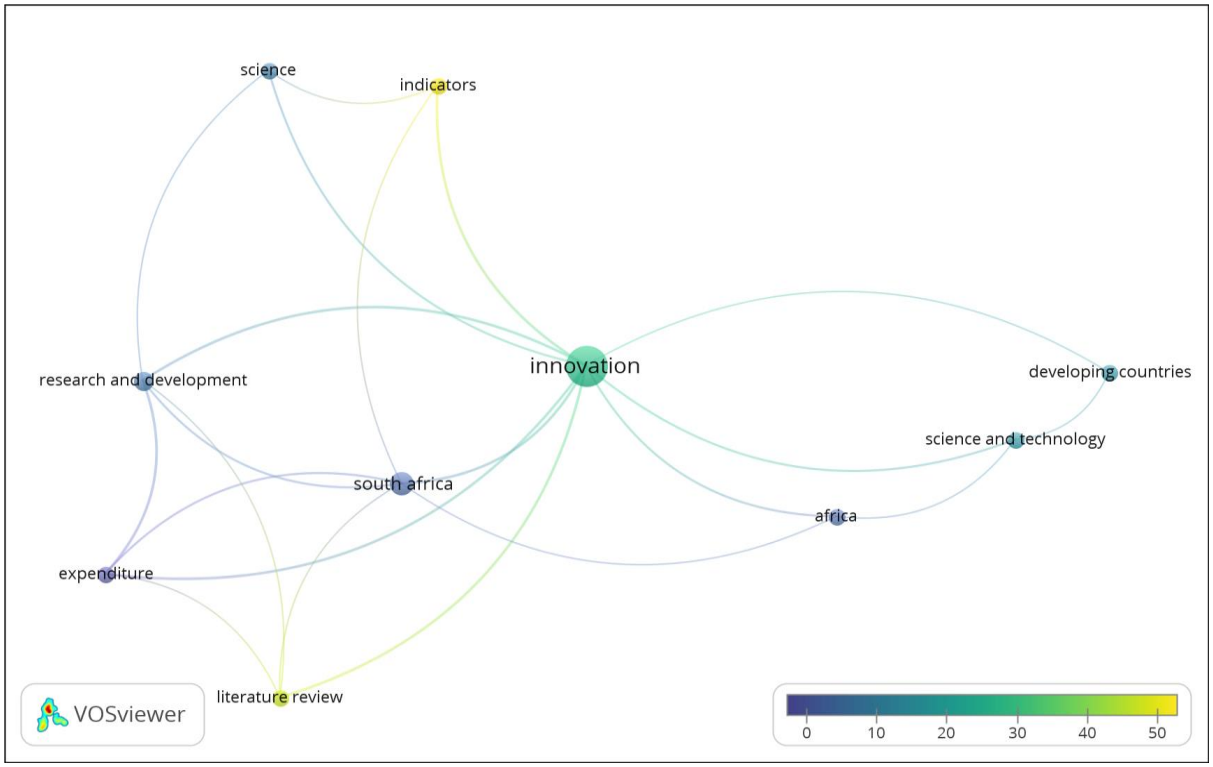

Figure 7. Network visualisation, occurrences (weight) by average citations (score)

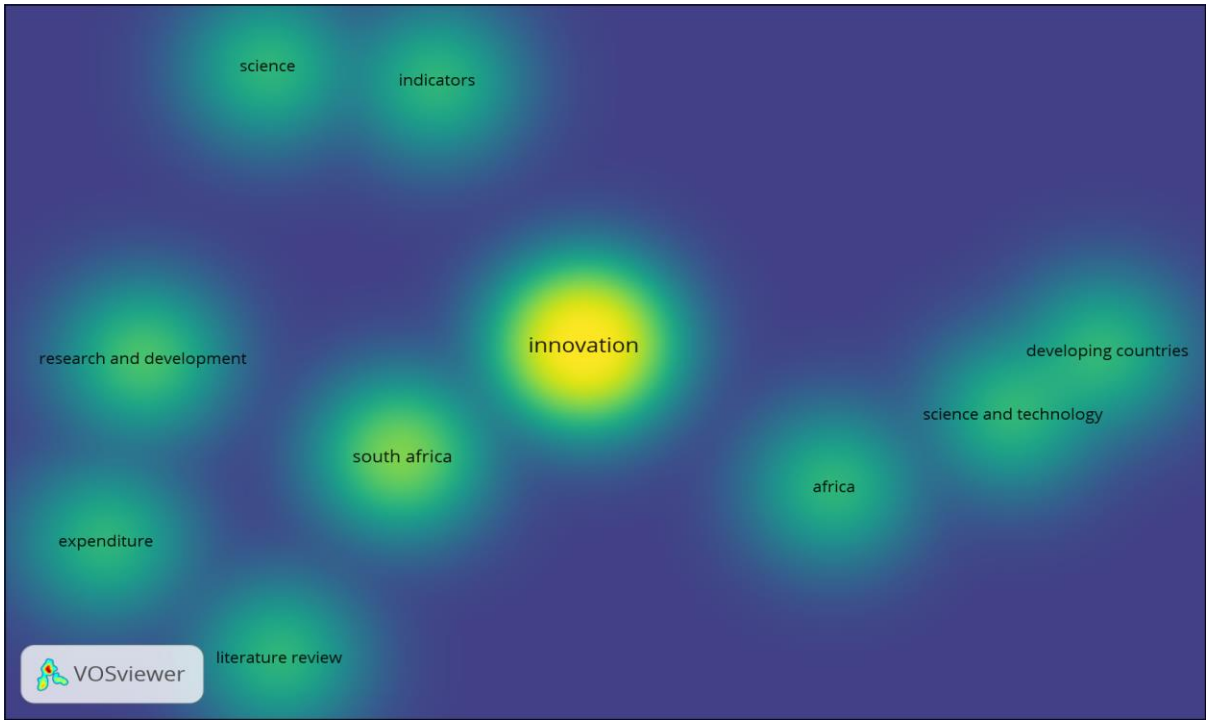

Figure 8. Density visualisation

1.2. Topical coverage (title and abstract)

The abstract and title fields were used to extract data to compare subject terms with each other from the 36 outputs that were either primarily indexed (27) or indexed as secondary documents. This excludes structured abstract labels (consisting of multiple labels) and copyright statements. For the keyword visualisations, the minimum number of occurrences of the term was three, with a selection of 117 of the most frequently occurring terms, which were used out of 872. For each of the 233 terms, a relevance score was calculated. Based on the score, the most relevant terms were selected. The default choice was to select 60% most relevant terms.

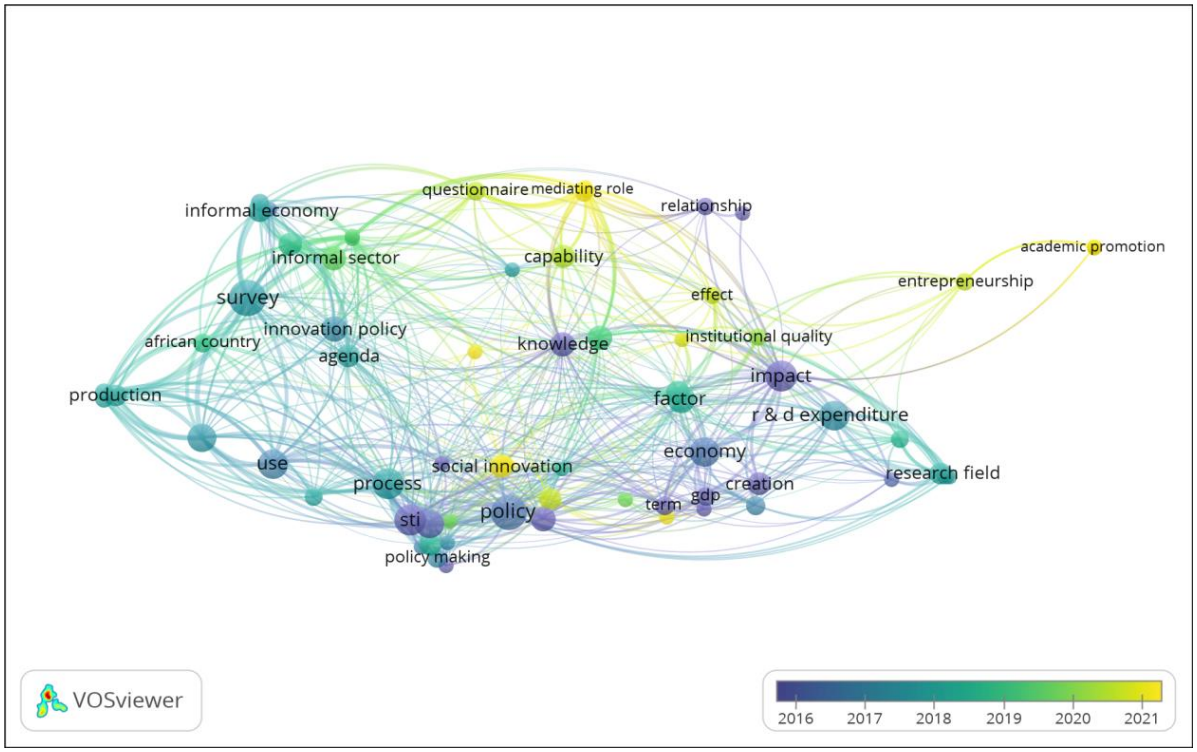

Figure 9. Network visualisation, occurrence of terms appearing a minimum of three times, by average publication year (score)

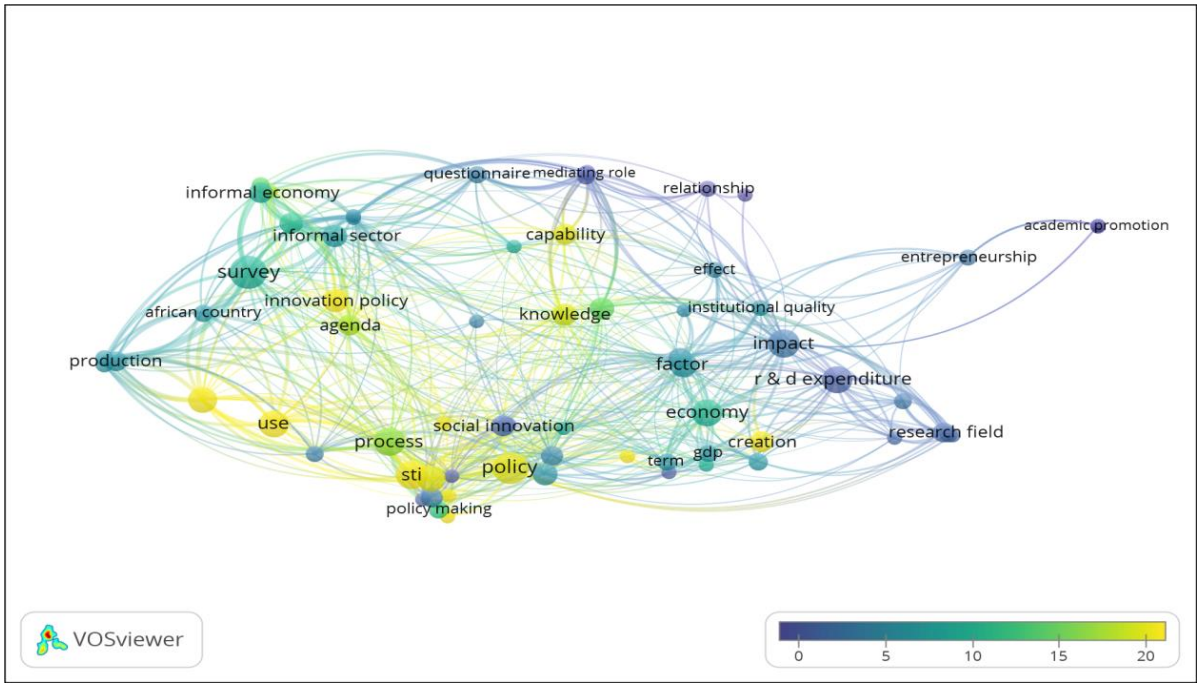

Figure 10. Network visualisation, occurrence of terms appearing a minimum of three times, citations (score)

1.3. Geographical scope – 42 outputs identified by CeSTII

Table 2. The top six countries that produced a minimum of two documents

Country	Documents	Citations	Total Link Strength
South Africa	13	72	4
Netherlands	4	300	3
United Kingdom	4	333	3
Uruguay	2	20	2
Iran	2	7	1

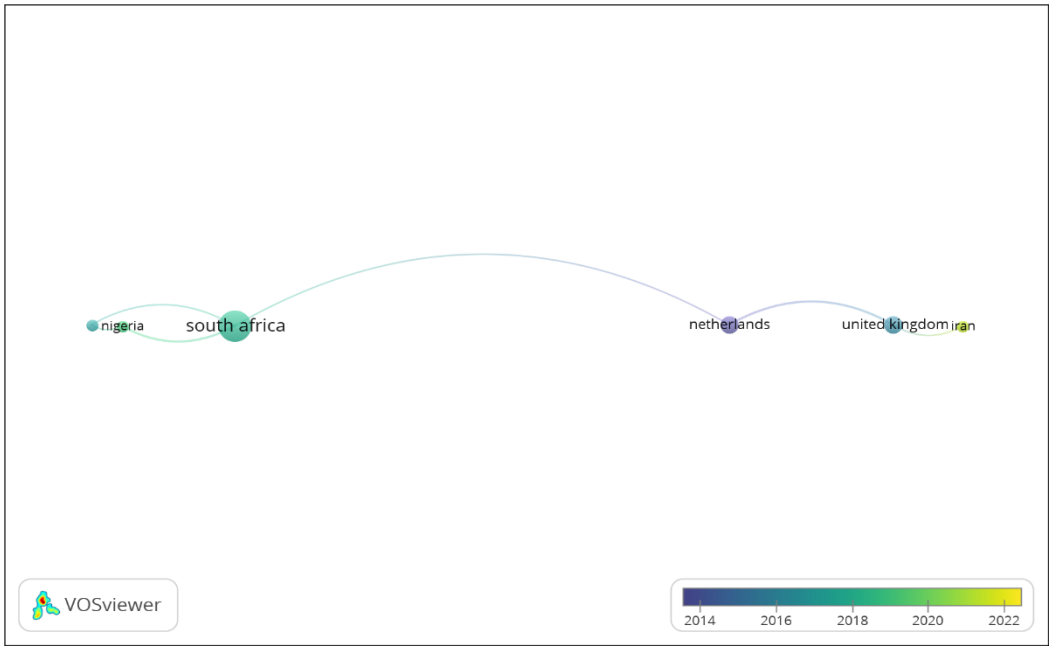

Figure 11. Network visualisation, citations (weight) by average publication year (score)

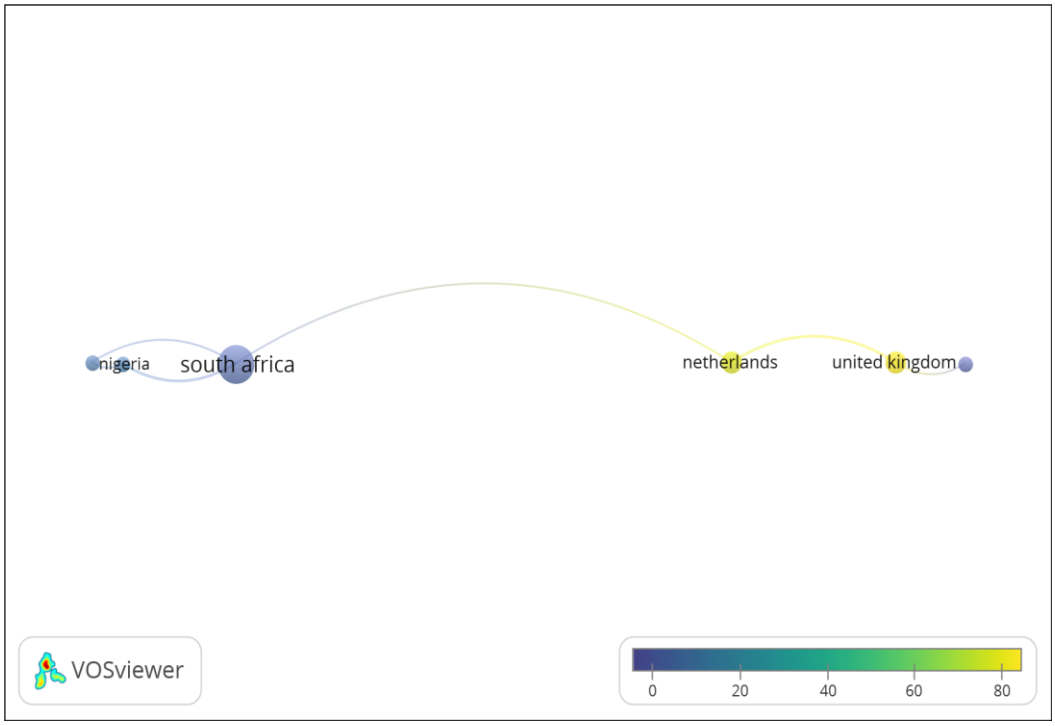

Figure 12. Network visualisation, citations (weight) by average citations (score)

SECTION 2: 527 RESOUCES THAT CITED THE 27 RESEARCH OUTPUTS

2.1. Topical coverage (keywords – Indexed and author keywords)

For the keyword visualisations, a minimum co-occurrence of words of five, with a selection of 144 of the most frequently occurring terms, was used out of 3026 keywords. The occurrence of these keywords ranged from five to 165. Figure 13 and Figure 14 show the keyword occurrence of those that occurred five and more times, demarcating between the average citations (Figure 13) and average year of publications (Figure 14).

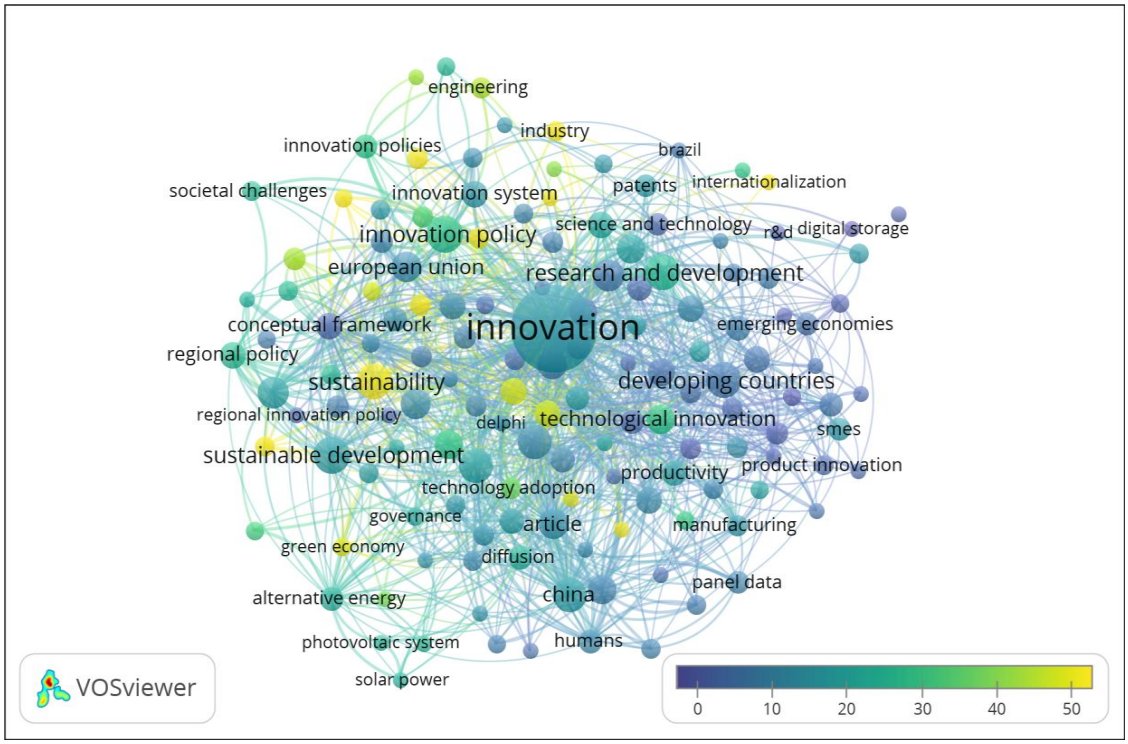

Figure 13. Network visualisation, keyword occurrence (five and more times), by average citations

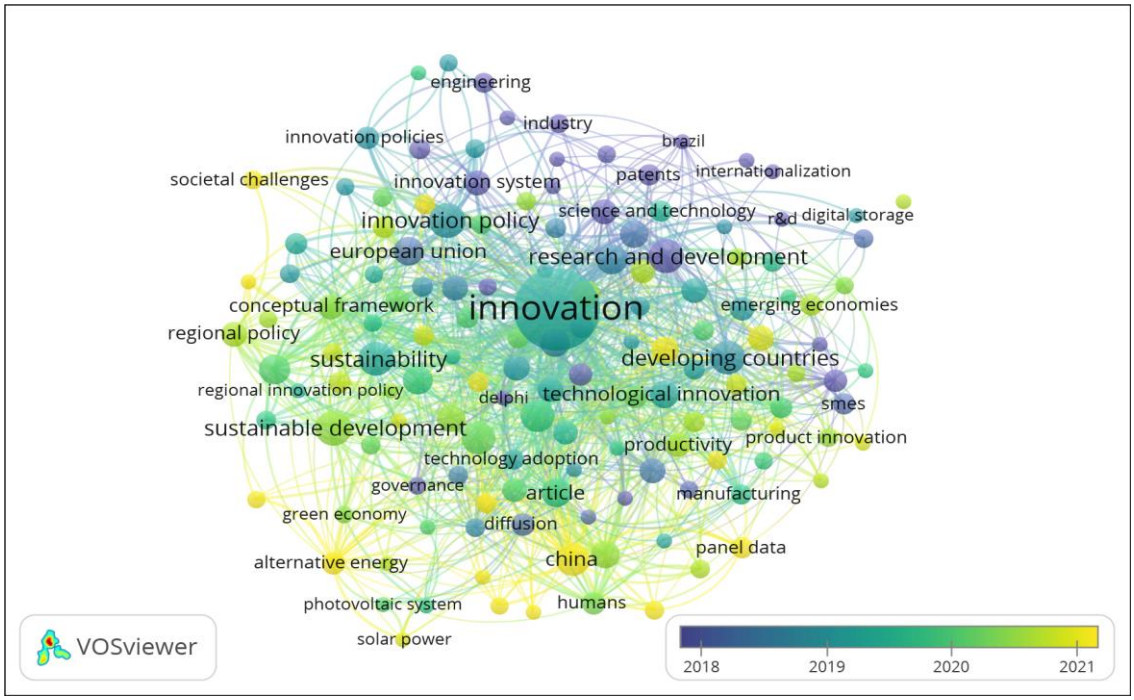

Figure 14. Network visualisation, keyword occurrence (five and more times), by year of publication

2.2. Geographical Scope – 527 resources that cited the 27 research outputs

Figures 15 and 16 show the geographical structure of citations, with the condition that the country reports a minimum number of five articles.

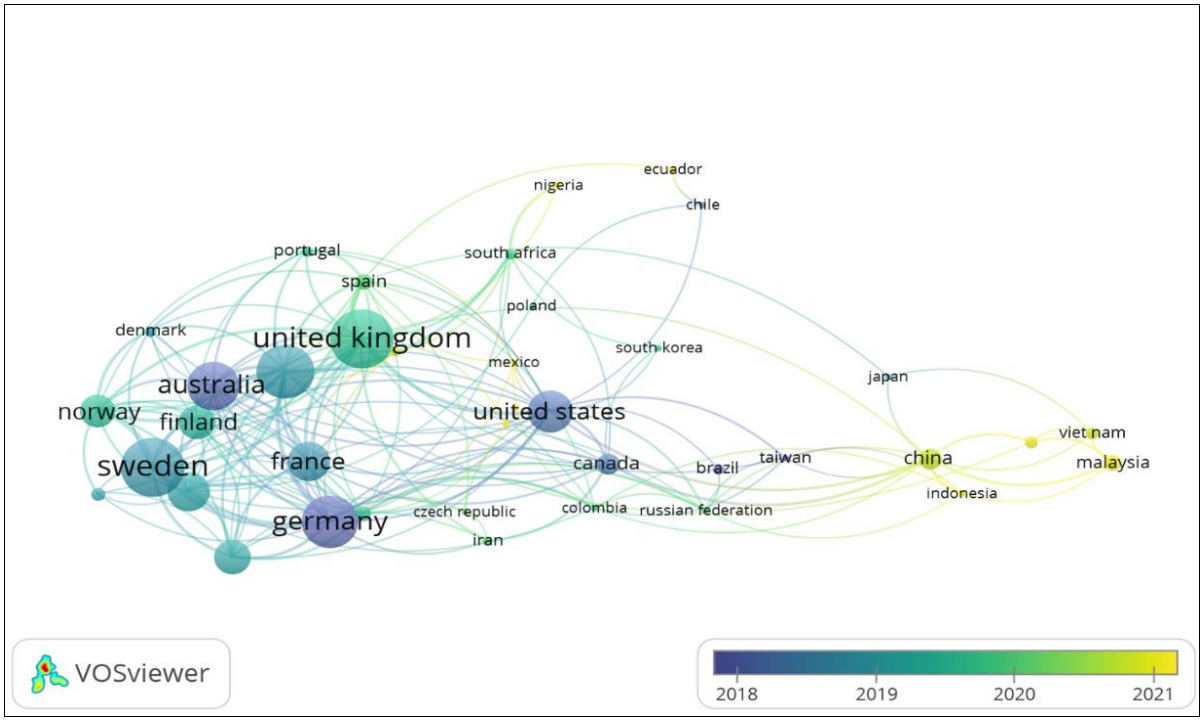

Figure 15. Network visualisation, geographical structure of citations (weight) by publication year (scores)

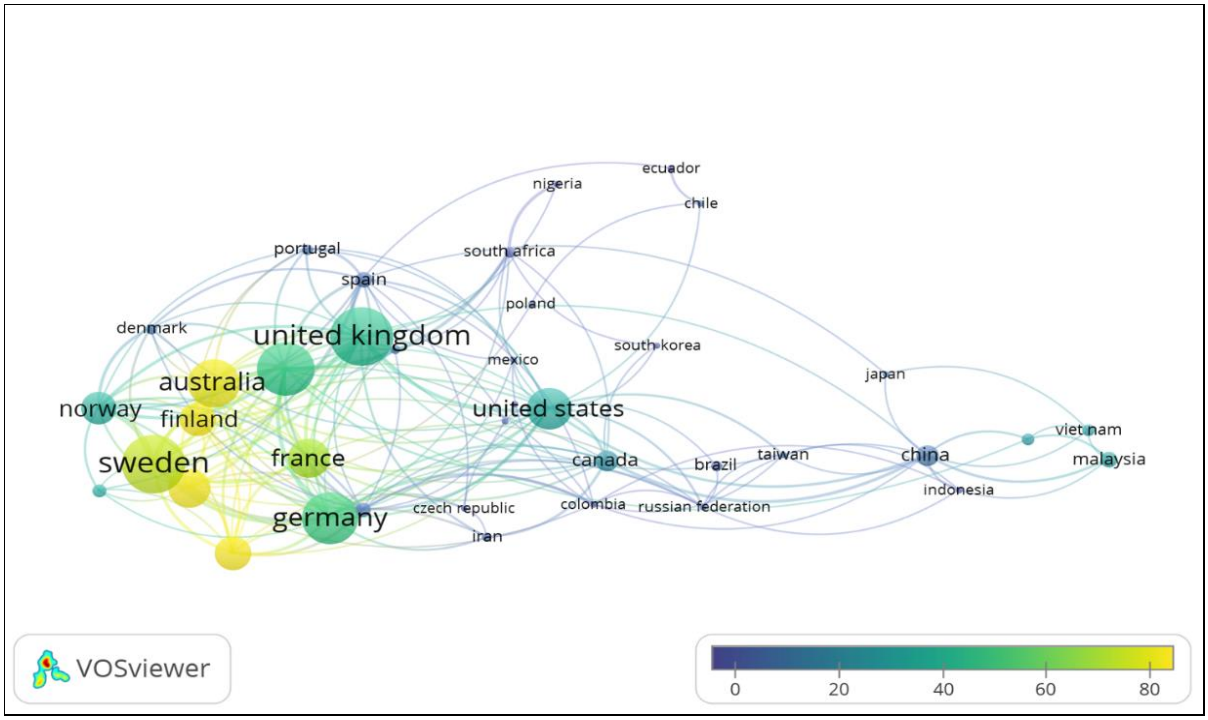

Figure 16. Network visualisation, geographical structure of citations (weight) by average citations (scores)