The Knowledge Basis of Africa – Status and Perspectives

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Introduction

The independence of African countries in the 1960s was linked to the hope of a fast economic growth. Ambitious development plans were set up, in particular based on the modernisation of agriculture and the extension of industry.[2] After the obvious failure of these approaches, more specific strategies were discussed, such as "diversification of exports", "substitution of imports", focus on "appropriate technologies" or "dissociation and self-dependent development".[3] However, the present situation in most African countries is still disillusioning, as in most cases, they depend heavily on the export of raw materials, and with the deterioration of the terms of trade, there is no realistic hope of a substantial improvement.

Against this background, strategies aiming at a stronger focus on an industrialisation seem to be most promising, and thus the recently proclaimed Africa Action Plan of the World Bank is primarily based on this approach (World Bank 2005). However, the structure of industry in advanced countries has changed considerably, so that the prospects of traditional industrialisation are called into question. The goods produced in these countries are increasingly based on research and development (R&D), and also the services provided are increasingly knowledge-based.[4] So advanced countries have become knowledge-based societies, and their competitive advantage is increasingly based on the strong position in knowledge generation in science as well as technology. To keep pace with advanced countries, it will be necessary to look more closely at the knowledge basis in African countries as well.

These theoretical considerations are supported by the obvious success of various catch-up countries, such as South Korea, Taiwan, Brazil, China, India, or Singapore. Their success is primarily based on knowledge-intensive goods and services and less on low-tech products.

Against this background, this paper deals with the mapping of the knowledge basis of Africa and draws conclusions as to its future perspectives. This approach does not imply a recommendation to neglect the support of agriculture or health, but intends to highlight the potential of a supplementary knowledge-based strategy.

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2 See for instance, Amin (1965).

3 See, e.g., Senghaas (1997), Senghaas (1979), Müller-Plantenberg (1973), Schumacher (1973), Wallerstein (1987), Wallerstein (1986), Füllberg-Stolberg et al. (1999).

4 Legler et al. (2000), Bell (1973), Freeman (1973).

Methodology and Data

To describe the African knowledge basis in science and technology, we use publications in expert journals and International and European patent applications as indicators. The performance of science is difficult to measure, the more so as the structures in specific disciplines often differ considerably. The statistical analysis of scientific publications has proved to be meaningful, as far as they are conducted with a careful methodology.[5] The analyses of this contribution do not only refer to scientific areas with close relation to technology, but also to the natural, life, and engineering sciences in total. The statistical analyses of scientific publications were conducted in the database Science Citation Index (SCI), a multi-disciplinary database with a broad coverage of about 6,000 journals; each year, the SCI records about 1 million new articles. Because of this broad coverage, the SCI has become the standard for international comparisons in science.

At first sight, the analysis of publications in the SCI seems to be appropriate for advanced countries, but less for developing countries, as its database covers high level journals with a good international reputation. The same concern may be raised to International and European patent applications, as they have to meet the severe criterion of novelty at an international level. In this context, Bernardes and Albuquerque (2003) and Albuquerque (2004) showed that it is possible to describe the knowledge stage of all types of countries by these two indicators, although in the case of developing countries, the SCI publications and patent applications only reflect the tip of the iceberg and not all knowledge-linked activities. Against this background, publications and patents document to what extent these countries are active in leading-edge areas of science and technology, and by this means, their knowledge structure can be described in an international comparison.

As to the Science Citation Index, we consider the period from 1980 to 2004, in terms of publication years, in order to describe the long-term development. In the paper, only African countries south of the Sahara are taken into account. As a first step, the numbers of annual publications are analysed. In this context, it proved to be useful to introduce a differentiation between Nigeria, South Africa and other African countries, as the overall trend is dominated by Nigeria and South Africa. For these three countries/ groups of countries an analysis by segments of scientific activities is performed, based on a disciplinary classification provided in the database. As a special feature, the SCI does not only record the institution of the first author, but all institutions concerned, including their nationality. By this means, the international co-publications can be determined. This type of analysis is made for the three groups of countries mentioned above.

It is difficult to assess the scientific activity of a country in an appropriate way without a useful benchmark. For that purpose, the publication activities of other catch-up countries are investigated as well.

The different segments of scientific activity are not directly comparable on the basis of absolute publication numbers, as the publication behaviour by field differs, and the da-

5 See, e.g., Van Raan (2004), Moed (2005).

tabase coverage of fields differs as well. To compensate these distortions, we introduce the specialisation index RLA (Relative Literature Advantage) which is calculated in the following way:

$$RLA_{ij} = 100 \tanh \ln [(Publ_{ij} / \sum_i Publ_{ij}) / (\sum_j Publ_{ij} / \sum_{ij} Publ_{ij})].$$

In this formula, i refers to the country and j to the field analysed. The RLA index is constructed in such a way that its value range ± 100 includes the neutral value zero. Positive values indicate a specialisation above average, negative ones a specialisation below average with the world activities as reference. As to patent applications, the specialisation index RPA (Revealed Patent Advantage) is used which is calculated in an analogue way.[6]

For the analysis of the structures in R&D-intensive technologies, foreign patent applications have proven to be valuable indicators.[7] As to patent applications, non-European countries increasingly use International Patents according to the Patent Cooperation Treaty (PCT patents) as typical paths of registering their inventions.[8] However, some countries such as Singapore or Taiwan still register a substantial share of their foreign applications directly at the European Patent Office, so we analyse the EPO and PCT applications in parallel.[9] In the case of patent applications we consider the period of 1994 to 2003 in terms of priority years, i.e. first years of application. We have to stop the analysis in 2003, as patent applications are published with a delay of 18 months. Hence 2003 was the most recent year available at the time of the database searches (September 2005). In this context, it has to be taken into account that in the case of publications, a delay of about one year between the submission of an article to a journal and its publication can be assumed; thus the publication year 2004 and the priority year 2003 are largely equivalent.

For the publication analysis, the on-line database SciSearch of the host STN was used, for the analysis of patent applications the databases EPPatent and WOPatent of the host Questel-Orbit.

Findings

To start with SCI publications, since the total numbers are, of course, dominated by Nigeria and South Africa, a breakdown by these groups of countries is appropriate for an improved interpretation of the results. In the case of South Africa, the number of publications shows an enormous increase until 1987 and a stagnation at the beginning of the 1990s which may be linked to the specific political situation at that time due to the abolition of apartheid (Figure 1). Since 2000, a stronger increase becomes visible again.

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6 Instead of publications patent applications are introduced in the formula.

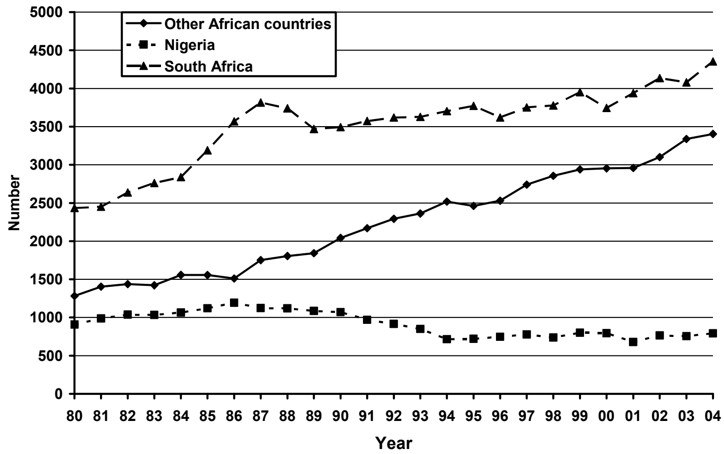
7 For further details see Hinze and Schmoch (2004).

8 Schmoch (1999).

9 EPO = European Patent Office.

As to Nigeria, the number of publications in the 1980s was quite high, but steadily decreased since about 1986. This decline may be explained by the political instability that characterised the situation of this country for a long time. According to experts, a high number of Nigerian scientists left the country and now work in foreign countries; however, the database does not record the nationality of the authors, but the location of the organization involved.

Figure 1: Number of SCI publications of African countries south of the Sahara



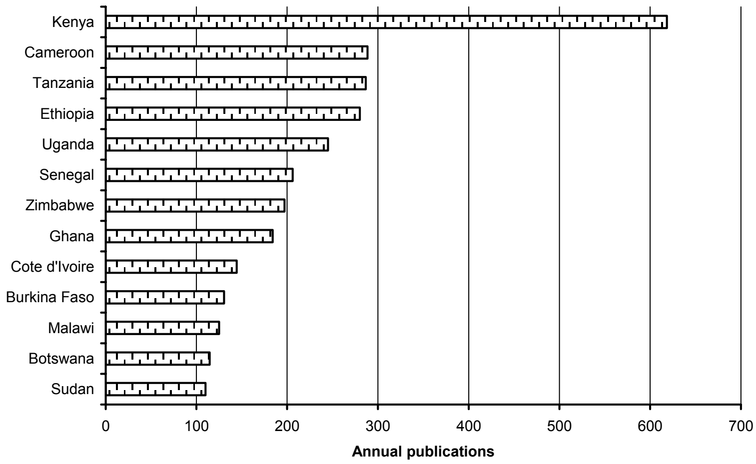
Source: SCISEARCH (STN), computation of Fraunhofer ISI

The number of publications by the other African countries combined had a quite low level at the beginning of 1980s and was only slightly higher than the Nigerian one. But since that time, the publications of other African countries increased considerably and nearly reached the level of South Africa.

For the appropriate interpretation of these figures, it has to be taken into account that the total number of SCI publications increased in the observation period as well, for instance by 50% between 1990 and 2004. A large share of this increase may be linked to a worldwide increase of scientific activity, but a certain share is also due to a broader coverage of journals in the Science Citation Index. These two elements cannot be dissociated in an accurate way. Compared to the overall trend, the findings for African countries have to be considered in a different way. In this perspective, South Africa lags behind the international trend between 1990 and 2000, but keeps up again in recent years. Nigeria falls far behind the international reference, and the other African countries only grow slightly faster than the international average. However, you would expect that the other African countries would distinctly lag behind the international average dominated by large industrial countries. Against this background, the strong growth of their publications is a remarkable finding.

A further breakdown of the African countries shows a leading position of Kenya, followed by Cameroon, Tanzania, Ethiopia and Uganda (Figure 2). In this graph, the level of Cameroon, Senegal, Côte d'Ivoire, or Burkina Faso may be underestimated due to their focus on the French language, whereas the Science Citation Index has a bias towards English language journals.

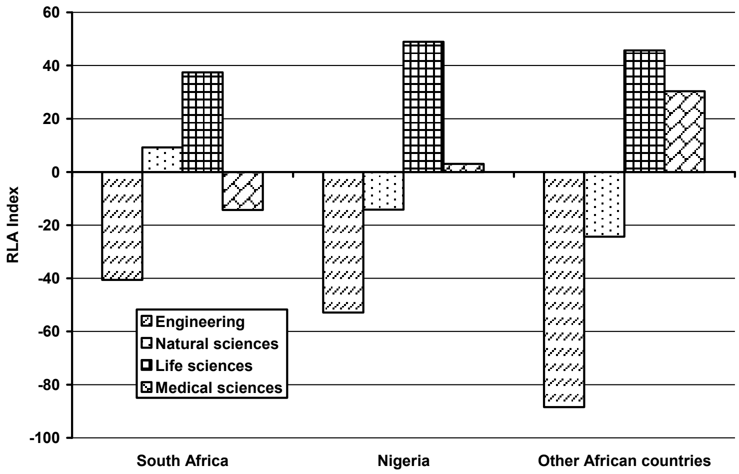
Figure 2: Countries with most publications in 2003/2004 among other African countries



Source: SCISEARCH (STN), computation of Fraunhofer ISI

A breakdown of the publication activities by scientific segments indicates a strong orientation of all African countries to the life sciences (Figure 3). In the other African countries, a further strong focus on the medical sciences is visible, and in Nigeria the publications in the medical sciences are nearly international average. All African countries have a specialisation distinctly below average in engineering. To sum up, the focus on the life sciences is a specific feature of African countries.

Figure 3: Specialisation of African countries on scientific segments



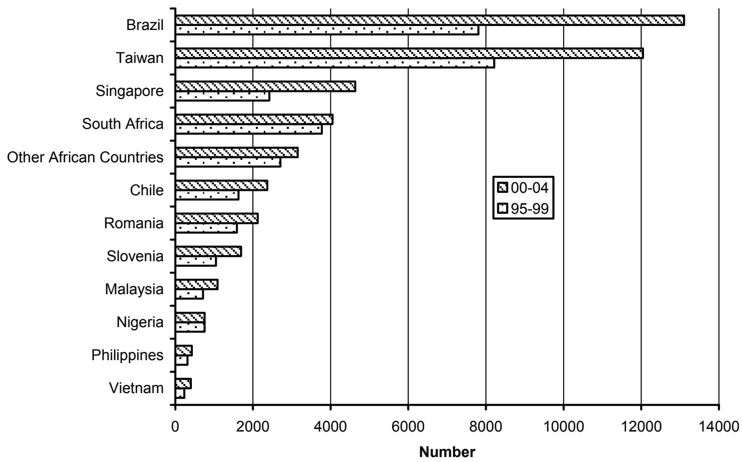
Source: SCISEARCH (STN), computation of Fraunhofer ISI

In order to assess the absolute number of African publications appropriately, we have selected some catch-up countries in South America, East Europe, and South-east Asia:

Brazil, Chile, Slovenia, Romania, Taiwan, Singapore, Malaysia, the Philippines and Vietnam. In this international comparison, Brazil and Taiwan have a leading position with regard to their present absolute publication numbers as well as the growth rates in the last decade (Figure 4). South Africa and the other African countries combined hold a good medium position in absolute terms, but their growth only reaches an average level. Nigeria is at the lower end of the countries considered and is the only country without any growth in the last decade.

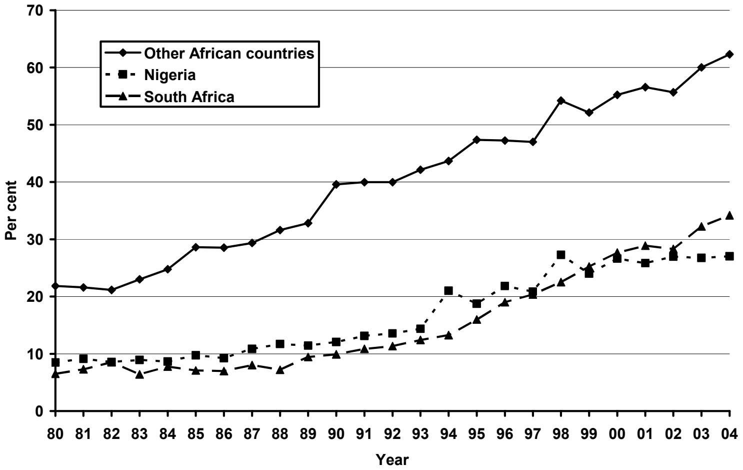
The further indicator of scientific performance is the international cooperation with advanced countries. For that purpose, we analysed the number of co-publications of the three African groups of countries with advanced countries in Western Europe, North America, and Japan. As result, we can observe a steady increase of the share of international co-publications for South Africa, Nigeria and the other African countries (Figure 5). In 2004, Nigeria reached a level of 27%, South Africa 34% and the other African countries 62%. The interpretation of these data is ambiguous. On the one hand, a high level of co-publications with advanced countries documents that African scientists are considered to be competent partners. On the other hand, a very high share of international co-publications may indicate the structural dependence on advanced countries. In this context, the reference to international averages is revealing. In advanced industrialised countries, we can also observe a strong increase of international co-publication, reflecting the general globalisation of the science system (Schmoch 2005). At the recent edge, advanced countries display an international co-publication level of 40 to 50% with reference to SCI publications. Thus the African countries follow the international increase of co-publications and South Africa and Nigeria are a little bit below the level of advanced countries. The extremely high level of the other African countries seems to reflect, at least to a certain extent, a structural dependence on advanced countries.

Figure 4: SCI publications of selected countries with reference to African countries



Source: SCISEARCH (STN), computation of Fraunhofer ISI

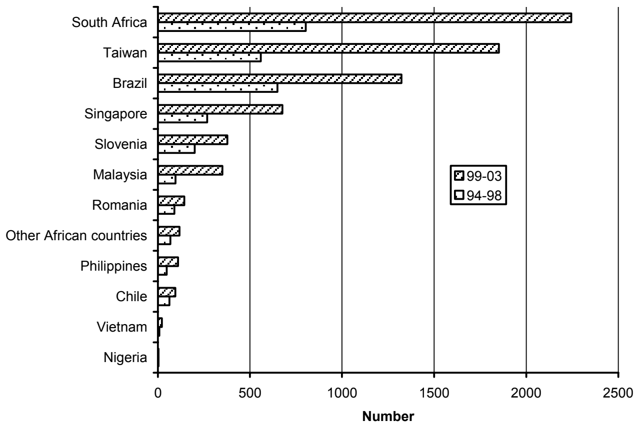
Figure 5: Share of co-publications of African countries with advanced countries



Source: SCISEARCH (STN), computation of Fraunhofer ISI

As discussed above, a good position in science does not necessarily indicate a high level of prosperity. It is important that the knowledge is closely linked to application and transferred into technological strength. Therefore, we considered the position of African countries and the selected reference countries for European and International patent applications. With regard to this performance dimension, South Africa has a leading position as to the absolute number of patents as well as to the growth rate in the last decade (Figure 6). In contrast, Brazil, which had a leading position in terms of publications, follows in the third rank. With regard to patent applications, the other African countries can be found at the lower level of the ranking, and Nigeria exhibits very few patents and is in the last position.

Figure 6: European and International patent applications of selected countries

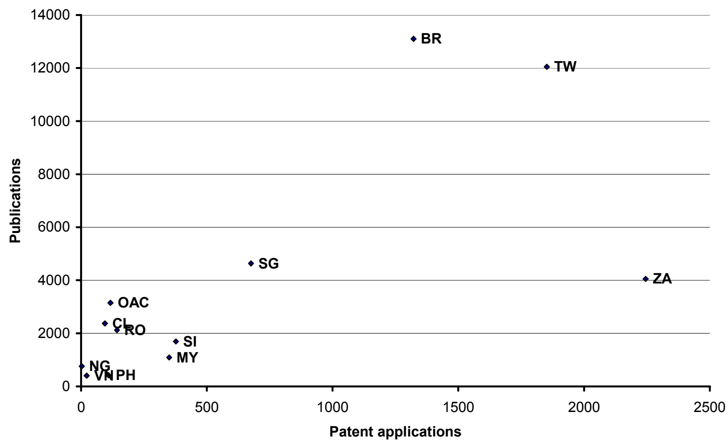


Sources: EPPATENT, WOPATENT (Questel-Orbit), computation of Fraunhofer ISI

Obviously, the threshold of international patent applications is too high to reflect the technological activities of Nigeria and the other African countries in an appropriate way. For instance in Nigeria, the assembly of computers is a relevant industrial activity (Oyelaran-Oyeyinka 2005); but it is not reflected in patents, as it does not lead to new technological concepts, yet. In technological terms, this activity may be described as imitation. As to the other African countries, the analysis of domestic patents may be more appropriate; however, these data are rarely available through on-line databases. The best database for this purpose is INPADOC (STN) which covers the documents of 73 patent authorities including Kenya, Malawi, the African Organisation of Intellectual Property (OAPI), South Africa, Zambia, and Zimbabwe.

We have illustrated the complex relations between patent applications and publications, i.e. scientific and technological activities, in a scatter plot. According to this, South Africa is characterised by a quite strong focus on technological activities, whereas Brazil and Taiwan have still a quite strong focus on science (Figure 7). This statement also applies to the other African countries (OAC) on a lower absolute level, and again, Nigeria appears on the lower end of the comparison with other catch-up countries.

Figure 7: Publications and patent applications of selected countries



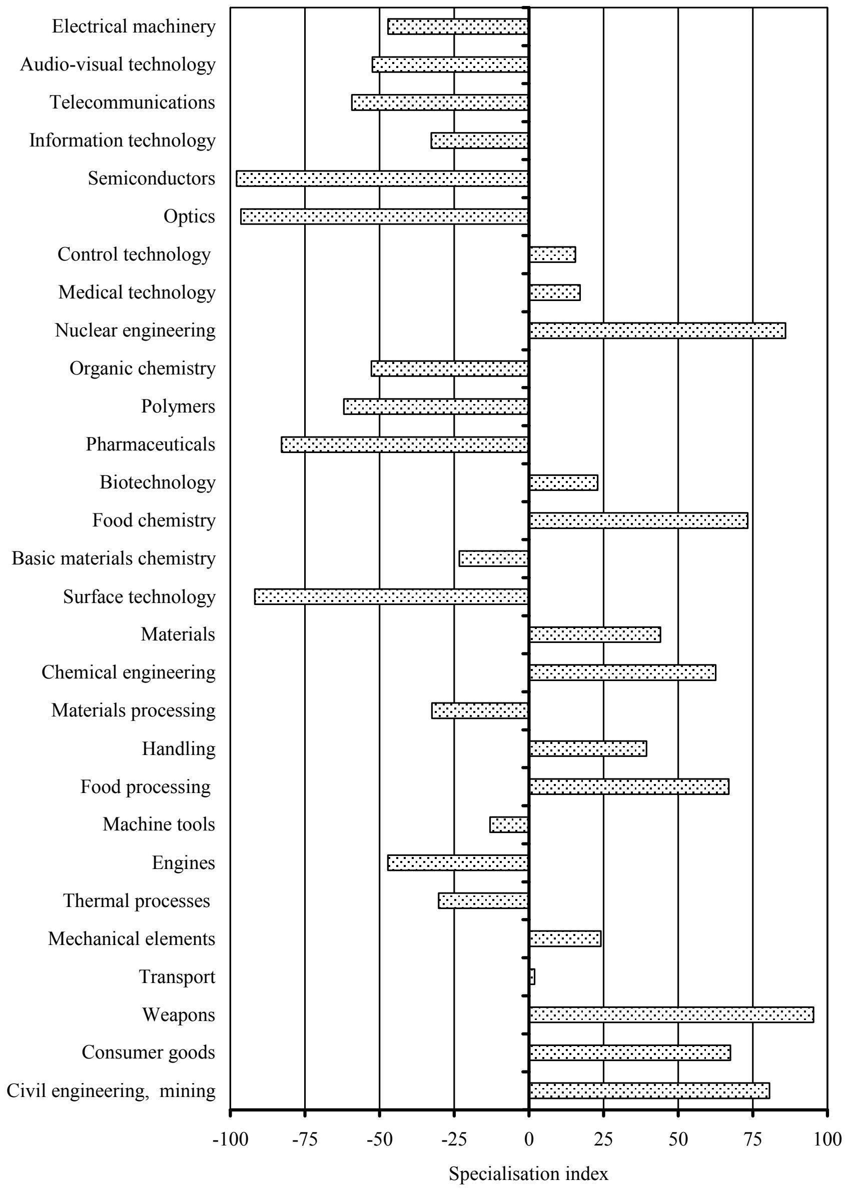
Sources: SCISEARCH (STN), EPPATENT, WOPATENT (Questel-Orbit), computation of Fraunhofer ISI

With regard to the relevant patent activities of South Africa, it is interesting to look more closely at its specialisation profile with reference to the world-wide average. For this purpose, we use a technology classification developed by Fraunhofer ISI in cooperation with the French Observatoire des Sciences et des Techniques (OST) and the French Patent Office (INPI).[10] According to this analysis, South Africa has a strong focus on Nuclear engineering and Weapons, a heritage of the former regime. Furthermore, an orientation distinctly above average can be observed in the fields of Consumer goods, Mining, Food chemistry and Food processing, but also the mechanical fields Handling and Mechanical elements. A remarkable outcome is the quite high index in Biotechnology, as with regard to the enormous activities of the United States and the

10 The definition of the fields by codes of the International Patent Classification (IPC) is documented in the appendix.

United Kingdom in this area, a relevant number of patent applications is necessary to achieve a high specialisation index with reference to the international average.

Figure 8: Specialisation profile of South Africa as to European and International patent applications, 1999-2003



Sources: EPPATENT, WOPATENT (Questel-Orbit), computation of Fraunhofer ISI

Conclusions

To summarise, the position of African countries in terms of scientific and technological activity is generally better than expected. Within Africa, South Africa has a distinctly leading position, its absolute level of publications is high, and after a decade of stagnation, the publications presently increase again. However, the specific strength of South Africa is its technological activities which grow with a considerable speed and have reached a relevant absolute level. As to the other African countries, their steady growth of internationally relevant publications is remarkable, but the transfer of the scientific knowledge to technological activities is still modest. But at this stage of development, the stronger focus on science is normal in comparison to other countries. To keep pace with the international development, it will be important that the smaller African countries reach a sufficient critical mass of their scientific activities. In this perspective, the position of Kenya is already remarkable, but these countries should look for opportunities of stronger cooperation in specific areas. In this regard, the common focus of African countries on the life sciences may be a good basis. As to Nigeria, the situation is obviously problematic, but the decrease of scientific activities in the 1990s has been stopped in recent years. Nigeria does not seem to be able to transfer the scientific knowledge into the generation of new technology, and in this regard, the country completely depends on foreign technology, although in principle, Nigeria is sufficiently large to initiate a self-dependent knowledge-based development. But for this purpose an enormous re-orientation of public policy would be necessary.

All in all, the knowledge basis of Africa is sufficiently large to engage in a knowledge-based development. In any case, African countries should not limit themselves to the provision of raw materials, but in the context of the debates on innovation systems and the triple helix, they should also engage in a knowledge-based initiative.[11] In this context, the use of S&T indicators is a useful tool to observe the status and change of the referring structures.[12] However, the focus on the S&T indicators suggested in this paper is only useful, if they are complementary to other economic and social indicators. But they can support considering the development of Africa in a new perspective.

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11 See for instance UN Millenium Project (2005), Viviers (2005), or Muchie (2003).

12 S&T = Science and technology

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Annex: Systematic of OST/INPI/ISI of six technology areas and thirty sub-areas defined by IPC symbols

	Area	IPC code
I.	**Electrical engineering**	
1.	Electrical machinery and apparatus, electrical energy	F21; G05F; H01B,C,F,G,H,J,K,M, R,T; H02; H05B,C,F,K
2.	Audio-visual technology	G09F,G; G11B; H03F,G,J; H04N-003,-005,-009,-013,-015, -017,R,S
3.	Telecommunications	G08C; H01P,Q; H03B,C,D,H, K,L,M; H04B,H,J,K,L,M, N-001, -007,-011,Q
4.	Information technology	G06; G11C; G10L
5.	Semiconductors	H01L, B81
II.	**Instruments**	
6.	Optics	G02; G03B,C,D,F,G,H; H01S
7.	Analysis, measurement, control technology	G01B,C,D,F,G,H,J,K,L,M,N, P,R,S,V, W; G04; G05B,D; G07; G08B,G; G09B,C,D; G12
8.	Medical technology	A61B,C,D,F,G,H,J,L,M,N
9.	Nuclear engineering	G01T; G21; H05G,H
III.	**Chemistry, pharmaceuticals**	
10.	Organic fine chemistry	C07C,D,F,H,J,K
11.	Macromolecular chemistry, polymers	C08B,F,G,H,K,L; C09D,J
12.	Pharmaceuticals, cosmetics	A61K, A61P
13.	Biotechnology	C07G; C12M,N,P,Q,R,S
14.	Agriculture, food chemistry	A01H; A21D; A23B,C,D,F,G,J,K, L; C12C,F,G,H,J; C13D,F,J,K
15.	Chemical and petrol industry, basic materials chemistry	A01N; C05; C07B; C08C; C09B,C,F, G,H,K; C10B,C,F, G,H,J,K,L,M,N; C11B,C,D
16.	Surface technology, coating	B05C,D; B32; C23; C25; C30
17.	Materials, metallurgy	C01; C03C; C04; C21; C22; B22, B82

IV.	**Process engineering, special equipment**	
18.	Chemical engineering	B01B,D (without -046 to -053), F,J,L;B02C; B03; B04; B05B; B06; B07; B08; F25J; F26
19.	Materials processing, textiles, paper	A41H; A43D; A46D; B28; B29; B31; C03B; C08J; C14; D01; D02; D03; D04B,C,G,H; D05; D06B,C,G,H,J,L,M,P,Q; D21
20.	Handling, printing	B25J; B41; B65B,C,D,F,G,H; B66; B67
21.	Agricultural and food processing, machinery and apparatus	A01B,C,D,F,G,J,K,L,M; A21B,C; A22; A23N,P; B02B; C12L; C13C,G,H
V.	**Mechanical engineering, machinery**	
22.	Machine tools	B21; B23; B24; B26D,F; B27; B30
23.	Engines, pumpes, turbines	F01B,C,D,K,L,M,P; F02; F03; F04; F23R
24.	Thermal processes and apparatus	F22; F23B,C,D,H,K,L,M,N,Q; F24; F25B,C; F27; F28
25.	Mechanical elements	F15; F16; F17; G05G
26.	Transport	B60; B61; B62; B63B,C,H,J; B64B,C,D,F
27.	Space technology, weapons	B63G; B64G; C06; F41; F42
VI.	**Consumption**	
28.	Consumer goods and equipment	A24; A41B,C,D,F,G; A42; A43B, C; A44; A45; A46B; A47; A62B,C; A63; B25B,C,D,F,G,H; B26B; B42; B43; B44; B68; D04D; D06F,N; D07; F25D; G10B,C,D,F,G,H,K
29.	Civil engineering, building, mining	E01;E02;E03;E04;E05;E06;E21