

# Mining-related National Systems of Innovation in Southern Africa

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**Abstract:** This paper explores the linkages between the National Systems of Innovation of Botswana, South Africa, Zambia, and Zimbabwe and their respective mineral extraction and mineral processing value chains, including input industries.

Our analysis reveals four individual National Systems of Innovation, with different outcomes in terms of engineering skills development, Technical Vocational Education and Training, research and development, innovation capabilities, and competitiveness of the domestic engineering consultancy services. These National Systems of Innovation are tentatively interconnected as an embryonic Regional System of Innovation, including institutional relationships, cross-border investment flows, flows of mining-related goods and services, and intra- Southern African Development Community flows of students, lecturers, technicians, and engineers. Notwithstanding important dynamics related to skills development and competence building happening across borders, more collaborative and synergistic initiatives between government, industry, and teaching and research institutions are required to shape a more balanced and coherent Regional Systems of Innovation.

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<sup>1</sup> This is a shorter version of the full working paper available at <https://www.wider.unu.edu/publications>.

## 1. Introduction

The mining sector in the Southern African region underlies substantial intra-regional flows of specialized equipment, engineering services, skills, and knowledge. South Africa, which historically had the most technologically sophisticated mining inputs cluster, has developed very strong linkages to the Southern African Development Community (SADC) region. South Africa's prominent role in the region has several dimensions: it is a major source of investment, exports and skills; attracts skilled labour and students; and has the most developed knowledge economy (Kraemer-Mbula and Muchie 2010). Moreover, South Africa is a mining supply 'hub' for the region, in terms of capital equipment and services (Fessehaie 2015). This appears to be more the result of corporate strategies rather than purposive inter-governmental cooperation. From a policy perspective, Fessehaie (2015) argues that policy developments in individual countries fail to recognize and leverage these regional linkages.

This research aims to explore the extent of technological upgrading and knowledge intensification around the mineral sectors, and in particular the role of South Africa in supporting these processes. These processes are analysed within the National System of Innovation (NSI) literature, which emphasizes the systemic and dynamic components of domestic innovation ecosystems. South Africa and Botswana, in different ways, have built or are trying to build technological competencies around mining. In Zambia and Zimbabwe, such upgrading trajectories seem to be weak, and have particularly been eroded by declined in public investment in the 1990s for Zambia and the 2000s economic crisis in Zimbabwe. Yet, looking at these NSIs in isolation risks missing important dynamics related to skills development and competence building happening across borders. The latter present challenges for technological efforts taking place within countries, but also opportunities to tap into. These issues are explored in this paper through desktop research, interview data, and the insights gained from fieldwork in Botswana, South Africa, Zambia, and Zimbabwe.

Section 2 provides a background on policy frameworks related to mining within the selected countries. Section 3 briefly reviews the literature on NSI and resource-based economic growth. Sections 4 to 6 discuss the main elements of NSI-building in Botswana, Zambia, and Zimbabwe, namely engineering and technical skills development, research and development (R&D) and innovation investment, and engineering consultancy services. Each section analyses the regional dynamics underpinning these elements. Section 7 concludes and poses key questions on the Southern African regional system of innovation (RSI).

## 2 Background

Mining plays a fundamental role in the economic trajectories of Botswana, South Africa, Zambia, and Zimbabwe. The contribution of mining to GDP was substantial across the selected countries: 33 per cent of GDP in Botswana (2014), 16.2 per cent in South Africa (2014), 25.7 per cent in Zambia (2013), and 17.5 per cent (2014) in Zimbabwe.<sup>2</sup> In Botswana,

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<sup>2</sup> Data was drawn from the World Bank Indicators (World Bank 2016) and may not correspond exactly to national GDP statistics as the WB makes some adjustments for cross-country consistency (<http://wdi.worldbank.org/table/4.2>).

the relative contribution of mining to GDP has declined since 1990 and will continue to do so as diamond deposits are depleted. Conversely, in South Africa, Zambia, and Zimbabwe, the contribution of mining has increased since the 2000s. In Zambia, this is due to an investment boom in the Copperbelt and so called 'New Copperbelt' (North West Province). In Zimbabwe, the rising importance of mining is a reflection of the decline of agriculture and manufacturing in GDP and exports (World Bank, 2014). The mining sector itself has become less diversified. Previously, it was dominated by gold and small-scale production of more than 40 minerals, but is now led by large-scale platinum production and to a less extent diamonds and gold.

In the four economies, the manufacturing sector continues to underperform. In Zambia and Zimbabwe, the manufacturing sector contribution to GDP has declined compared to 1990 and 2000 levels. In Botswana, its contribution remains low and stagnant. Also in South Africa, the leading economy in the region, the manufacturing sector performance has been disappointing. For this reason, all the countries analysed are engaging with linkage development strategies aimed at building upstream and downstream industries to mining.

Botswana's considerable resource rents have historically been managed effectively by investing in human resources and infrastructure. This was facilitated through the government's strategic relationship with De Beers via a 50-50 per cent joint venture (JV) called Debswana. Given that diamond production is expected to decline by 2025–27, Botswana's main policy objective in the past two decades has been focused on economic diversification. The National Development Plan 10 (2009-2016) and the Economic Diversification Drive 2011–2016 (GB 2011) are the policy drivers for the diversification but progress in this direction has not met expectations (GB 2008: 7).

The diamond beneficiation policy adopted in 2005 following licence renewal, has been remarkable in supporting Botswana's ambition to move up the global value chain in sorting and valuing, marketing, and polishing and cutting. (Mbayi 2011). The policy was strategically designed around De Beers, which exerts significant market power on domestic and global production, as well as global marketing and distribution channels. As a result, employment increased from 2,200 workers in 2008 to 3,750 in 2013. In 2015, however, Botswana's beneficiation strategy was in a serious crisis as the diamond industry faced a number of challenges. Supply and demand at different stages of the value chain was misaligned due to the rising prices for rough stones, collapsing demand, and shrinking margins for cutting and polishing firms. Subsequently, diamond cutters – MotiGanz, Leo Schachter, and Teemane Manufacturing Company – closed their plants in Botswana resulting in 500 job losses in 2015 (Grynberg 2015).

Zambia's linkages development strategy, as far as copper beneficiation is concerned, has relied heavily on foreign direct investment (FDI). Chinese investors initiated the building of an industrial park located in Chambishi (Copperbelt Province) in 2007 by taking advantage of Zambia's incentives for Multi-Facility Economic Zones and Industrial Parks. Policy developments around upstream linkage development on the other hand have been more complex and involved a multitude of institutional and private sector actors. Zambia's manufacturing capabilities in the mining supply chain were largely eroded during the 1990s, following the privatization of mining assets and the introduction of trade and investment liberalization measures (Fessehaie 2012). The International Council on Mining and Metals

(2014) estimated out of a total industry procurement of goods of approximately US\$ 1.75 billion annually, only 5 per cent (or US\$ 87 million) constitutes locally manufactured goods. Notwithstanding high level political statements on the government's intention to support local suppliers, upstream linkages development has not been effectively translated nor implemented into an industrial strategy.

Historically, Zimbabwe's mining sector was characterized by well-developed upstream and downstream industries (Jourdan et al., 2012). With the economic crisis in the early 2000s, capacity utilization in the manufacturing sector declined drastically from approximately 80 per cent in 2000 to 10 per cent in 2008 then increased to 26 per cent in 2015 (GZ 2011; MEPIP 2011: 19, 123; Field Interviews 2015).

FDI inflows into mining have resumed from a low level since 2010, coupled with significant imports of capital equipment. The mining sector is currently the main driver of economic recovery in Zimbabwe, and according to the World Bank (2014), it offers the most important demand for local manufacturing. In the high-level power struggle over mining rights and revenues, local content issues have been relatively marginalized. The crisis had a two-fold impact on the local supply chain. Some firms moved away from manufacturing to distribution while other international OEMs sold their subsidiaries to local investors.

Zimbabwe's policy framework is largely focused on mineral beneficiation and indigenization. According to an interview with the Ministry of Economic Planning and Investment Promotion in 2015, concerns over tax avoidance are leading policy-makers to look at beneficiation as a mechanism to introduce transparency in the sector. Currently, there is no interest in linking the indigenization agenda to increasing mining local content, even if several stakeholders interviewed for this research indicated that there would be concrete opportunities.

South Africa has a longer history of mining around which the overall national economy has evolved. While mining still plays an important part in the economy, particularly in its contribution to exports, a significantly greater degree of diversification out of mining has occurred in comparison to Botswana, Zambia, and Zimbabwe. The diversification has taken a particularly capital- and energy-intensive form with the emergence of a core set of mining and mineral-processing sectors (falling within the manufacturing sector) that have dominated the economy for many decades (Fine and Rustomjee 1996). South Africa's capital goods sector has developed around this minerals-energy-complex (MEC) core and the sector is playing a major role in supplying the regional mining industry with mining machinery, mining inputs, and associated engineering services. Conversely, the South African mineral industry is also reliant on imported technical and engineering skills from the region.

The South African mining inputs cluster, mainly located in Gauteng, is a well-established regional supply hub for Southern Africa (Fessehaie 2015). South Africa's mining inputs cluster, through global and domestic OEMs, is supplying capital equipment and engineering services to mining houses across the region. Often, these are supplied through relationships with Engineering, Procurement, Construction, and Management (EPCM) firms. Whilst previous research has analysed South Africa's mining inputs cluster (Walker and Minnitt 2006; Lydall 2009) and there is considerable policy and academic research on South Africa's

NSI, very little is known about developments in the rest of the region on mining-related NSIs and in relation to South Africa.

### 3 Natural resources, technological upgrading, and National Systems of Innovation

The contribution of technology to economic growth is well-established in the economic literature (Romer 1986; Grossman and Helpman 1991). The NSI approach, and related literature on technological capabilities, focuses on the micro-economic foundations of firm-level technological upgrading, adopting realistic assumptions on how firms operate: in imperfect markets and with imperfect information over which technologies are available (Nelson and Winter 1977; Pack and Westphal 1986; Lall 2000). The NSI literature, in particular researchers from Aalborg University (Freeman 1995; Lundvall and Lema 2014) broadened the analysis of technological upgrading to include multiple actors and activities. Building on the seminal work by Freeman (1987) on firm activities, and on Nelson and Winter's (1977) emphasis on the role of institutions, innovation is seen as the result of a variety of intra-firm and inter-firm activities, in particular 'feedback loops from the market and from production into the R&D system' (Freeman 1995: 10).

The NSI framework is 'constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge' (Lundvall 2010: 2). The innovation process is seen as socially-embedded and as the result of interactive learning (Lundvall et al., 2002), hence NSI research has placed considerable emphasis on historical contexts and the role of institutions (Lundvall 2010). Learning is seen as 'collective, cumulative and path-dependent' (Lall and Teubal 1998: 1372).

The institutions and relationships explored in NSI literature include the following ones:

- Internal organization of the firm
- Inter-firm relationships
- Role of public sector
- Financial sector
- R&D organization
- Training (Lundvall 2010)

Differences in these elements and in the relationships between them are seen as defining specific NSIs. Early NSI research focused on mature industrial economies and was concerned with differentials in their technological performance (Lundvall 2010: 3). Subsequent research however became increasingly concerned with the Newly Industrialized Countries (NIEs), in particular the four Asian Tigers. Arguing that the NIEs' catch up could not be explained only by high investment rates in physical and human capital, this research turned to other explanations linked to entrepreneurship, learning, and innovation (Pack and Westphal 1986; Kim and Nelson 2000).

Research on developing countries broadened the NSI framework in different ways: incorporating education, training, and technological adaptation, and looking at the role of industrial and FDI strategies. Training and education did not receive extensive attention in NSI research on mature economies (Lundvall and Lema 2014). Research on Asia and Latin

America however has incorporated education as a critical foundation of the NSI (Lall 2000; Viotti 2002). In particular, engineering, technical, and vocational education are critical to support technology absorption and adaptation, which are the first steps for developing countries' climbing up the technological ladder.

In particular, researchers have been concerned that FDI does not automatically contribute to the development of local innovation capabilities in host countries (Lall 2000; Viotti 2002). Multinational Enterprises' (MNEs) technological investments were usually limited to local design modification to meet domestic conditions and regulations (Freeman 1995).<sup>3</sup> Hobday (2000) highlighted that the success of South Korea and Taiwan in promoting indigenous innovation capabilities can be ascribed to their strategic approach to FDI, which supported significant knowledge transfer to domestic firms. These findings are consistent with the strategies adopted by resource-rich successful industrialisers.

The historical experience of resource-rich countries shows that natural resource sectors have catalysed important processes of productivity growth, technological innovation, and forward and backward linkages. Good institutions and investment in human capital and knowledge were critical for such processes (Rostow 1956; de Ferranti et al. 2002). The positive externalities of *learning by doing* found in manufacturing are also found in productive activities linked to natural resources' sectors (Davies 1995; Stijns 2005). Bartos (2007) argues that technological breakthroughs and productivity gains in the US mining industry have been comparable to other manufacturing sectors, with the exception of high-tech sectors. Natural resources exploitation, which requires specific knowledge and problem-solving, has given rise to localized and deep forms of technological intensification processes (Lorentzen 2008).

Effective NSIs have underlined the development of sophisticated industrial and technological capabilities across Scandinavian countries (Blomström and Kokko 2007) which allowed their resource-based industries to remain competitive against low-cost producers and develop a number of industries related to resource extraction: specialized machinery, engineering products, transport services, and equipment (de Ferranti et al. 2002; Blomström and Kokko 2007; Bitard et al. 2008). Scandinavian industries producing aircrafts, luxury cars, and designer furniture were initially developed as upstream industries to natural resource sectors. Similar trajectories have characterised the US (Wright 1990; Wright and Czelusta 2004, 2007; Maloney, 2007) and recently Australia and Norway (David and Wright 1997; Wright and Czelusta 2007; Grønning et al. 2008).

In Africa, the processes of technological upgrading and linkage development across countries have differed (Morris et al. 2012). Whilst most countries failed to develop processing or supply industries, and have under-developed human capital and governance; there are few countries in which these have been growing and improving, with deeper knowledge intensification processes taking place. South Africa is undoubtedly the most

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<sup>3</sup> Indeed, it was argued that MNEs could actually undercut the development of local technological capabilities, because the subsidiary's access to parent companies for 'just in time' technological solutions made it unnecessary to develop local technological capabilities, and also inhibit efforts by local, smaller competitors that could not compete with MNEs (Viotti 2002).

successful country in this respect, endowed with a well-developed mining inputs cluster and, to a lesser extent, some beneficiation industries.

In sum, the historical experience of resource-rich countries suggests that ‘the broad lesson is that the inherent character of resources does not matter for resource-based development, but rather, the nature of the learning process through which economic potential is achieved’ (Wright and Czelusta 2007: 184–5). Learning and innovation determine the creation, distribution, and use of new resources (Andersen 2012). The NSI literature, especially research on developing countries, suggests that technological learning requires coherent and dynamic NSIs, with emphasis on engineering, technical, and vocation skills; strategic industrial and FDI policies; and linkages between universities, research centres, and industry.

#### 4 Engineering and technical skills

Across Botswana, Zambia, and Zimbabwe, the mineral sector has played a very important role in human capital development, in particular, in relation to engineering and technical skills. In Botswana, investment in skills development has been sustained through proactive government education policies with strong resonance from the productive sector (Debswana). The 1990s and 2000s witnessed considerable public investment in the engineering segment of the tertiary education system. However, the 2008 economic crisis slowed down this pipeline: government sponsorships have been shrinking, and increasing gaps in math and science education at secondary level persist.

In Zambia and Zimbabwe, the role of the mineral sector and government in supporting skills development around the mining complex declined much earlier and more dramatically than in Botswana. Between the 1970s and 1990s, the mining industry contributed greatly to skills development in Zambia and Zimbabwe. In Zambia, this took place through State Owned Enterprise (SOE) Zambia Consolidated Copper Mines (ZCCM) and the ‘Zambianization’ policy. Training took place within the mining company, through peripheral training institutions, and within the manufacturing complex linked to mining.

Since the 1990s, the training capability of the state and the mining sector has eroded and today, the total output of technically qualified people is low. The fragmented and privatised ownership of the mining sector undermined the previous relationships with education and training institutions. Moreover, Zambia’s education policy has been predominantly focused on basic education. The decline in financing of the secondary and upper secondary sector has contributed to a decline in Science, Technology, Engineering, and Math (STEM) education. Structural challenges in terms of basic STEM knowledge trickle down to the competency of graduate students, which also has an implication on state funding since few students obtain the minimum results to pass and are awarded a scholarship for engineering and science. The success rate of the enrolled students and quality of education is then undermined by the lack of staff in universities as departments struggle to fill these knowledge gaps adequately.

In the 1960s and 1970s, Zimbabwe emerged as one of the most industrialized economies in Southern Africa. Post-independence education and other policies resulted in a robust NSI

that was not only centred around mineral extraction and manufacturing, but around other industries. Currently, Zimbabwe has 40 universities, polytechnics, and vocational schools. Out of the 13 universities in Zimbabwe, five support technical education, which directly feed into the engineering and metals sector, namely University of Zimbabwe (UZ), National University of Science and Technology (NUST), Harare Institute of Technology (HIT), Chinhoyi University of Technology (CUT), and Bindura University of Science Education (BUSE).<sup>4</sup> Meanwhile, mining companies have spent significant efforts to increase the share of African staff, especially via in-house training and offering work placement opportunities for students.

Economic decline since 2000 has led to fraying of the education system. This is acutely reflected in the exodus of skilled Zimbabweans to other countries, mainly to South Africa, evidenced by the decline in registered students between 2001 and 2012 from more than 3,000 to 600 (Nkala 2012). The massive loss of indigenous skills has adversely affected the mining industry and education and technology institutions. The Zimbabwe Chamber of Mines estimates that in early 2008, there were 1,116 vacancies for professional and technical staff (Hawkins 2009).

#### 4.1 Engineering skills

There is a significant difference among the three countries regarding the engineering disciplines and the number of graduates. Botswana's turnover has been influenced by the small population and the limited number of mining companies in the economy. Conversely, Zambia's turnover does not match the needs of a large mining sector and its potential supply chain, while Zimbabwe has experienced significant brain drain following the demise of the economy in the mid-2000s.

On average, the University of Botswana (UB) produces approximately 100–120 graduates per year, with around 15–20 master's and other post-graduate qualifications (Table 2).

The UZ Department of Metallurgy was non-functional in 2006 due to skills flight and poorly furnished laboratories and operating the mining and metallurgy departments separately had become unsustainable. Due to inability to sustain the detached entities, the mining and metallurgical departments were subsequently merged, and in 2011, benefactors funded the re-opening of the Department of Metallurgy. In 2015, 30 graduates were enrolled.

The combined output from the schools of mines and engineering from the University of Zambia (UNZA) and the Copperbelt University (CBU) is approximately 400 graduates, higher than Botswana and Zimbabwe. However, the proportion of master's students is very low, with the exception of the CBU School of Mines and Mineral Sciences (approx. 40–50 per year). The number of students from CBU needs to be viewed with caution. According to interviews, the university management is churning out high numbers in order to reduce

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<sup>4</sup> The universities offer four-to-five year Bachelor of Technology (BTech) or Bachelor of Engineering (BSc Eng Honours) degrees in fields such as mechanical and production engineering, industrial engineering, water engineering, chemical engineering, electrical engineering, energy, and fuels amongst others (ZEPARU 2014). Other degree programmes uniquely offered by UZ include civil engineering, electrical, mining, and metallurgical engineering as well as geo-informatics and surveying.

costs, which subsequently may affect the quality of graduates and distort the actual number of graduates.

Table 3: Mining and engineering graduates and post-graduates—Zambia (2015)

	Graduates per annum	Masters per annum	PhD enrolled	Staff and (vacancies)
School of Mines, University of Zambia	50	7–12	A few	Geology Dept. 6 (6) Mining Engineering 6 (6) Metallurgy 11(1)
School of Engineering, University of Zambia	70 Civil/ Environmental 20 Mechanical 20 Electrical 20 Agricultural 5 Geomatics 5	-	-	Departments: Agricultural 11 (5) Civil& Environmental 11 (5) Electrical & Electronic 11 (5) Geomatic 11 (5) Mechanical 11 (5)
School of Engineering, Copperbelt University	Approx. 300–400 students at graduate and diploma level	5	-	-
School of Mines and Mineral Sciences, Copperbelt University	150 graduates 150 diploma	30–40	-	-

Source: Field interviews.

The quality and output of graduates from regional universities is sub-standard and an additional constraint on skills as supported by regional statistics. The key challenges for engineering skills development identified: lack of infrastructure, poor institutional capability and poor human capital; will be discussed in more detail, looking across the country experiences, to understand its impact on the RSI.

#### *Lack of infrastructure*

Lack of infrastructure is a key impediment to UNZA’s teaching and research activities. Non-existent laboratories force lecturers to teach with no equipment and without being able to undertake practical demonstrations. According to the Association of Consulting Engineers of Zambia (ACEZ), the quality of UNZA graduates is of a high standard, but the lack of practical experience is a major hindrance to producing well-rounded engineers. Another challenge is the weak apprenticeship programme. Although mining houses complain about the quality of graduates, their assistance in addressing this issue has not been consistent, but rather ad-hoc project-based, such as an e-library or the donation of vehicles and equipment to the School of Mines (UNZA n.d.).

#### *Poor institutional capability*

Access to trained appropriately staff has also been a significant impediment for universities in the region as they battle to fill vacant posts due to more attractive working conditions outside the home country, among other factors.

Frozen budget constraints limit UNZA’s capability to retain experienced teaching and academic staff. Half of the teaching positions in two out of three departments at the School of Mines, and one third of the teaching positions at the School of Engineering are not filled.

Out of 300 lecturers at CBU Schools of Mines/Engineering/Natural Resources/Built Environment, only 50 have PhDs. Lack of funding to upgrade the qualifications of the existing teaching body aggravates the quality of education as vacancies are filled by underqualified staff.

In Zimbabwe, vacancy rates are also high. In 2015, of the 10-member staff complement at the Department of Engineering, there were six vacancies. Departments that had 15 lecturers each after 2000 were downsized to three-to-four permanent staff. The Mining Department does not have a full-time dedicated qualified lecturer and has resorted to sending students for post graduate studies to UNZA, which also has its own set of challenges.

#### *Poor human capital planning*

Poor human capital planning has been highlighted in both Botswana and Zimbabwe. Recent years have witnessed an increased role by private providers of tertiary education and training skills across the region. These institutions are driven more by short-term profit motives and tend to offer courses of study for skills that are not necessarily in short supply. Partly as a result, Botswana in 2015 had a surplus of IT graduates and diplomas, estimated at around 10,000 which the government is attempting to infuse into the NSI development efforts. This situation arose from a combination of private institutions courses and international scholarships programme, and a lack of planning.

Mechanisation of mining operations imply an increased need for mechanical and electrical engineers. However, countries in the region have traditionally focused on mining engineering. This concentration has borne multifaceted challenges with regards to engineering skills. For example, South Africa has an excess of mining engineering skills, only partly absorbed by consultancy firms and mining houses. According to the Southern African Institute of Mining and Metallurgy (SAIMM), 20 per cent of 2014 graduates are unemployed and less than 5 per cent of 2015 graduates (800) have guaranteed jobs. Universities are providing internships so that graduates can prolong their stay at the universities for another year by supporting the institutions and/or enrolling for other qualifications exacerbating the oversupply of skills. The South African Chamber of Commerce reports shortages of mechanical and electrical engineers.

The status of skills across South Africa, Botswana, Zambia, and Zimbabwe is skewed. Botswana seems the least affected due to the low demand from mining companies in the country. Furthermore, mining companies in Botswana have been instrumental in retaining academic staff in the engineering departments through salary supplementation and guaranteed access to consulting work. The mining industry is involved in additional ways: revision of the curriculum, and student attachments, especially sandwich programmes for diplomas i.e. students' alternate time spent at school and attached to firms. In addition to the relationship with the mining industry, the Faculty of Engineering and Technology signed a MoU with the Chamber of Mines that provides work placement for students during their practical training.

Zambia has a high output of graduates, though the quality of the students is questionable leading academic and research staff to South Africa for greener pastures. Zimbabwe's academic and research staff underwent an exodus to international countries, mainly South

Africa, following the economic downturn. South Africa seems to have benefitted from the movement of skills across borders. Nonetheless, these countries are failing to churn out students appropriately trained in engineering with the requisite technical skills individually.

## 4.2 Misalignments in TVET systems

Gaps in Technical Vocational Education and Training (TVET) are pervasive across Botswana, Zambia and Zimbabwe and affect the mining and manufacturing sectors. However, very different dynamics are at play. Despite the seemingly unravelling of the Zimbabwe NSI, its technical and vocational training institutions in Harare, Bulawayo, and Gweru are still producing high calibre mining and metallurgy skills. The TVET segment of Zimbabwe's NSI seems to have been more resilient to economic decline than the engineering segment. The Zimbabwe School of Mines in Bulawayo, established in 1926, provides technical and artisanal training to National Diploma and Higher National Diploma level Mine Geology, Mine Survey, Mining Mineral Processing and Extractive Metallurgy, and Metallurgical Assaying.<sup>5</sup> The School of Mines Bulawayo has marketed itself well to secure part-time senior professorial staff. According to 2015 interviews, it is actively supported by the Chamber of Mines and by the mining industry through provision of training for students from across the SADC region.

Conversely, Zambia's case starkly illustrates a combination of misalignments in investment in skills development within the public sector (with technical skills being largely marginalized), and between public and private sector. While there is a gap in Zambia's graduate engineering skills, the shortage of technical and artisan skills is more severe, estimated at 11,000 in 2015. For some time there has not been a coherent skills development policy in Zambia. Zambia's TEVETA was established in 2000 and designed to address the shortage of technical and artisanal skills. Increasing recognition of the importance of technical/vocational skills has not been matched by funding as resources were reduced by five per cent in the 2015 annual budget.

Firm-level initiatives are at different stages and adopt different philosophies depending on the scale of their respective operations. According to the International Council on Mining and Metals (2014), the mining companies are investing in a combination of in-house and outsourced training.<sup>6</sup> Although individual companies tend to start training employees immediately after employment and maintain good learning record systems, workers receive no certification so their skills are neither accredited nor portable.

A structured collaborative process is currently underway between TEVETA, the Chamber of Mines, and individual mining firms to integrate company-specific qualifications within a National Qualification Framework (NQF). There is no training or skills development obligation on the mining companies under current Zambian legislation. The Zambian Government has been discussing a mandatory skills levy, since TEVETA was established in

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<sup>5</sup> For information on the School of Mines, see <http://www.zsm.ac.zw/zsmsite/about-zsm/historical-perspectives> (accessed 17 May 2016).

<sup>6</sup> 'Data provided by three mining companies indicates that together they spent around US\$ 5 million on outsourced training in 2012. The spending on training in recent years, in absolute terms and as a share of total labour costs, has increased' (ICMM 2014: 64).

2000. This has received strong industry opposition, partly because of scepticism about the ability of government to collect and spend the levies appropriately. This policy debate, the need to address local skills shortages, and stricter immigration rules have resulted in the setting up of the Zambia Mining Skills and Education Trust (ZAMSET) the end of 2014. All the major mining companies (except Chinese-owned Chambishi) have joined the initiative, under the Chamber of Mines. ZAMSET was expected to become operational by the end of 2015, with strategies in place and more importantly financing.

### 4.3 The regional dimension

NQFs pursue important education policy objectives such as quality assurance and coherence across the various public and private components of the system. Industrial policy objectives of an NQF include ensuring that the education and training system is dynamic and coherent enough to respond to changing industrial and economic production requirements and to facilitate the transfer of skills across firms and sectors. South Africa has the most developed NQF, with systems already implemented and are reviewed and monitored. Botswana and Zambia have TVET qualification frameworks in place and are in process of establishing NQFs. Zimbabwe is at the earliest stages of NQF development.

The emergence of NQFs within individual countries will facilitate the movement of engineering and technical skills across the region. Interviews with SADC confirm that information exchange between national institutions is increasing. In 2000, SADC established a Protocol to establish a Regional Qualification Framework. As of November 2015, the first stage had been implemented, namely the development of one framework for all skills. This is a long process because member states are required to build their respective NQFs first then establish their own NQAs.

A striking feature of the SADC education systems analysed is the extent to which national tertiary institutions are unable to accommodate their national student complement (Table 4). A very large proportion of students from Botswana (71 per cent), Zimbabwe (29.9 per cent), and Zambia (14.7 per cent) study outside their home country. Even though Zimbabwe has a low proportion in relative terms, in absolute terms, Zimbabwe has by far the largest stock of students abroad (16,700) in SADC, given the decline of the domestic education system. Botswana has the second largest stock (9,500) in absolute terms, while Zambia has a relatively low stock both in absolute numbers and as mobility rate.

Table 4: Intra-SADC student flow

Country	Students from a given country studying abroad			Top five destinations for outbound mobile students	Number of students from abroad studying in given country
	Total	Outbound mobility rate (per cent)	Gross outbound enrolment ratio		
Angola	5942	45.9	0.4	Portugal (3,367), South Africa (839), USA (442), Namibia (354), France (205)	50
Botswana	9471	71.6	4.5	South Africa (7,012), Australia (792), UK (700), USA (488), Malaysia (152)	n/a
DRC	3956	6.6	0.1	Belgium (1,271), France (816), South Africa (378), USA (340), Burundi (276)	n/a
Lesotho	4537	74.3	2.0	South Africa (4,366), UK (42), USA (39), Australia (15)	116
Madagascar	3995	9.5	0.2	France (3,487), USA (109), Germany	1219

				(100), Switzerland (80), Canada (41)	
Malawi	1438	28.3	0.1	South Africa (417), UK (404), USA (399), Australia (77), Canada (22)	n/a
Mauritius	7224	40.6	7.0	France (1,893), South Africa (1,732), UK (1 646), Australia (860), India (366)	75
Mozambique	2366	10.6	0.1	Portugal (1,066), South Africa (815), USA (93), UK (71), Australia (67)	n/a
Namibia	6847	58.1	3.5	South Africa (6,530), USA (95), UK (74), Australia (24), Germany (16)	1026
South Africa	5619	0.8	0.1	USA (1,971), UK (1408), Australia (643), Cuba (340), Germany (196)	49979
Swaziland	2106	31.9	1.7	South Africa (1,882), USA (86), UK (67), Lesotho (17), Australia (13)	127
Tanzania	3907	9.1	0.1	USA (1,471), UK (1,053), South Africa (283), Australia (119), Germany (115)	275
Zambia	3610	14.7	0.3	South Africa (1,363), USA (859), UK (541), Australia (317), Namibia (228)	n/a
Zimbabwe	16669	29.9	1.1	South Africa (10,586), UK(2,741), USA (1,999), Australia (892), Namibia (71)	n/a

Source: CREST (2011).

These figures are not disaggregated by schooling level or disciplines. Enrolment data from Schools of Engineering at University of Cape Town (UCT) and Stellenbosch University shed some light on trends by country (Table 5). Zimbabwean students seem more likely to move abroad for undergraduate degrees. Students from Zambia undertake graduate and even more postgraduate courses abroad.

Table 5: Enrolment of regional students at Stellenbosch University and UCT

	Stellenbosch University			UCT		
	2013	2014	2015	2013	2014	2015
<b>Undergraduate</b>						
Botswana	0	1	1	20	17	11
Zambia	1	1	1	17	14	14
Zimbabwe	42	48	43	145	145	122
Others Africa	112	109	109	254	252	244
<b>Postgraduate</b>						
Botswana	2	4	3	5	3	4
Zambia	13	21	24	13	17	18
Zimbabwe	24	24	30	57	55	67
Others Africa	97	108	94	149	155	185

Source: Fieldwork, 2015/16

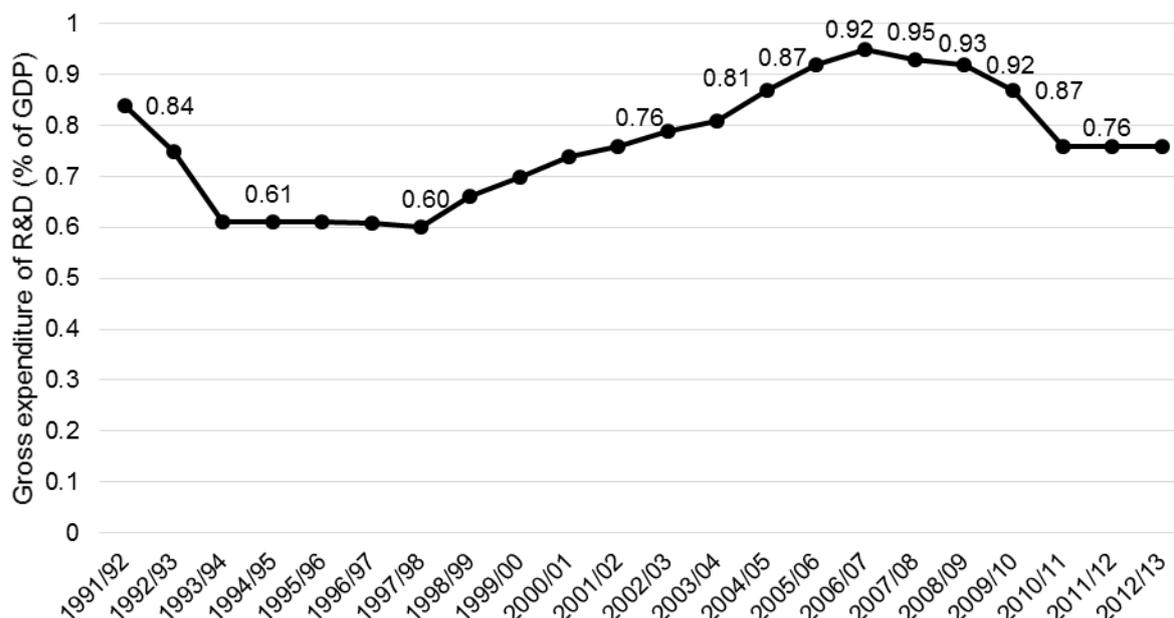
South Africa was the largest destination country for the three countries selected, and hosted a total of almost 50,000 foreign students (Table 4). This points to a largely regionally integrated education system. The development of the RQF lags behind such that it is difficult to obtain recognition for courses obtained in home countries. The particular dynamics of the education system within the region have led to students moving across to South Africa and attaining South African qualifications. For example, notwithstanding the fact that Botswana has education statistics comparable to South Africa, if not superior in terms of tertiary education enrolment, South Africa's tertiary education system has over decades developed centres of excellence in engineering, in particular at Wits and UP. As discussed in the next sections, many Zambian and Zimbabwean graduates tend to remain in South Africa's university systems or engineering consultancy sector after completing their studies.

At UB, individual departments and faculties have MoAs with other universities including Stellenbosch University and UCT while Zambia's CBU has no cooperation agreement. So far, relationships with South African universities have been mainly built through informal channels, such as connections between supervisors in South Africa and postgraduate students returning to CBU. UNZA's School of Mines promotes regional cooperation and its strategic plan encourages synergies with institutions anywhere in the world. At the moment, there is an MoU with UCT/Stellenbosch University. UNZA School of Mines has four PhD students at Stellenbosch (chemical/environment engineering), whilst the School of Engineering has two students at Stellenbosch University. There was a previous agreement with UJ's Geoscience department but this was not renewed. The School is looking at establishing a relationship with the University of Venda, building on the current informal relationship whereby UNZA provides external examination and quality assurance. There are also exchanges not related to South Africa: UNZA School of Mines report there are academic exchanges in place with the region, and it is currently hosting several post-graduate students from Zimbabwe and eight post-graduate students who are staff members at UZ.

## 5 R&D and innovation

African governments are the main source of R&D funding, accounting for more than 60 per cent of total R&D expenditures (UNECA 2014). This is confirmed for SADC, where the majority of countries and most of the universities (with the exception of South Africa) relies for more than 70 per cent of their total research funding on international funding organizations; the comparative figure for South Africa was six per cent (CREST 2011). In the continent, industry R&D is very low, with weak firm R&D capabilities and industry-research institutions collaborations (World Bank 2011). South Africa is a relatively large investor, with 0.76 per cent of GDP spent on R&D and 363 R&D researchers per million people. By international standards, South Africa is below the BRICS and South Korea, but not too far from India. (Department of Science and Technology 2013). South Africa's R&D expenditures nevertheless have been declining in both absolute and percentage terms since the second half of 2000s (Figure 2). The decline is also reflected by the decline in the number of researchers employed by industries' R&D departments from 6,172 in 2008 to 4,556 in 2013. Conversely the number of researchers in universities increased from 9,953 in 2008 to 13,744 in 2013. One-third of researchers at PhD and post-doctoral level were non-South Africans.

Figure 2: South Africa gross expenditure on R&D (1991–2013, per cent GDP)



Source: Department of Science and Technology, South Africa (2013).

Unlike the rest of the region, in South Africa, industry, mostly national firms, is the largest source of R&D funding, 44.3 per cent of total expenditures in 2012/2013, amounting to R 10.5 billion (Department of Science and Technology 2013). Manufacturing (machinery and equipment) and mining were the second and third most important sectors for industry R&D. Industry funded mainly its own research, with small shares directed to universities (six per cent) and science councils (one per cent). This is consistent with the view that industry-research links are insufficient (World Bank 2011).

Patent registration data show very low activity within Botswana, Zambia, and Zimbabwe (Table 7). In South Africa, two worrying trends were noticeable: patent registrations trend have been stagnant, compared to high growth in Asian countries, and the ratio of resident to non-resident patents equalled 0.1 in 2013, due to declining numbers of resident patents—from 1,003 in 2005 to 638 in 2013. This ratio was low by international standards: for example it was 0.33 in India and 3.56 in South Korea.

Table 7: Patent and trademark registrations, selected countries (cumulative 2004–2013)

	Botswana		Zimbabwe		Zambia		South Africa	
	non-resident	resident	non-resident	resident	non-resident	resident	non-resident	resident
Patents	18	14	0	0	194	92	64,613	8,145

Source: World Bank (2016).

All the countries surveyed have or are building central institutions to coordinate and facilitate science funding and research funding. The research findings confirm that the main common impediments to R&D, innovation and the evolution of a robust NSI include:

- R&D and intellectual property (IP) funding
- R&D and IP commercialization
- Skills

- Industry relationships with NSI education and research institutions

## 5.1 Case studies on Botswana and Zimbabwe

Botswana and Zimbabwe present two contrasting experiences, whilst the former is laying the foundations for an ambitious NSI, the latter has seen the rapid deterioration of its NSI, which used to be SADC's second most established one after South Africa before the economic crisis.

### *Botswana's ambitious NSI and innovation policy*

The establishment of the Botswana Innovation Hub (BIH) in 2007 and the 2008 Botswana Excellence Strategy represent the government's intention to move Botswana towards a knowledge economy. Innovation has been hampered by a number of factors. A small domestic market and narrow resource base discouraged investment in manufacturing. For this reason, Botswana's current focus is on upgrading technological capabilities for niche industries. Interviews highlighted that the main gaps in the development of a dynamic NSI consist of insufficient R&D funding, poor commercialization, and weak management skills of start-up firms. Private firms spend little on innovation and public R&D efforts have been limited. Two organizations have been designed to address these constraints: Botswana Institute of Technology, Research and Innovation (BITRI) and BIH.

In 2012, primary research capacity was consolidated under BITRI, largely through the incorporation of previous research institutions. BITRI has two thematic focus areas (BITRI 2014): technologies (electronics, energy, ICT) and natural resources and materials. BITRI's task is to identify, absorb, and innovate technologies. Hence, there are significant efforts to acquire intellectual property, adapt foreign technologies to domestic conditions, and pursue incremental innovation. In this spirit, BITRI has concluded an agreement with Singapore Solar Energy Research Institute (SERIS) to develop new applications for their existing products. BITRI is funded by government and parastatals commissioning services from their labs and research centres. So far, cooperation with the mining sector has been minimal with management forecasting a change.

By 2015, BITRI had equipped almost all laboratories. The institute has three sites and several centres devoted to ICT, chemistry, engineering, and industrial workshops (CNC equipment and metalworking). At full capacity, BITRI has a staff complement of 250 personnel. However, in 2015, it had 97 staff and 60 interns. Personnel include expatriates for strategic positions, with large numbers of juniors trained to take senior roles in future. The previous institutions had five PhDs, while BITRI already has 35.

BITRI is establishing two pilot plants for the coal to liquid and coal beneficiation research programme in line with resource-based industrialization. It is particularly interesting that the coal to liquid plant research is targeting chemicals and fertilizers rather than fuel (which is the main product of coal to fuel technology perfected by SASOL). Interviews with management indicated that future areas of research would target copper, gold, and soda ash.

BIH was established in 2008 and has a staff complement of 20. Its mandate is to attract FDI in innovation-driven economic activities, develop a science and technology park, support commercialization of innovation, and intellectual property protection of domestic innovators. The priority areas include mining, energy and environment technologies. BIH has transformed from being completely government owned to being 51 per cent parastatal in 2012, and aspires to become fully private in future. The model of transformation enables BIH to pursue a very dynamic and responsive business strategy securing more than 80 partnerships with academic, research institutes, and the private sector. The most noticeable partnership is with Microsoft, where it managed to establish a fully equipped laboratory and has supported software development start-ups.

By 2015, the BIH had established seven private firms in incubation and ten virtual companies. One of the incubators is the mining entrepreneurship development programme, based in Selebi Phikwe, funded and supported by BCL, a large copper and nickel producer, and run under the Southern African Innovation Support Programme.<sup>7</sup> BIH provides incubation and development support for mining supply entrepreneurs with around 20 firms focused on:

- Hydro-geology
- Aero-spatial mapping (drones)
- Protective clothing/containers for mining samples manufacturing
- Pumps re-engineering
- Software development

The programme is part-funded by mining firm BCL, which set up the facilities and is carrying out the training and mentoring. BIH together with BCL and private companies are working on a project to utilize the slag from the BCL mine to produce nickel and iron powders. The current slag stockpile is estimated in excess of 40.5 million tonnes containing various amounts of iron, nickel, copper, and cobalt.

In 2014, Botswana's NSI was enhanced by the creation of the National Technology Transfer Office, to assist local firms with IPR management and the protection and commercialization of their innovations (BIH 2016).

The challenge for Botswana (and other countries surveyed) is to align better skills and R&D programmes to the needs for entrepreneurial firms and to create more R&D relationships between industry and universities. Universities have not traditionally been focused on R&D. In an effort to expand post-graduate R&D, the Botswana International University of Science and Technology (BIUST) was established in 2012. Located around 270 km from Gaborone, the institution has completed its first enrolment and is more commercially oriented aiming to carry out research with BIH assisting with the commercialization. Moreover, Botswana's PhD intake has increased recently through a consortium of ten African universities sponsored by the EU, which promotes intra-African exchange students for PhDs.

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<sup>7</sup> The Southern Africa Innovation Support (SAIS) programme, funded by the Finnish Ministry of Foreign Affairs (MFA), is a four-year pilot project supporting collaboration between the innovation systems of African countries.

### *The decline of Zimbabwe's NSI*

Zimbabwe's NSI has been unravelling since the early 2000s, which is not only illustrated by the extent of brain drain discussed earlier, but also by the performance of national research and teaching institutes. The trajectories of the Institute of Mining Research (IMR) and Scientific and Industrial Research and Development Centre (SIRDC) are instructive.

The IMR was established in 1969 with a fourfold mandate: innovation (relevant for industry and government); responsive research (for government); sample analysis for the mining companies; and mining exploration (for government). Before the crisis, the IMR produced significant output in terms of technical reports and explorations, also successfully registering a patent for fertilizer production. The downward trend started in 2002, and in 2009, it accelerated. The loss of capacity can be assessed in many areas. In terms of labs for sample analysis, whilst the coal lab and chemical labs are functional, the crushing and pulverizing machines, carbonite and sulphur testing machines, and XRF are not working. In terms of research staff, there have not been new appointments since 2009 due to the requirement that applicants hold a PhD. Yet to attract this calibre of applicants, IMR should improve salary and work conditions, which at the moment is not feasible. Some posts could be filled by lower qualified staff but the PhD requirement has been institutionalized. This has resulted in only three out of 14 post-PhD position posts being filled, with no geologist, and only one of two chemists. Three out of five technician positions are filled, and there are no research assistants. In terms of funding, government only provides operational funding, which is insufficient—only one equipment piece is in working condition, there is only one vehicle for fieldwork, and there is no funding for consumables (chemicals).

The SIRDC was established in 1993 to undertake research for the mining sector, which also entails working hand-in-hand with the Ministry of Mines and the Chamber of Mines. In particular, SIRDC provides environmental impact assessments, optimization services, and waste management solutions for the mining companies. It also has a foundry for spares casting and lab testing services, which support manufacturing firms. There are 12 institutes, of which three are mining-related: geo-information and remote sensing, metallurgical research, and national metrology.

At full capacity, SIRDC employs 400 engineers, scientists, and artisans, however in 2015, only 150 were employed and mostly not at senior level. Brain drain has been severe, across all staff categories with staff mainly locating to South Africa due to better working and living conditions (Wits, Mintek, and CSIR). Often, staff would leave in teams, with scientists and engineers leaving first and other team members following. In some instances, scientists and engineers left with their databases and research output, then patenting the research in South Africa. There were also instances where SIRDC lost contracts because the mining company had a specific relationship with the researcher who left. The decline affects also physical facilities, which are caught in a 'catch 22' situation: personnel will not remain because laboratories are not up to standards, but laboratories do not remain up to standards because they are not utilized nor funded.

Government funding has been shrinking, and now only covers salaries, not operations, with the exception of a recent purchase of lab equipment for crosscutting analysis, which in 2015 would cover only 30 per cent of their operational expenditures. As such the institute sources

grants from international donors or domestic customers. The decline of the domestic manufacturing sector has also had a negative impact on the institute as it deprived it of current and potential customers and partnerships in technology development.

## 5.2 The regional dimension

An analysis of mining-related NSI in Southern Africa has to focus on the role of South Africa for a couple of reasons. Firstly, South Africa has the highest R&D capabilities in the region. For example, according to royalties, licencing fees, and using payments as proxy for technology transfer and capabilities, South Africa accounted for 92 per cent of Africa's total payments for 2013 (World Bank 2016).<sup>8</sup> Secondly, South Africa operates at the global technological frontier for mining related technologies (Kaplan 2012).

There are three key centres for public mining-related research in South Africa: CSIR, Mintek, and the universities.

A regional research alliance has been in place between South Africa's CSIR, Botswana's BITRI, and Zimbabwe's SIRDC with the aim of sharing knowledge, information, and exchange personnel. Priority areas were identified in mining, pollution, water, and food security in mining communities. Interview findings suggest that the initiative has not been successful, for reasons including lack of resources available to undertake projects and weak leadership in driving this partnership forward from the CSIR. This alliance has deteriorated due to lack of funding.

Mintek traditionally has strong R&D capabilities related to mineral processing. Mintek balances long-term, break-through research (where the payback in terms of implementable technology may be 10–20 years) with short-term, incremental research suitable for rapid implementation. Mintek's focus is more domestic than the region, although its capabilities in the development and optimization of mineral processing systems to cater to different minerals can be extended to any mining operation, as is evident in its global activities outside of SADC. The potential for regional R&D and innovation work is illustrated by a number of regional projects reported for 2015: grinding media quality control projects in Botswana, and assistance to a number of regional base metal producers to optimize their plant throughput. An obvious limitation is that Mintek does not work on open cast, which is prevalent in Africa—its focus area is not aligned to regional needs. However, significant research and technical staff at Mintek and CSIR originate from the region, which implies that there may be scope to tap into open cast mining services.

The South African Minerals to Metals Research Institute (SAMMRI) is a leading research collaboration between South African universities and industry (12 OEMs and mining houses) focused on incremental innovation. There is also a lot of knowledge transfer taking place, with industry members mentoring principal investigators and researchers. SAMMRI is very competitive; hence some of these OEMs have a genuine interest in its activities. SAMMRI has a competitive advantage on some innovation, but it needs to make sure that application is successful. A significant number of researchers originate from DRC, Zimbabwe, and

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<sup>8</sup> Payments rather than receipts are a more accurate proxy for technology transfer and capabilities, because the latter include mining licences and royalties (UNECA 2010).

Ghana. However there is no regional cooperation programme in place, except for personal networks through the investigators themselves.

The Wits Centre for Mechanised Mining Systems was set up by mining houses, consultants, and OEMs for graduate training in mechanization. The current student composition is mainly from Zimbabwe and Zambia, and rarely non-English speaking countries such as Mozambique and Angola. The majority of post-graduates are foreigners however due to the Black Economic Empowerment (BEE) and immigration laws, securing employment is challenging. There are a proportion of students who are potentially interested in returning to their home countries. Demand for their skills will grow across the region as underground mines become increasingly mechanized.

At the same time, Botswana NSI is developing its own regional linkages. BITRI has a MOU with the Namibian National Commission for Science and Technology. In parallel, a similar programme to the mining entrepreneurship development programme, based in Selebi Phikwe is underway in Zambia, run by the Motivational Centre for Africa Transformation, the Lumwana Mining Company, and Lumwana Community Business Association and facilitated by business incubation experts.

At SADC level, progress has been slow. Science and technology (S&T) is a relatively new policy area for SADC, with a regional protocol signed only in 2008 and ratified by only four countries, Botswana, Mauritius, Mozambique, and South Africa. Of the many S&T objectives contained in the Revised SADC Regional Indicative Strategic Development Plan (RISDP), the priorities include a framework on innovation and technological transfer, IPR, and Centres of Excellence.<sup>9</sup> Whilst South Africa is taking a leadership position in this area, for example seconding to SADC an official from its Department of Science and Technology, this S&T programme still has to secure funding. The NSI is impacted by, amongst others, industrial policy. A regional SADC industrial policy is evolving as is a specific programme on mining that includes an action plan for the implementation of SADC mining legislative regulatory framework, a study in mining sector skills development across SADC, and a minerals beneficiation study.<sup>10</sup>

## 6 Engineering consultancy services

The depth and breadth of a country's indigenous consulting engineering sector is a valuable indicator of the strength of the respective country's NSI.

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<sup>9</sup> The Regional Indicative Strategic Development Plan (RISDP) is a comprehensive development and implementation framework guiding the Regional Integration agenda of the Southern African Development Community (SADC) over a period of fifteen years (2005–2020).

<sup>10</sup> Other important initiatives include the Pan-African Minerals University of Science and Technology, which focuses on energy, water, and environment. It is an African Union initiative and it will be based in Zimbabwe in partnership with SIDRC.

Consulting engineering service companies are present in all countries surveyed. Consulting engineering services straddle a wide range of knowledge-intensive activities including the design of products, processes (new and process modification), project design, project management, contract administration, and other engineering management services. These capabilities have evolved around the mining and utility sectors of the respective countries. Domestic firms consist of national citizens as well as foreign engineers. In general, we have observed that the engineering service requirements of domestic (largely state-owned) utility sectors for civil, public works, electricity, and water sectors have tended to be serviced by indigenous engineering service firms, some of whom have expanded to support the mining sector while mining and other sectors are serviced by international engineering services.

Research findings point out that whilst there is significant competition amongst construction firms operating in the region's large infrastructure projects, especially from domestic, South African, and Chinese firms, in mining-related projects, South African engineering consultancy firms have a strong regional presence and face less competition. This is probably due to strong inter-firm linkages that characterize South African regional exports: when South African EPCM firms move into the region, they tend to bring with them specialized engineering consulting firms and OEMs (Walker and Minnitt 2006; Rustomjee 2007; Kuriakose, Kaplan and Tuomi, 2011).<sup>11</sup>

## 6.1 Domestic engineering consultancy sectors

South Africa's consulting engineering capabilities are significant. The industry is organized and represented by Consulting Engineers South Africa (CESA), which has 540 member firms employing more than 24,300 staff, with a total fee income in excess of R 25 billion per annum (CESA 2014a). Most South African consulting engineering work is carried out within South Africa on public sector infrastructure projects as well as on projects across the mining and manufacturing sectors. Consulting engineering activities are interwoven with machinery and engineering service inputs into the SADC mineral sector; South Africa's capital goods sector has developed strong export capabilities, particularly in the SADC region. It is estimated that some 10 per cent of total annual South African engineering consulting sector income comes from exports of services, usually associated with infrastructure and mineral sector projects. However, this figure may be inaccurate because the service may have been recorded as part of equipment exports, or turnkey projects under a separate coding, or not recorded because transaction took place at intra-firm level (Rustomjee 2007).

Due to Botswana's proximity to South Africa and due to its relatively small population, mining and metallurgical skills in this country have been traditionally supplied from South Africa. Botswana engineering sector relies on government for business, but in recent years this has been difficult. Local firms range from one-person companies, to some, very large international ones, mostly from South Africa. Mining companies tend to give work to South African companies, with whom they have done business before, with limited opportunities

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<sup>11</sup> According to a 2007 study on engineering services trade, industry data shows that exports, mostly to SADC, accounted for less than 10 per cent of total income in the engineering consulting sector (Rustomjee 2007) However the report finds that exports of construction services were not accurately captured because they were often recorded as part of equipment exports, or turnkey projects under a separate coding, or not recorded because transaction took place at intra-firm level.

to local firms. The local content requirements under the citizen empowerment policy, is not really monitored and enforced in this sector, and engineering companies can decide if and how to implement provisions, with no penalty.

In Zimbabwe, there are more than 30 engineering consultancy firms (ZEPARU 2014). They are organized under the Zimbabwe Association of Consulting Engineers (ZACE 2016). Most of the registered companies are involved in civil, structural, mechanical, and electrical consultancy. South African firms are increasingly entering the market by partnering with local firms, with better knowledge of the domestic business environment. South African firms sub-contract to Zimbabwean firms at low rates, whilst retaining most of the profits. When South African and Zimbabwean firms bid together for tenders, the South African firms tend to crowd out the Zimbabwean firms and keep all the business and profits. An example of this was the pre-feasibility study of a platinum mine.

According to key informants brain drain was the major reason behind limited local expertise. There are several small-scale engineering consultancy firms in existence due to the relatively high number of technical graduates in Zimbabwe (ZEPARU 2014). However, most of them are not formally registered and lack the experience to handle big projects. According to the law, foreign engineering firms are supposed to partner with domestic firms, but interviews highlight this has not been monitored and enforced. Ironically, the foreign expertise, included experienced Zimbabwean engineers and scientists mainly based in South Africa, having been lured by better working conditions during the economic crisis. Many Zimbabwean engineers have also been working in Zambia.

In Zambia, most domestic firms are relegated to the lowest value added of the engineering value chain: small and medium scale civil works. Currently, Zambia's domestic engineering firms have capabilities in civil engineering (township development, road network development) and to a lesser extent mechanical engineering. There is some capacity in electrical and specialized mining engineering (civil, mechanical, electrical) but firms need support and access to procurement opportunities. Other capabilities such as EPCM and shaft sinking are not available. A number of South African consulting and engineering firms have, in terms of mining law conditions, established local offices in the Copperbelt to provide specialized services such as hydrogeology, exploration, and other work. They tend to be small firms employing a few locals to meet localization requirements.

The Engineering Institution of Zambia (EIZ) regulates the accreditation of engineers, technologists, technicians, and craft persons. EIZ currently manages a database of 25,000 members. The Zambian Development Agency's (ZDA) investment promotion objectives often override domestic skills development objectives. Importing management and engineering expatriates is usually part of the investor's conditions of investment. The domestic labour market is quite open. There are engineering skills from India, China, South Africa, and South America, especially in the mining sector. Investors can bring their own engineering staff, and sometimes registration requirements with EIZ are waived. Respondents argue that the EIZ should be engaging with ZDA to impose tougher conditions and it should also provide more information on available Zambian skills to guide the ZDA. Yet, when the Engineering Board of Zambia tries to implementing some regulations in this direction, mining companies manage to oppose successfully through other government

ministries. The lack of conditionality on FDI effectively undermines the development of local linkages and consulting engineering capabilities.

The professional competence of engineering graduates, technologists, and technicians training institutions are subject to their respective country's accreditation systems. For example, engineering graduates from the UNZA would have their professional training qualifications and work experience recognized and accredited by the Zambia's EIZ. That engineer or technologist would not be eligible to carry out certain professional duties in South Africa or Zimbabwe, without having to register with the ECSA or the Zimbabwe Institute of Engineering (ZIE), which would independently attest to their competence or require the candidate to undergo further training. The mobility of engineering skills can be enhanced by bilateral and multilateral agreements.

Cooperation between national engineering professional councils is deepening. The ECZ has signed a MoU with ECSA in South Africa under which they convene discussion platforms with the mining houses in South Africa, Zambia, and Malawi to discuss regional strategies, challenges, and opportunities as well as possible areas of coordination. The MoUs facilitates coordination and also serve to ensure fair treatment in the recognition of qualifications and experience of members.

There are three international mutual recognition agreements that recognize equivalence in the accreditation of national qualifications. The Washington Accord covers national engineering degrees, the Sydney Accord engineering technology qualifications, and the Dublin Accord engineering technician qualifications. Within SADC, only South Africa is a signatory of these accords.

The strength of domestic consulting engineering services appears to be impacted by three main factors. First, these capabilities are dependent on the quantum of engineering-intensive activities in the economy—around mining and infrastructure for example. In a growing world economy, engineering skills are sought after and are mobile. Second, consulting capabilities are influenced by the robustness of the respective domestic NSI skill development system to develop and sustain such capabilities. Third, the accreditation standards adopted by the respective authorities also make a difference. Accreditation standards provide assurance on the quality of engineering work. This often directly impacts on public and workplace safety. However, accreditation systems also provide a degree of protection from outside competition for the individual domestic engineering and consulting professionals. If such standards are too high, they confer an undue degree of protection, potentially raising domestic engineering service costs. Conversely, if such standards are not high enough or are not enforced fairly, it can undermine public safety and can lead to the failure of the engineering projects. But poorly enforced accreditation standards can also weaken the respective domestic consulting engineering fraternity to the point that it discourages domestic entrants and/or encourages domestic engineering and consulting professionals to look for opportunities outside of the country concerned. This, in turn, adversely impacts on that part of the respective country's NSI, which is geared towards the generation of national technical and engineering skills and capabilities.

## 6.2 The regional dimension

There is significant movement of engineering skills across the region: many Zambian engineers are employed in the region, even more Zimbabwean engineers, and South African and Zimbabwean skills are employed in Zambia. International companies particularly in the mining sector are driving these trends. Engineering professionals tend to remain in Botswana, only some leave for South Africa. According to data from South Africa Chamber of Mines, in 2014, the percentage of foreign workers in the mining sector was 14 per cent. Looking at the sectoral breakdown, foreign workers represented nine per cent of total engineers working in consultancy services.<sup>12</sup> They find it easier to find work in the consultancy sector rather than the mining companies because of South Africa's policy of Black Economic Empowerment (BEE).

There is evidence of intra-SADC skill mobility also for technical skills. In Zambia, specific skills sourced from Zimbabwe include plastering of ceilings (construction), agricultural skills, and heavy equipment operators. Skills imported from South Africa include mining-related skills, coded welders, and steel fixers and the severity of the scarcity of these skills results in some cases where these skills are sourced even from South America.

The mining houses with operations in Africa tend to source engineering skills from South Africa, especially at the phase of designing and constructing a mine. With time, when the mine is operational, there is more interest in local employment and use of local engineers. Some mining houses with good training facilities in South Africa, relocate to the region personnel in charge of training to establish similar facilities (Glencore, Xstrata). This applies to greenfield projects rather than old mines in Zambia or Zimbabwe.

Three key factors underlying the regional market for engineering services were unveiled by this study: domestic markets open to foreign engineer professionals; local content policy enforcement and the role of returning engineers in the industry.

#### *Domestic markets open to foreign engineer professionals*

Botswana, Zambia, and Zimbabwe engineering bodies confirm that it is relatively easy for foreign engineers to operate in their domestic markets. Zimbabwe's chief immigration officer reported 3,000 Chinese engineers operating in the country, yet only 1,000 were registered with ZIE. It appears that clauses contained in high-level government-to-government agreements on major engineering projects have granted the respective project developer exemption from a range of national regulations, including engineering registration requirements. Moreover, all the professional registration bodies experience challenges in verifying the qualifications of foreign engineers. This points to the need for more effective management of accreditation systems.

Similar problems are reported at technical level in Zambia. Firms can import skills when they can justify that there are no locally available skills more so because local skilled labour is often not officially qualified. Other loopholes exist for example where some technical personnel people enter the country as trainers, then they change their positions to floor

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<sup>12</sup> Sub-sectoral breakdown: Coal diamond 2 per cent; Gold 27 per cent (agreements in place with Lesotho, Swaziland, Malawi, and Mozambique); Platinum 15 per cent; Others 7 per cent; Cement 1 per cent.

supervisors and stay. TEVETA (Zambia) is trying to regulate the system, engaging the immigration department.

On the other hand, Botswana, Zambia, and Zimbabwe's respondents agree that it is difficult to register in South Africa if the qualification was not obtained in South Africa or in countries that subscribe to the Washington Accord. Zimbabwean stakeholders report issues with Zimbabwean engineers in South Africa being professionally recognized, with recognition denied or delayed by ECSA with no clear justification. This was also echoed in a survey that was conducted by ECSA where the main reasons for not being able to register were complicated registration process and qualification not being recognised (ECSA, 2014). If a professional is not registered, he/she will be paid a lower fee as a technician as this may render their skills lower quality. SADC confirms barriers to recognition of engineers in South Africa.

#### *Lack of enforcement of local content provisions*

All the countries reviewed have local content measures in place, usually by reserving a percentage value of the contract work for local companies. The Zimbabwean government has a statutory requirement that at least 30 per cent of consultancy has to be given to Zimbabwean firms. Moreover, engineering companies are required to have national understudies. However, enforcement and monitoring has lacked across all countries. In Botswana, the Engineering Board is moving towards including mentoring obligations on engineering practitioners in order to address the problem of graduates lacking practical experience. In other countries, there has been no movement in this direction.

#### *Returning engineering skills struggle to enter the market and call for more linkages between foreign and domestic engineering firms*

Zambian engineers are returning to take advantage of the opportunities from massive infrastructure investment. Some set up their own independent businesses—consulting engineering firms with lots of intellectual capital, where size does not matter, others enter through JVs. According to ACEZ, however individual firms often fail to secure sufficient business to sustain operations. These cases prove that skills and experience are not sufficient to participate in the most valuable contracts related to mining.

Similarly, Zimbabwe's stakeholders argue that whilst competence of Zimbabwean engineers is widely recognized, this is not translated into access to business opportunities with the mining houses. The latter prefer to contract with South African firms or their home country engineers while domestic engineering firms are involved as sub-contractors. One respondent indicated that he provides his services under the affiliation of a South African firm because of the lack of confidence in local capabilities.

The depth of a country's consulting engineering sector is an important indicator of the strength of the respective NSI. Our research shows that South Africa has the largest consulting engineering sector, which is also deeply integrated within a well-developed capital goods sector. The consulting and capital goods sector are increasingly exporting their capabilities, most significantly into the SADC area and other African countries.

## 7 Conclusions: a southern African regional system of innovation?

The mining sector has played an important role in shaping the economic trajectories of Botswana, Zambia, and Zimbabwe. In particular, Zambia and Zimbabwe have seen large-scale investment in the mining sector during the last decade. This has pulled demand for capital goods, technical skills, engineering services, mining-related technological solutions, and infrastructure. Such large-scale investments create opportunities to build NSIs and local manufacturing and service industries.

A country's NSI covers a very wide range of sectors, activities and issues. We focus on that part of the NSI that impacts on the mineral extraction and mineral processing value chain. The boundaries of our analysis have extended across those parts of the vocational and tertiary training systems that impact on the mineral value chain. We have also chosen to focus particularly on production and utilization of consulting engineering skills which is an important indicator of the strength of the respective NSI.

The evolution of country-level NSIs in relation to the mining sector reviewed in this paper differs greatly. Botswana is crafting a space for a strong domestic NSI, with high public investment in institution building, infrastructure, skills, and policies to attract FDI and talent. BITRI and BIH have not only important and broad mandates, but have also been endowed with the resources and political backing to achieve these. In order to compensate for a small domestic market and very small manufacturing sector, Botswana is to all effects re-defining its comparative advantages to attract knowledge-intensive economic activities. The response by industry, both domestic and foreign, will ultimately determine the success of this strategy. This process however is at an early stage, and it is not yet possible to make an assessment.

Different from Botswana, Zambia's potential to develop its mining-related NSI is largely theoretical. There exists multiple large-scale mining houses, ongoing investment in new geographical areas and new mineral commodities, a more established mining inputs cluster with potentially large demand domestically and across the border, in the DRC, and an existing NSI infrastructure established in the 1970s and 1980, although ageing (university facilities, engineering and TVET skills, teaching body). However the political economy of mining in Zambia has resulted in limited room for policymakers to leverage mining investment to re-build the NSI or increase local value addition. As a result, these efforts have been left to industry initiatives, with voluntary participation and contribution of the mining houses to ZAMSET and the Zambia Mining Local Content Initiative. Nevertheless, there are legitimate concerns among stakeholders that without a comprehensive vision and policy framework set by the state; these initiatives will not achieve the overall objectives of re-building the NSI.

Zimbabwe's NSI, once the second most developed in Southern Africa, has been affected by the overall economic crisis experienced since the 2000s. The erosion of Zimbabwe's NSI has been taking place at multiple levels: the brain drain of skilled workers, the decline of SIRDC and IMR, the closure of engineering manufacturing activities that had traditionally pulled significant demand for technologies and skills, and increased import penetration in engineering consultancy services. Whilst the government is focusing on indigenization and

beneficiation, there is acute awareness that without reinvigorating the NSI, these goals will be difficult to achieve.

In regard to the R&D component of the NSI, our research reveals varied patterns. While all countries purport to be building central institutions to coordinate and facilitate science funding and research funding, Botswana appears to have the most ambitious programme, while Zimbabwe NSI systems appear to be rapidly deteriorating.

A key research question investigated by this paper concerns the regional dynamics affecting NSIs in Botswana, Zambia, and Zimbabwe in relation to South Africa. The findings point to four NSIs, which are partly interconnected. Whilst we did find evidence of a Southern Africa Regional System of Innovation, this system seems to be characterized by a 'hub and spokes' structure. South Africa, as a hub, has the most developed NSI in relation to mining: a large and well established mining sector and a mining inputs cluster that is, in some areas, globally competitive; centres of excellence in engineering skills development, R&D, and innovation; and a large engineering consultancy sector with domestic and international engineering firms based in South Africa to serve the regional market.

South Africa's NSI interaction with the rest of the region is complex. Whilst TVET skills development is a challenge across the four NSIs and has remained framed within national contexts, engineering skills development has a strong regional dimension.

All of the countries investigated have conscious public policy objectives of skills development through the primary, secondary, tertiary, and vocational segments of the respective education systems. Poor human capital development planning in Botswana, Zambia, and Zimbabwe has been revealed through our research. Our research has outlined the various processes that are underway that need to be accelerated—in particular, the coherent implementation of existing TVET and NQF qualification frameworks.

Given the scale of mining-related activities in the countries surveyed, there is considerable potential for collaborative and synergistic initiatives between firms and the TVET systems acting to accelerate their evolution. Collaboration within this part of the NSI should extend to the associations representing the engineering and technical professions. Our research shows that the professional associations in each of the countries are making efforts to improve the integrity of their accreditation, quality management, and training systems. But as outlined earlier, these efforts are being undermined by the unintended consequences of conceding to exemption demands by foreign investors.

Our findings suggest that it is important that Botswana, Zambia, and Zimbabwe improving the quality of tertiary and vocational training systems and the associated national accreditation and quality management systems as a way to accede to the Washington Accord for example. This will greatly strengthen the individual NSIs and contribute towards their integration into a Regional System of Innovation.

Analysis of intra-SADC student flow reveals that significant engineering skills development for the region is taking place in South Africa, but these skills tend to remain in South Africa. To a large extent, this can be explained by different economic opportunities in the home countries: engineering students from Botswana tend to return home, to pursue

employment in government or the mining sector, although employment opportunities in other economic activities are limited. Zimbabwean students are increasingly pursuing undergraduate and postgraduate studies in South Africa, where they remain, as a coping strategy to the decline of their education system, and reduced opportunities with private firms and government. Zambia is the most negatively affected by the regional dynamics of the engineering education system, because its students pursue post graduate studies in South Africa and most do not return. Hence whilst investing public resources in its education system until undergraduate levels, Zambia loses engineers with advanced tertiary degrees, which could feed back into the demand for lecturers, professionals, and government officials. Poor employment conditions at the universities and the struggle to find business opportunities as individual professionals make returning a difficult choice for postgraduate students. This is particularly concerning as Zambia recorded high GDP growth rates during the past decade, 7.76 per cent on average between 2004 and 2013, well above the 5 per cent sub-Saharan Africa average (World Bank 2016).

South Africa taps into the flows of regional skills to address its own skills deficit. Hence regional skills are employed in the engineering services sector and contribute significantly to South Africa's R&D and innovation capabilities. Very different dynamics however take place within these two sectors: South African R&D and innovation institutions tend to have a weak regional focus, with research areas and customers that are narrowly defined in terms of domestic interests, notwithstanding the demand for mining technologies across the region. The evidence is found in Mintek's domestic mandate, and in scarce and weak formal linkages between universities and research institutions across the region. Conversely, South Africa-based engineering firms have a strong regional outlook, irrespective of whether they are international or South African owned. Through these firms, regional engineers conduct projects in their own countries, but with little spill-overs into their domestic economies: sub-contracting and knowledge transfers are limited—notwithstanding the existence of local content measures in the legislation of neighbouring countries.

At SADC level, the regional legal frameworks to support flows of skills and knowledge lag behind. For example, progress on the RQF is hampered by the fact that countries first have to establish effective NQFs. Regional cooperation on R&D and innovation has only just started. Whilst, laying the groundwork for important institutional frameworks for the RSI, South Africa needs to consider whether a multifaceted approach would be more effective. Even though supporting SADC efforts for multilateral and highly institutionalized frameworks is important, South Africa could pursue cooperation with selected countries on mining-related skills development, R&D, and consulting engineering aimed at creating a more balanced distribution of benefits. In the words of one Zambian high-level government official: 'regional cooperation can be driven by shared interests or by shared problems. In terms of cooperation driven by shared interests, there is a great potential for South Africa and Zambia to cooperate because of the long, shared history of the mining sector' (Field interview).

Relating these findings to the NSI literature, we would like to highlight four themes. Firstly, whilst the literature analyses the NSI through its individual components and their inter-relationships, macro-economic variables cannot be taken for granted and will determine the overall trajectory of the NSI. Macro-economic variables explain the erosion of Zimbabwe's NSI, and the advantages of Botswana's NSI in terms of skills retention and resources

available for public investment. Secondly, the quality of relationships between different elements in the NSI, namely industry, mining houses in particular, and government institutions is shaped to a large extent by political economy. Political power, or lack thereof, has greatly contributed to determine the type of interaction between industry and institutions in every aspect of the NSI reviewed in this paper: skills development, R&D, and engineering consultancy services. Thirdly, whilst the NSI literature provides an important framework to guide policy making, there is no one size fits all approach, at least within the countries reviewed. R&D is critical in Botswana's NSI development strategy given the inherent limitations of its manufacturing sector; while TVET skills are more important than R&D for Zambia's NSI and linkage development strategies. Finally, within Southern Africa, focusing on country-level NSIs without looking at regional dynamics would miss very important spaces of competency building and industry linkages, which underpin, explain, and should be tapped by country-level NSIs.

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## Appendix 2: Acronyms and abbreviations used in the Working Paper

ACEZ	Association of Consulting Engineers of Zambia
ACPM	Association of Construction Project Managers
ASAQS	Association of South African Quantity Surveyors
BEE	Black Economic Empowerment
BIH	Botswana Innovation Hub
BITRI	Botswana Institute of Technology, Research and Innovation
BIUST	Botswana International University of Science and Technology
BOTA	Botswana Training Authority
BOTEC	Botswana Technology Centre
BRSTFA	Botswana, Research Science and Technology Funding Agency
BUSE	Bindura University of Science Education
CBU	Copperbelt University
CESA	Consulting Engineers South Africa
COMRO	Chamber of Mines Research Organisation
CSIR	Council for Scientific and Industrial Research
CUT	Chinhoyi University of Technology
CZI	Confederation of Zimbabwe Industries
ECSA	Engineering Council of South Africa
ECZ	Engineering Council of Zimbabwe
EIZ	Engineering Institution of Zambia
EPCM	Engineering, Procurement, Construction and Management firms
FDI	Foreign direct investment
HIT	Harare Institute of Technology
IMR	Institute of Mining Research
IP	Intellectual property

JV	Joint Venture
MNEs	Multinational Enterprises
MoU	Memorandum of Understanding
MSMEs	Micro, Small and Medium Enterprises
NAMACO	National Manpower Advisory Council of Zimbabwe
NIEs	Newly Industrialized Countries
NQF	National Qualifications Frameworks
NSI	National System of Innovation
NUST	National University of Science and Technology
OEMs	Original Equipment Manufacturers
R&D	Research and Development
RQF	Regional Qualification Framework
S&T	Science and Technology
SADC	Southern African Development Community
SAIMM	Southern African Institute of Mining and Metallurgy
SAIS	Southern Africa Innovation Support
SOE	State Owned Enterprise
SSA	Sub Saharan Africa
STEM	Science, Technology, Engineering and Math
TEVETA	Technical Education, Vocational and Entrepreneurship Training Authority
TVET	Technical Vocational Education and Training
UB	University of Botswana
UCT	University of Cape Town
UNZA	University of Zambia
UP	University of Pretoria
UZ	University of Zimbabwe

Wits	University of the Witwatersrand
ZACE	Zimbabwe Association of Consulting Engineers
ZAM	Zambia Association of Manufacturer
ZAMSET	Zambia Mining Skills and Education Trust
ZCCM	Zambia Consolidated Copper Mines
ZDA	Zambian Development Agency
ZEPARU	Zimbabwe Economic Policy Analysis and Research Unit
ZIE	Zimbabwe Institution of Engineers