Engineering Numbers & Needs in the SADC Region

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Foreword

In 2015, African nations adopted Agenda 2063, which is a strategic framework for the socio-economic transformation of the continent over the next 50 years.

In response to Agenda 2063, SADC countries have developed a suite of Vision documents and Action Plans for achieving the Sustainable Development Goal targets, and have adopted the **SADC Industrialisation Strategy (2015–2063)**. The strategy has three pillars: industrialisation as the driver for economic and technological transformation; competitiveness as an active process to move from comparative advantage to competitive advantage; and regional integration.

Member States are blessed with many natural resources and the climate supports extensive agricultural production, but few countries have moved from being producers and exporters of primary commodities to providing value-added end products. The Strategy focuses on agro-processing, mineral beneficiation and downstream processing, and industry- and service-driven value chains.

Countries have recognised, however, that many of the goals cannot be achieved without developing economic infrastructure such as roads, rail, ports, airports, water and energy supplies, and telecommunication networks. To achieve regional integration, corridors are key to maximise trade opportunities. The Industrialisation Strategy identifies the lack of adequate infrastructure and of skills and capacities in science, technology, engineering and mathematics (STEM) as among the binding constraints for industrial development. Of particular importance is the availability of engineering skills. Specialist engineers are required to conceptualise, design and develop projects, products, systems and processes.

To this end, the SADC Ministers of Science and Technology endorsed an *Engineering Numbers and Needs Study* to gain a better understanding of the actual engineering capacity in the region and the needs of Member States. The outcome of the study is intended to offer input towards key SADC policies such as the Protocol on Education and Training, and the Protocol on Science, Technology and Innovation.

The study investigated the demand for, and supply of, engineers, engineering technologists and engineering technicians in both the public and private sectors, considering the size of the current engineering workforce, projects planned, growth

projections and the flow of graduates from tertiary institutions, among others. All sectors requiring engineering capacity were investigated, including agriculture; construction; energy, water and gas; manufacturing; mining; and transport and communications.

The SADC Secretariat is pleased to have been able to facilitate the efforts of the Member States in supplying data and offering input on areas that required attention.

The findings identified a range of shortcomings, including inadequate mathematics and science teaching at schools; capacity, resourcing and quality challenges in tertiary education; non-alignment of engineering qualifications; the lack of graduate appointments and training in industry; little recognition of the need to develop middle management; and limited investment by, and engineering capacity in, public sector structures. All these shortcomings limit the opportunities to grow local engineering experts and strategic leaders for the future.

Although the findings are of great concern, the many recommendations offer direction on how to address the weaknesses. The *Engineering Numbers and Needs Study* is thus very significant for the SADC region as it emphasises the need for SADC Member States to harmonise their approaches to the education, training and registration of engineering professionals and service providers, and to align with best practice internationally. SADC looks forward to exploring the recommendations with experts in education and training, and with employers and funders, to develop and implement solutions that will strengthen regional cooperation and integration, in the spirit of Agenda 2063.

Dr. Stergomena L. Tax
SADC Executive Secretary
December 2018

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Appreciation also goes to SADC staff for their support, coordination and for identifying contacts in Member States.

On behalf of the SADC Secretariat, special thanks must go to the SADC Ministers of Science and Technology for their vision and leadership in initiating this project.

SADC Secretariat
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Glossary

Academia	Refers to the collective term for tertiary education institutions.
Academic	A teacher in a university or other tertiary institutions offering higher education qualifications.
BEng or BSc(Eng)	Bachelor of Engineering or Bachelor of Science in Engineering. The duration of study is usually a minimum of four years full time but can be five years.
Candidate **Engineer-in-training** **Graduate-in-training**	Terminology varies from country to country but refers to graduates who are registered as being in the training phase of their careers. It takes a minimum of three years from commencement of training in the workplace before graduates may apply to become professionally registered, but it may take a longer period of training to develop the level of competence required for professional registration. It must be noted that those in training may not work independently but must work under the supervision of registered professionals. In some countries it is compulsory to be registered as being '*in-training*' during this phase, failing which experience gained will not be recognised, while in others registering bodies only engage with those ready for assessment for professional registration.
Coach	A guide who will develop specific skills that are used in the workplace. Skills transfer as a result of coaching translates directly to clearly defined performance outcomes that are achieved over a short period of time.
Continuing Professional Development (CPD)	Engineering professionals are required to continue to develop professionally. A minimum number of CPD points is to be accumulated each year for an engineering professional to maintain his/her professional status.
Dublin Accord	Refers to an internationally agreed standard according to which national diploma qualifications in engineering are structured and accredited.
Engineer	Refers to someone holding a qualification that meets the standards for a professional Bachelor's degree in engineering recognised by the registration body.
Engineering practitioner	Three engineering occupations are considered in the study: engineers, engineering technologists and engineering technicians. Throughout this report the term 'engineering practitioner' will be used as the collective term to describe this group, whether professionally registered or not.
Engineering professional	Where reference is specifically made to registered professional engineers, engineering technologists and engineering technicians, the collective term of engineering professionals will be used to describe this group.
Engineering Technician	Refers to the someone holding a qualification that meets the standards for a national diploma or an advanced certificate in engineering recognised by the registration body.
Engineering Technologist or Incorporated Engineer	Refers to someone holding a qualification that meets the standards for a Bachelor of Technology degree or higher national diploma in engineering recognised by the registration body.
Higher education	Refers to undergraduate studies leading to the award of academic degrees and post-graduate qualifications, from Bachelor's degrees to doctoral level, at levels 8 to 10 on the SADC Qualification Framework. With the advent of universities of technology and polytechnics this has been expanded to include the award of advanced certificates, diplomas and higher diplomas at levels 6 and 7.
Industrial attachment	As part of a national diploma and some engineering degrees, there is a requirement for students to complete practical training in the workplace. This must be structured and controlled to ensure that students derive maximum benefit from the experience so that it enriches and amplifies their academic knowledge.
Learner	For the purpose of this study, a learner is someone enrolled in primary or secondary education.
Mentor	A wise and trusted advisor or guide who will support a less experienced person to chart a comprehensive career path and offer advice as and when required.
National Diploma	A three-year undergraduate engineering qualification offered by universities, universities of technology, polytechnics or other tertiary institutions usually consisting of four semesters of theory and one year of workplace experience, known as an industrial attachment in some countries.
Non-governmental organisation (NGO)	A not-for-profit agency not affiliated with any government or private sector entity, devoted to raising funds, managing resources and implementing projects with the goal of addressing social problems or serving particular constituencies. NGO activities also include research, information distribution, training, local organisation and community services, legal advocacy and lobbying for legislative change. NGO access to strategic information can be used as a critical lobbying tool to mobilise and build power in endeavours to address particular shortcomings or inequalities.
Professional body	A collective term referring to all organisations with professional interests in the engineering sector, including voluntary associations (VAs) and registering bodies (RBs)

Professional registration	After engineering practitioners have obtained the required qualifications and experience, engineering registration boards register them in the following categories: Professional Engineer Professional Engineering Technologist or Incorporated Engineer Professional, Registered or Certificated Engineering Technician depending on the country.
Public sector	National government, provincial government, local government, parastatals, extra-budgetary governmental institutions, social security funds and non-financial public enterprises.
Registering body	A body set up to regulate the performance of individuals or companies in the engineering sector.
Sector Education and Training Authorities (SETAs)	Training authorities which address training and skills development per sector in a structured manner.
Skills development levy	A payroll tax designed to finance training initiatives, in terms of the skills development strategy.
Small, Micro-and Medium Enterprises (SMMEs)	Small, micro- and medium enterprises combine formal and informal sector activities. The order varies from country to country. For instance, micro-, small and medium enterprises (MSMEs) is used in Lesotho, Mauritius and Mozambique.
Southern African Development Community (SADC)	A regional governmental organisation that promotes collaboration, economic integration and technical cooperation throughout Southern Africa. Member nations are Angola, Botswana, the Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe. The Comoros joined SADC after the commencement of this study and has not been included in the scope of work.
Student	For the purpose of this study, a student is someone enrolled in tertiary education.
Subvention	Refers to a grant of money or aid received from donors or government sources to top up the salaries of academics to make them more market related and attractive.
Supervisor	A person who manages or supervises work. In the context of engineering work a supervisor may double as a coach.
Sydney Accord	Refers to an internationally agreed standard according to which the Higher National Diploma or Bachelor of Technology in engineering are structured and accredited.
Tertiary education	Refers to a third level of education after completing secondary education. This may be in higher education following undergraduate studies or in trade schools or colleges completing a vocational qualification. Generally, certificates and diplomas are awarded by vocational institutions, while diplomas and academic degrees are awarded by higher education institutions.
Voluntary Association	A voluntary association is an institute, institution, association or society established by engineering practitioners to achieve a common non-profit objective of creating awareness and sharing knowledge in their profession and areas of practice.
Washington Accord	Refers to an internationally agreed standard according to which professional Bachelor of Engineering degrees are structured and accredited.
Workplace training (candidate/graduate-in-training phase)	In the candidate or graduate-in-training phase, those who have already attained a recognised qualification in engineering are trained in the application of engineering principles and methods. They are given increasingly complex work and progressively more responsibility until they can accept professional responsibility and make engineering decisions appropriate to the category of professional registration to which they are striving. .

Acronyms and abbreviations

ACEN	Association of Consulting Engineers of Namibia
ACEPS	Association for the Construction and Engineering Professionals of Seychelles
ACET	Association of Consulting Engineers Tanzania
ACEZ	Association of Consulting Engineers of Zambia
ACIC	Association Congolaise des Ingénieurs Civils (Congolese Association of Civil Engineers)
ADER	Agency for the Development of Rural Electrification
AEDOSA	Association of Engineers of DRC Origin in South Africa
AEMC	Associação de Empresas Moçambicanas de Consultoria (Association of Mozambican Consulting Companies)
AESAP	Architects, Engineers, Surveyors and Allied Professionals Registration Council
AfDB	African Development Bank
AGM	Annual General Meeting
AGOA	African Growth and Opportunity Act
AIDI	Africa Infrastructure Development Index
AIET	Agreement for International Engineering Technicians
ANHRD	Agency for National Human Resources Development
APEC	Asia-Pacific Economic Cooperation
APET	Associação Professional Engenheiros Técnicos Angola
ARC	Agricultural Research Council
ARM	Madagascar Roads Authority
ARVs	Anti-Retroviral Drugs
ASDS	Agricultural Sector Development Strategy
ASIAC	L'Association des Ingénieurs Agronomes du Congo (Association of Agricultural Engineers of the Congo)
ASSITAC	L'Association des Ingénieurs Techniciens Agronomes du Congo (Association of Agricultural Technical Engineers of the Congo)
AU	African Union
BCET	Botswana College of Engineering and Technology
BIE	Botswana Institution of Engineers
BIUST	Botswana University of Science and Technology
BNCQF	Botswana National Credit and Qualifications Framework
BoE	Board of Engineers
BQA	Botswana Qualification Authority
BRT	Bus Rapid Transit
BUAN	Botswana University of Agriculture and Natural Resources
C&G	City and Guilds
CAADP	Comprehensive Africa Agriculture Development Programme

CAMES	Conseil Africain et Malgache pour l'Enseignement Supérieur (African and Malagasy Council for Higher Education)
CBD	Central Business District
CBE	Council for the Built Environment
CDE	Centre for Development and Enterprise
CEB	Central Electricity Board
CESA	Consulting Engineers South Africa
CFMK	Chemin de Fer Matadi-Kinshasa
CHE	Council for Higher Education
CIC	Construction Industry Council Swaziland
CIDB	Construction Industry Development Board
CIF	Construction Industries Federation of Namibia
CIFOZ	Construction Industry Federation of Zimbabwe
CMT	Cut, Make, Trim
coltan	columbite-tantalite
COMESA	Common Market for Eastern and Southern Africa
CPD	Continuing Professional Development
CRPE	Council of Registered Professional Engineers
CTIA	Cape Town International Airport
CWA	Central Water Authority
CZI	Confederation of Zimbabwe Industries
DOEs	Domestic Oriented Enterprises
DRC	Democratic Republic of the Congo
DSL	Digital Subscriber Line
DUAT	'use right to land'
DVDA	Direction des Voies de Desserte Agricole
DWS	Department of Water and Sanitation
EAB	Engineering Accreditation Board
ECN	Engineering Council of Namibia
ECSA	Engineering Council of South Africa
ECZ	Engineering Council of Zimbabwe
EDB	Economic Development Board
EEC	Eswatini Electricity Corporation
EHEA	European Higher Education Area
EIT	Institution of Engineers Tanzania
EITI	Extractive Industries Transparency Index Reports
EIZ	Engineering Institution of Zambia
ENAEE	European Network for Accreditation of Engineering Education
ENDE-EP	National Electricity Distribution Company
EngRB	Engineering Registration Board
EOEs	Export Orientated Enterprises
EPA	Engineering Professions Association of Namibia
EPC	Engineering, Procurement and Construction
EPZ	Export Processing Zone
ERB	Engineers Registration Board
ESCOM	Electricity Supply Corporation of Malawi Ltd
Eskom	Electricity Supply Corporation (South Africa)

ESP	Economic Stimulus Programme
ESPs	Écoles Supérieures Polytechniques
ESSA	École Supérieure des Sciences Agronomiques
EST	Est. – an abbreviation used for Estimated in graduation tables in country reports
EU	European Union
FANR	Food, Agriculture and Natural Resources Directorate (SADC)
FAO	Food and Agriculture Organization (UN)
FDI	Foreign Direct Investment
FEANI	European Federation of National Engineering Associations
FEC	Federation of Congolese Enterprises
FMCGs	Fast-Moving Consumer Goods or Consumer Packaged Goods
FNOIM	Federation Nationale des Organisation d'Ingeniéurs Malagasy (Federation of Engineering Organisations)
FTTB	Fibre To The Business
FTTH	Fibre To The Home
FTTP	Fibre To The Premises
GBI	Greenbelt Initiative
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GVA	Gross Value Added
HIE	Higher Education Institution
HEMIS	Higher Education Management Information System
HEPSSA	Higher Education Partnerships in sub-Saharan Africa Programme
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
HPP	Harambee Prosperity Plan
HR	Human Resources
ICT	Information and Communication Technologies
IEA	International Engineering Alliance
IEM	Institution of Engineers Mauritius
IETA	International Engineering Technologists Agreement
IHSM	Institut Halieutique des Sciences Marines
ILO	International Labour Organization
IMF	International Monetary Fund
IoE	Internet of Everything
IoT	Internet of Things
IPAP	Industrial Action Policy Plan
IPD	Initial Professional Development
IPEA	International Professional Engineers Agreement
IPER	International Professional Engineers Register
IPP	Independent Power Producer
IRCCOP	Regulatory Institute for Civil Construction and Public Works
IRP	Integrated Resource Plan
IRPET	International Register of Professional Engineering Technologists

ISIC	International Standard Industrial Classification
ISTA	Institut Supérieur de Techniques Appliquées
ISTs	Instituts Supérieurs de Technologie
IST-T	Institut Supérieur de Technologie d'Antananarivo
ISTUC	Instituto Superior de Transportes e Comunicações
IT	Information Technology
JIRAMA	Jiro sy Rano Malagasy
JV	Joint Venture
KIA	Kamuzu International Airport
KPIs	Key Performance Indicators
LAE	Lesotho Association of Engineers
LEC	Lesotho Electricity Company
LFS	Labour Force Survey
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LMD	Licenciate, Master's and Doctorate
LNDC	Lesotho National Development Corporation
LNG	Liquefied Natural Gas
LP	Lerotholi Polytechnic
LPG	Liquified Petroleum Gas
MAV	Mineral Asset Valuations
MDGS	Malawi Growth Development Strategies
MEI	Malawi Engineering Institution
MHILT	Ministry of Habitat, Infrastructure & Land Transport
MIE	Malawi Institution of Engineers
MIREMPET	Angolan Ministry of Mineral Resources and Petroleum
MNOs	Mobile Network Operators
MNRE	Ministry of Natural Resources and Energy
MOU	Memorandum of Understanding
MQA	Mauritius Qualifications Authority
MSMEs	Micro, Small and Medium Enterprises
MTC	Ministry of Transport and Communications
MTCAPM	Ministry of Tourism, Civil Aviation, Ports & Marine
MTL	Malawi Telecommunications Limited
MUST	Malawi University of Science and Technology
MVA	Manufacturing Value Added
N/A	Not applicable
NACTE	National Council for Technical Education
NASE	Namibian Society of Engineers
NATMAP	National Transport Master Plan 2050
NCC	National Construction Council (Tanzania)
NCC	National Council for Construction (Zambai)
NCIC	National Construction Industry Council
NDP	National Development Plan
NEAT	National Engineering Advisory Team
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organisation

Acronyms and abbreviations

NHBRC	National Home Builders Registration Council
NHRDS	National Human Resource Development Strategy
NIP	National Infrastructure Plan
NISTI	National Institute for Science, Technology and Innovation
NPE	New Energy Policy
NQF	National Qualifications Framework
NRZ	National Railways of Zimbabwe
NSDP	National Strategic Development Plan
NUL	National University of Lesotho
NUST	Namibia University of Science and Technology
NWSMP	National Water and Sanitation Master Plan
NWTGC	North West Transmission Grid Connection
OEA	Ordem dos Engenheiros de Angola
OEM	Original Equipment Manufacturer
OET	Portuguese Ordem dos Engenheiros Técnicos
OIM	Order of Malagasy Engineers
ONATRA	Office National des Transports (National Transport Agency)
OrdEM	Ordem dos Engenheiros de Moçambique
OSD	Occupation Specific Dispensation
PB	Professional Body
PENAMT	Strategic National Accessibility, Mobility and Transport Plan
PET	polyethylene terephthalate
PGM	Platinum Group Metals
PIDA	Programme for Infrastructure Development in Africa
PNIA	National Agricultural Investment Plan
PNSD	National Strategic Development Plan
PPADB	Public Procurement and Asset Disposal Board
PPP	Purchasing Power Parity
PPPs	Public-Private Partnerships
PRASA	Passenger Rail Agency of South Africa
PUC	Public Utility Company
PVC	Polyvinyl chloride
QCTO	Quality Council for Trades and Occupations
QLFS	Quarterly Labour Force Survey
RA	Roads Authority (Namibia)
RBs	Registering Bodies
RED	Regional Electricity Distributor
RIDMP	Regional Infrastructure Development Master Plan
RISDP	Regional Indicative Strategic Development Plan
RPL	Recognition of Prior Learning
SA WISE	Association of South African Women in Science and Engineering
SAAES	Swaziland Association of Architects, Engineers and Surveyors
SACPE	South African Council of Professional Engineers

SADC	Southern African Development Community
SADCQF	SADC Qualifications Framework
SADP	Smallholder Agricultural Development Programme
SAFEO	Southern African Federation of Engineering Organisations
SAICC	Swaziland Association of Indigenous Construction Consultants
SAICE	South African Institution of Civil Engineering
SAICE-PDP	SAICE Professional Development and Projects
SANRAL	South African National Roads Agency Limited
SAPP	Southern Africa Power Pool
SAQA	South African Qualifications Authority
SCADA	Supervisory Control and Data Acquisition
SCDP	Secondary Centres Development Programme
SCOT	Swaziland College of Technology
SCTP	Société Congolaise des Transports et Ports (National Transport & Ports Company)
SDG	Sustainable Development Goal
SDGS	Sustainable Development Goals
SEAP	Structured Engineers Apprenticeship Programme (Zambia)
SETAs	Sector Education Training Authorities
SEZ	Special Economic Zone
SHHA	Self Help Housing Agency
SIDS	Small Island Developing State
SIPs	Strategic Integrated Projects
SIT	Seychelles Institute of Technology
SKA	Square Kilometre Array
SLA	Seychelles Licensing Authority
SME	Small and Medium Enterprise
SMMEs	Small, Medium and Micro-sized Enterprises
SNCC	Société Nationale des Chemins de Fer du Congo
SNEL	Société Nationale d'Électricité (National Electricity Company, DRC)
SPTC	Swaziland Post and Telecommunications Corporation
SQA	Seychelles Qualification Authority
SSDS	Seychelles Sustainable Development Strategy
SSEF	Stratégie Sectorielle de l'Education et de la Formation (Sector Strategy for Education and Training)
STEM	Science, Technology, Engineering and Mathematics
SWC	Soccer World Cup
SWSC	Swaziland Water Services Corporation
TAAG	Transportes Aereos de Angola
TANESCO	Tanzania Electric Supply Company Limited
TANROADS	Tanzania National Roads Agency
TAZARA	Tanzania Zambia Railway Authority

TB	Tuberculosis
TBD	To be determined
TCCA	Technical Committee on Certification and Accreditation
TCU	Tanzania Commission for Universities
TDM	Telecomunicações de Moçambique
TDV	Tanzanian Development Vision
TEC	Tertiary Education Commission
TNF	SADC Trade Negotiating Forum
YEP	Youth Employment Programme (Mauritius)
TEU	Twenty-foot Equivalent Unit
TEVETA	Technical Education, Vocational and Entrepreneurship Training Authority
TNPA	Transnet National Ports Authority
TRC	Tanzania Rail Corporation
TVET	Technical and Vocational Education and Training
TVETA	Technical and Vocational Education and Training Authority
UAN	Universidade Agostinho Neto
UB	University of Botswana
UNAM	University of Namibia
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United National Industrial Development Organization
UNISA	University of South Africa
UNISWA	University of Swaziland

UoM	University of Mauritius
UoT	University of Technology
UPC	Abu Dhabi’s Urban Planning Council
USA	United States of America
USAID	United States Agency for International Development
UTM	University of Technology
UZ	University of Zimbabwe
VAs	Voluntary Associations
WACS	West African Cable System
WASCO	Water and Sewerage Company
WASH	Water, Sanitation and Hygiene for All
WHO	World Health Organization
WMA	Wastewater Management Authority
WomEng	Women in Engineering
WSS	Water Supply and Sanitation
WUC	Water Utilities Corporation
YEP	Youth Employment Programme
ZACE	Zimbabwe Association of Consulting Engineers
ZAQA	Zambia Qualifications Authority
ZEPARU	Zimbabwe Economic Policy Analysis Research Unit
ZESA	Zimbabwe Electricity Supply Authority
ZESCO	Zambia Electricity Supply Corporation
ZIE	Zimbabwe Institution of Engineers
ZINARA	Zimbabwe National Roads Administration
ZINWA	Zimbabwe National Water Authority
ZPC	Zimbabwe Power Company

Executive Summary

In 2015, African nations adopted Agenda 2063, which is a strategic framework for the socio-economic transformation of the continent over the next 50 years. Its builds on and seeks to accelerate the implementation of past and existing continental initiatives for growth and sustainable development. In the same year, the Sustainable Development Goals (SDGs), which replaced the Millennium Development Goals (MDGs), were launched.

SADC PLANS

In response to Agenda 2063, SADC countries have developed a suite of Vision documents and Action Plans for achieving SDG targets, and have adopted the SADC Industrialisation Strategy (2015–2063). The strategy has three pillars: industrialisation as the driver for economic and technological transformation; competitiveness as an active process to move from comparative advantage to competitive advantage; and regional integration. These are the context for industrial development and economic prosperity.

Countries have recognised, however, that many of the goals cannot be achieved without developing economic infrastructure such as roads, rail, ports, airports, water and energy supplies, and telecommunication networks. Regarding regional integration, corridors are key to maximise trade opportunities. The Industrialisation Strategy identifies the lack of adequate infrastructure and of skills and capacities in science, technology, engineering and mathematics (STEM) as among the binding constraints for industrial development.

To this end, the SADC Ministers of Science and Technology have endorsed *an Engineering Numbers and Needs Study* to gain a better understanding of the actual numbers of engineers, technologists and technicians in the region and the needs of Member States. This will allow for better planning and implementation of infrastructure programmes and ensure that there will be sufficient capacity for industrialisation. The outcome of the study is intended to offer input towards key SADC policies such as the Protocol on Education and Training, and the Protocol on Science, Technology and Innovation.

THE NEED FOR ENGINEERS

Engineering skills are required not only in manufacturing, but also in all engineering sectors that contribute to the GDP, namely construction; manufacturing; mining; energy, gas and water; transport and communication; and, in specific aspects, agriculture. Figure 1 shows the sector contributions per country.

THE ENGINEERING SECTORS

The main sectors which require engineering capacity are briefly outlined below. It is recognised that engineering skills are used in many other sectors, but to a far smaller extent. The use of and demand for engineering skills in the following sectors were examined in detail:

- **Agriculture,** which covers crops and animal production, forestry, fishing and aquaculture, agricultural support and post-harvest activities.
- **Mining and quarrying,** which covers the mining of coal, ores, precious stones, crude petroleum and natural gas, stone, sand and clay. This could be underground, open pit, offshore or in alluvial sands.
- **Manufacturing,** which covers many industries, grouped as follows:
  - Food, beverages and agro-processing
  - Textiles, clothing and leather
  - Plastics, chemicals and non-metallic mineral products
  - Pharmaceuticals
  - Computers, optical products, and electronic and electrical equipment
  - Metal industries, machinery and equipment.
- **Electricity, gas and water,** which covers a range of engineering sectors, including:
  - Electricity, gas, steam and air-conditioning
  - Water collection, treatment and supply, including water networks and stand-alone systems
  - Waste collection through sewage networks and stand-alone systems, treatment, disposal activities, materials recovery and other waste management services.
- **Construction,** which covers buildings and civil engineering works including public services such as transportation, communication, water and energy. Construction may cover new work, maintenance, additions and alterations, and the erection of temporary structures.
- **Transport and communication,** which covers two large sectors as follows:
  - Transportation, including the provision of passenger or freight transport, by rail, pipeline, road, water or air, as well as terminal and parking facilities, cargo handling, storage, etc.
  - Telecommunication services, including the transmission of voice, data, text, sound and video.

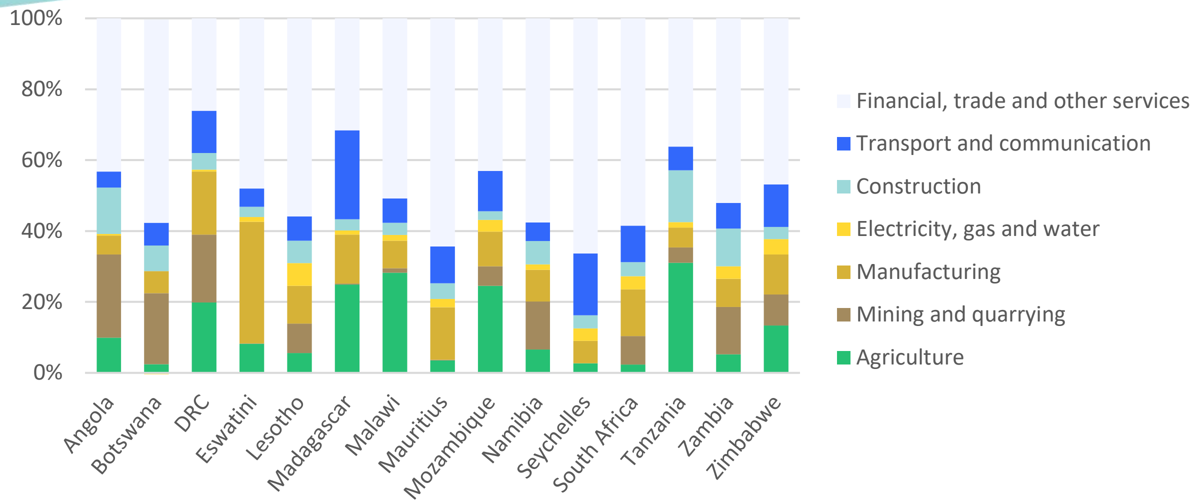

Figure 1: Percentage contribution to the GDP per sector
(Graphic presentation of Table 2)

THE ENGINEERING LIFE CYCLE

Developing infrastructure, products or processes is not a trivial exercise, but requires many steps to ensure that a cost-effective and sustainable solution is developed, utilised and maintained. Whether a road, a new mobile phone, a vehicle or a streamlined data processing system for a financial institution is being designed, it is necessary to investigate and identify the need, to carry out feasibility studies, planning and detailed design, and to document the final solution before execution can begin. Once the development is complete, ongoing use, optimisation and maintenance must be managed. When the asset has reached the end of its useful life, the process of designing a replacement or an upgrade begins again. This cycle requires the dedication of engineering teams.

Teams are made up of a range of occupations working at different levels, from elementary workers to engineers and planners. This study has examined the number and need for engineers, technologists (also known as incorporated engineers) and technicians in the following disciplines:

- Agricultural engineering
- Chemical engineering
- Civil engineering
- Electrical, electronic, systems and telecommunications engineering
- Industrial engineering
- Mechanical engineering
- Metallurgical engineering
- Mining engineering.

DEVELOPING AND HARNESSING ENGINEERING PROFESSIONALS

The engineering skills pipeline is shown in Figure 2. The requirements to succeed are as follows:

- **Schooling:** Demonstrate an aptitude for mathematics and science as required by each programme in tertiary education.
- **Theory:** Complete an accredited professional degree or diploma through a university, polytechnic, university of technology or college.
- **Workplace**: Complete a workplace training phase, usually over three or more years, in a community of expert practice under supervision and mentorship.
- **Assessment:** Be assessed through an examination or peer review or both to determine whether the required level of competence has been achieved.
- **Registration:** Be awarded a designation commensurate with the person's education, training and experience.
- **Professional practice:** Work in a professional environment which values engineering professionals and offers them opportunities to develop as experts or to grow into management and leadership roles.
- **Institutional commitment:** Work in an environment where appropriate staff, systems, processes, support and necessary service providers are in place or may be appointed.
- **Investment:** Work in an environment where investment in planning, development, operations and maintenance of infrastructure, products, systems and/or processes takes place.

Recent graduates are only part of a substantial team of engineering practitioners, each with a different role to play. Conceptualising and designing mega

projects require expertise, developed through years of experience, and the confidence to manage and lead change. When employers complain of not being able to find engineers, they are not referring to recent graduates, but rather to seasoned experts, able to tackle the most complex of challenges and run with them. The frenzy to increase the number of engineering graduates is misplaced and is only part of the process to develop engineering professionals for the future.

Each of the elements listed needs to be in place to allow young graduates to grow into the strategic leaders required. However, many of these elements were found to present challenges during the study.

ENGINEERING STANDARDS

The ideal of developing a pool of engineers, technologists and technicians able to move around Member States, depending on the type and size of projects and expertise required, can only be realised if professionals are recognised from country to country.

The SADCQF

The SADC Qualifications Framework (SADCQF) has been set up, with 10 levels and descriptors per level, for countries to classify their existing qualifications and adjust them to match the regional measures where required. Ten levels, commencing from school through to doctoral studies, have been decided upon. Technician, technologist and engineer qualifications appear to be at Levels 6, 7 and 8 respectively, although there is not consensus on the complexity required at Level 6, which must be addressed.

The IEA

The International Engineering Alliance (IEA) is a body that was first set up in 1989 to recognise the substantial equivalence of engineering degrees among countries. Signatories to the initial agreement were largely the UK, Ireland, Australia, New Zealand, Canada and the USA. South Africa became the only African signatory in 1999. By 2016 there were 17 signatories and several others held provisional status. The cornerstone of the agreements has been the development of graduate attributes which must be achieved. Assessment looks at programme design, resources and the teaching and learning process, as well as student experiences and results. A similar approach needs to be adopted in the SADC region.

The IEA has also developed mobility agreements to identify the competency standards and equivalent levels of practice expected of registered professionals. South Africa is also a signatory to these agreements. There is a need for registration standards in the balance of the SADC Member States to be aligned with these international standards.

ELEMENTS OF THE STUDY

The study considers the long-term projects planned, the water, sanitation, electricity and other engineering-related SDG targets that must be achieved, the manufacturing industries to be developed or expanded, and the types of engineering skill required to address these needs. Engineering disciplines and the role of the engineer, technologist and technician are outlined.

Recognising that skills are not static, but rather that there is a constant flow of skills, it was necessary to determine the current workforce, the demands, inflows from graduation and other sources, and outflows due to retirement, mortality, retrenchments, etc. Engagements with government

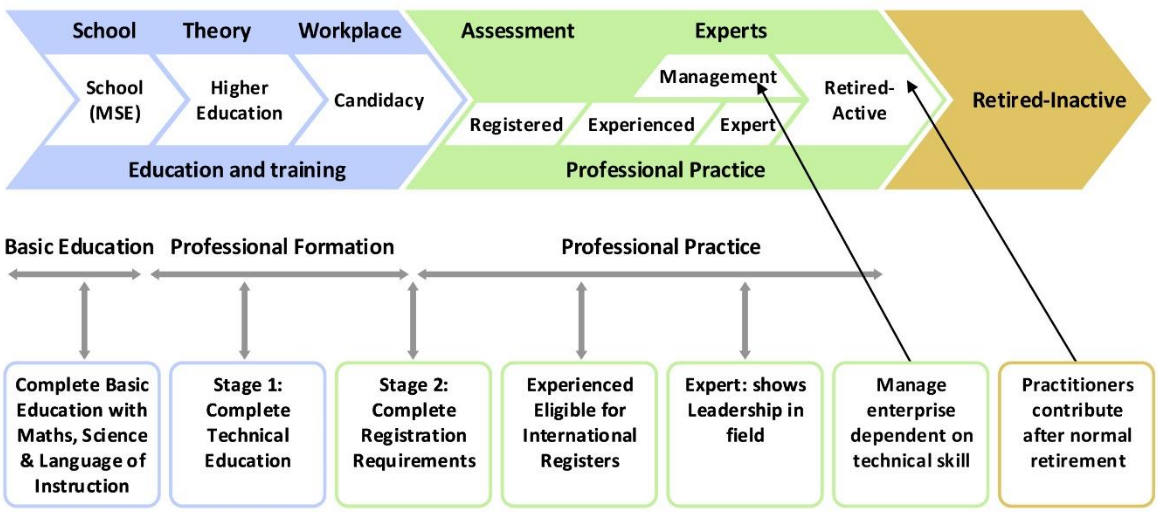

Figure 2: The engineering skills pipeline

departments, professional bodies and industry in each country yielded different insights. The information researched and sources from each country included:

- The supply of engineering graduates from tertiary education
- The engineering skills base per country and the mobility of engineering personnel
- Sectors in which engineering skills are required and the roles practitioners play
- Policies relating to engineering development and the regulation of engineering professionals
- Development and economic trends relating to each sector
- Projects planned for each country and the region.

SECTOR STATUS QUO

Considering each sector, it is clear that there is an enormous amount of work for the engineering profession.

AGRICULTURE

In many countries, 50% or more of the population are subsistence farmers eking out an existence, living off the land. However, most countries only farm a small portion of the arable land and irrigate a small portion of the irrigable land. There are many opportunities for agricultural engineers to contribute to bringing about change, along with civil and mechanical engineers to address mechanisation, storage and post-harvest processes, among others. Increased irrigation, small-scale mechanisation, improved seeds, diversification of crops and access to markets are some of the many solutions that could be adopted, but all too often limited funding, infrastructure and support is a challenge.

MINING

The region is a treasure trove in terms of mineral wealth and there is still huge potential to increase mining output. However, poor infrastructure, high risks, national policies and political instability in many countries drive potential investors away.

MANUFACTURING

The potential to increase mineral beneficiation and secondary and tertiary processing, and develop agro-processing value chains and medium- and high-end technology is enormous and should contribute significantly to economic growth. However, in many cases, insufficient energy and water supplies, and inadequate transport networks and ports limit opportunities to expand markets and support manufacturing growth.

SOCIAL INFRASTRUCTURE

By 2015, few countries had achieved the MDGs. In some cases less than 50% of the population had access to safe drinking water, and significantly lower percentages had access to improved sanitation. Countries are working hard towards achieving the 2030 SDGs, but to develop from 10% or 20% in 2015 to 100% by 2030 will require enormous investment, engineering skills for the development of services, and, most importantly, maintenance teams to ensure that the new infrastructure does not deteriorate prematurely.

CORRIDORS AND TRANSPORT SERVICES

Substantial multi-modal corridors have been planned, including linking and developing roads and rail, and the use of waterways to improve the movement of resources and end products and ensure regional integration. In many instance roads and rail are not continuous and links must be developed, while in others refurbishing or substantial upgrading of aging infrastructure is necessary.

ICT

Considerable progress has been made with establishing modern telecommunication systems in each country. It is said that there are more mobile phones in Africa than taps. The need for electrical, electronic, software and telecommunications engineers continues to grow as the demand for extended connectivity, higher speeds and more mobile devices grows.

CONSTRUCTION

Construction is important in any country due to its ability to create jobs and develop skills. Massive projects have been identified, but without adequate funding they cannot go ahead. Where private sector funding needs to be raised, return on investment and the development of bankable projects become important. The inability to prepare such motivations has proved to be a stumbling block.

THE AFRICA INFRASTRUCTURE DEVELOPMENT INDEX

The Africa Infrastructure Development Index (AIDI) is a measure of infrastructure development. It considers the extent and condition of water, sanitation (collectively WSS), electricity, transport and ICT infrastructure and countries are ranked accordingly. It is measured out of 100. The Seychelles is ranked the highest, with an index of 94.3, followed by Egypt at 85.8. The lowest rank of 54 is held by Somalia, with four SADC countries ranked between

Table 1: The Africa Infrastructure Development Index, 2018

COUNTRY	RANKING 2018	AIDI 2018	WSS	ICT	ELECTRICITY	TRANSPORT
Angola	29	19	40	12	6	2
Botswana	10	37	81	31	22	22
DRC	50	8	32	7	2	2
Eswatini	17	26	62	18	6	8
Lesotho	35	16	55	16	4	7
Madagascar	46	11	23	6	1	3
Malawi	25	21	66	7	2	5
Mauritius	5	77	98	59	40	38
Mozambique	44	12	27	11	12	2
Namibia	13	29	63	22	11	15
Seychelles	1	94	97	60	64	50
South Africa	4	79	80	77	75	22
Tanzania	43	13	28	10	2	3
Zambia	23	22	49	15	14	5
Zimbabwe	19	25	54	16	10	12

43 and 50, indicating the extent of upgrading and development of both economic infrastructure and water and sanitation services required.

THE ENGINEERING SKILLS REQUIRED

When considering the huge developments planned, it is evident that experienced engineering professionals, rather than recent graduates, are required to conceptualise, motivate, plan, design and oversee the development of these projects. Mega projects are the ideal training ground for recent graduates so that they, too, will one day be able to play similar roles. The entire skills pipeline needs to be developed, but there appear to be blockages almost every step of the way.

THE CHALLENGES

From early childhood education to the selection of service providers, opportunities in the region are not conducive to growing tomorrow's engineering leaders.

THEORY

From early school days to graduating as engineers, there are many bottlenecks that require attention.

Schooling

In many countries, the percentage completing secondary education is limited. As a result, inadequate numbers with the aptitude to enter engineering studies are available. Where the numbers are higher, the quality of the school leaving qualifications is not up to standard and as a result students struggle with engineering studies and often drop out. The challenges include poor facilities, lack of textbooks and, most importantly, the limited numbers of well-qualified teachers. Due to the sheer number of learners, national programmes harnessing technology need to be considered to compensate for the shortage of suitably qualified teachers.

To identify those with potential, significant career guidance and assessment programmes need to be mounted and funding needs to be made available to attract those who excel in mathematics and science to enter engineering.

Tertiary education

Due to the ongoing lament from employers about the lack of engineering skills, countries have driven a large increase in tertiary education enrolment and have also encouraged private universities to open and expand offerings in the tertiary space.

Gathering engineering graduation data covering several years in order to understand the trends proved almost impossible, but consideration of the data available from 2010 shows that the graduate numbers in the region have increased by almost 80% in the six years, as illustrated in Figure 3. Institutions advise that the numbers have continued to climb and some report that graduations in 2018 were more than double those of 2015.

The proliferation of tertiary education institutions offering engineering qualifications and the dramatic increase in the numbers studying at existing institutions has had many unintended consequences, including inadequate resourcing, a critical shortage of academics, poor quality of graduates and the production of many more graduates than the industry can absorb. Investment should rather be

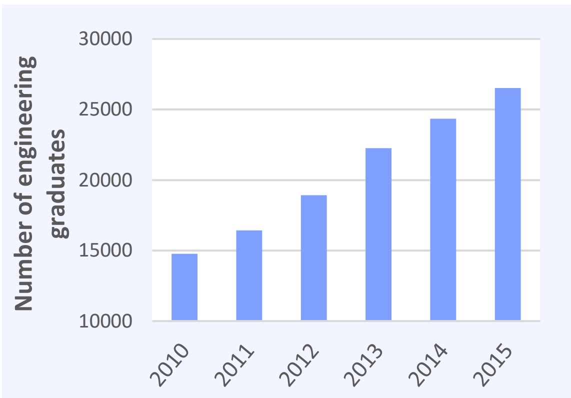

Figure 3: Engineering graduations in the SADC region
(Summary of Figure 23)

made in strengthening the established institutions to produce the desired calibre of graduates.

The alignment of qualifications requires attention. The content, degree of problem-solving and complexity involved in these qualifications vary from country to country and unless graduate attributes are aligned in time, this will restrict the mobility of graduates and later professionals in the region.

Accreditation processes also vary significantly in the region. A subcommittee needs to be set up under the Technical Committee on Certification and Accreditation (TCCA) to decide on levels, outcomes and accreditation regimes, and to develop a 10- to 15-year plan to ensure that institutions in the region work towards offering equivalent qualifications.

GRADUATE TRAINING

The claims of engineering staff shortages over decades do not relate to the shortage of graduates and the need to open more universities, but rather to the shortage of experienced personnel. This has come about due to the demise of the formal training programmes that were in place in large structures before outsourcing and unbundling took place.

Historically, it was the public sector that planned, designed, developed, operated and maintained infrastructure, managed and maintained fleets, and developed and managed their own significant systems. Public sector structures were therefore fertile training grounds for recent graduates and most engineers reaching retirement at present started their careers in the public sector.

Most of the meaningful work on which graduates can be trained today is in the private sector, but companies cannot afford to train large numbers when having to compete for work and tender at rock-bottom prices. Linking graduates to major public sector construction or manufacturing projects for training is also not proving viable as international companies are often appointed which provide their own staff and do not always speak the local language.

Large national programmes need to be reinstituted to develop graduates in order not to waste the funds invested in them at undergraduate level. A team composed of organisations which have successfully rolled out graduate training programmes should be put in place to design a model for the region and suggest funding options and terms and conditions.

PROFESSIONAL REGISTRATION

The requirements for professional registration vary from country to country, and in some countries, there is no requirement for engineering practitioners to be registered at all. Without a recognised measure of competence, mobility in the region will be limited.

An additional subcommittee under the TCCA composed of registering bodies, potential registering bodies, the Southern African Federation of Engineering Organisations (SAFEO) and advisers from the IEA when required, should be set up to interrogate all Acts, establish best practice, and ensure that all countries adopt one set of outcomes per category and similar assessment processes.

DEVELOPING TOMORROW'S LEADERS

Returning to Figure 2, it can be seen that the end of the candidacy (graduate-in-training) phase is only the beginning of the professional's career. Being assigned increasingly complex work and more responsibility, and continuing to develop through post-graduate or management studies or ongoing research are some of the many continuing professional development (CPD) activities necessary to become recognised specialists and/or engineering leaders. All too often, after the graduate phase, no further investment takes place in developing engineering staff and they are assigned routine tasks to repeat year in and year out. Unless young professionals work in engineering environments where there are experts from whom to learn, countries will continue to lament the shortage of engineers, as inexperienced staff will not match their employment requirements.

THE PUBLIC SECTOR

Four of the six GDP contributors studied rely heavily on government spending, while the success of manufacturing and mining depends on government support and is affected by the policies in place. There are several challenges in the public sector that are impacting successful development.

Engineering professionals

The numbers employed in the public sector are dwindling because salaries are low and conditions are not conducive to technical decision-making. In some countries, there has been a moratorium on employment in the public sector, while in others, the requirement for appointing only engineers who are professionally registered means that juniors cannot be appointed and developed through the ranks.

Technical expertise is required for long-term planning, overseeing service providers and managing

operations and maintenance. Without technical structures and the requisite skills, the quality of the infrastructure developed is often problematic, and this infrastructure is not maintained, leading to premature failure. Structures, responsibilities, packages and training regimes must be revisited.

Construction and manufacturing policies

Although international service providers may have the requisite skills and resources for large or complex projects, appointing foreign consultants and contractors as a matter of course should not be an ongoing phenomenon. Many projects, such as standard school structures, community halls and the like are well within the abilities of local companies.

As part of large projects, small contractors must be trained and where international service providers are appointed, local skills, materials and equipment must be used. In addition, designs, drawings and operating instructions must be made available in the official language of the country and must be checked and approved to ensure that they satisfy local needs.

As with professional registration, the categorisation of contractors varies throughout the region. In some countries, contractors need only apply for a licence, while in others they are categorised by skills, capital, equipment and past experience and may only be awarded contracts within their range of experience.

The SADC Trade Negotiating Forum (TNF) is focused on the liberalisation of the construction, energy and tourism sectors. Before relaxations can be agreed in terms of construction, it will be necessary to set up a subcommittee composed of contractor registering or licensing bodies to interrogate all Acts and to agree on a common approach when appointing both regional and international contractors. A threshold must be set below which only local contractors may be appointed in order to support contractor development and job creation.

Similarly, the Industrial Development Forum should consider criteria to be included in offset agreements with manufacturers wishing to invest in Member States. These should include the development of small manufacturing companies to supply components, and the use and training of local skills including engineering professionals. They should also use local materials and equipment where available.

Investment

There are many areas which require increased investment before it will be practical to increase engineering capacity. These include investment in:

- Appointing and training technical staff in the public sector
- Expanding economic and social infrastructure
- Ongoing operations and maintenance
- Agricultural and manufacturing development
- Development of sustainable communities
- Building robust national data systems which will allow more robust skills planning.

NUMBERS AND NEEDS

The temptation is to train many engineers in the hope that they will change the fortunes of the country. The numbers required, however, are dictated by the extent of the infrastructure, the levels of service offered and the level of sophistication of manufacturing, among other factors. If infrastructure is limited as per the AIDI ranking, then there will be little work for engineering practitioners. If the levels of service are basic, then the complexity of engineering work and the numbers required will be limited. If manufacturing is limited to low-tech food processing, the demand for engineering skills will be lower than for high-tech processes in, for instance, automobile and electronics manufacturing.

Countries need to take a close look at and determine their development plans and purposefully train and develop the skills required for the niches identified.

The concept and aim of industrialisation is to accelerate growth, create employment and improve living conditions. Skills must be developed as part of the process. Furthermore, construction has long been recognised for its job creation potential, but construction projects must also be used to develop the large number of unemployed engineering graduates and apprentices, and to develop small contractors, subcontractors, suppliers and emerging manufacturers. The region needs to agree on rolling out infrastructure projects and investing in industrialisation, linked with localisation policies, and policies must be enforced in the spirit of Agenda 2063 if job creation and poverty alleviation is to succeed.

Although many trends have emerged, the most important ones, which require attention, relate to the proliferation of tertiary institutions offering engineering qualifications, the lack of investment in graduate training, the inconsistencies in the professional and contractor registration, and the free rein that international service providers are given when delivering services and products in the region. The rebuilding of experienced engineering capacity in public sector structures is also important

RECOMMENDATIONS

At a regional level, there are several areas in which harmonisation and collaboration are essential to ensure quality service delivery and that the appropriate capacity for industrialisation is developed. These are detailed in each chapter and in the country reports.

School support

The enrolment in, and quality of, primary and tertiary education needs to be improved. Many elements, including teachers, teaching methods and career guidance, require attention and consideration needs to be given to harnessing technology and the 'flipped classroom' approach to reaching and teaching the large numbers currently excluded from quality education.

Rationalisation of tertiary education

The number of tertiary institutions, the number of students being enrolled, and the shortages of academics and appropriate resources need to be addressed.

Alignment and accreditation of qualifications

Alignment of qualifications and development of accreditation standards are important for mobility in the region. A subcommittee under the TCCA must be set up to debate graduate attributes for each level of qualification. A programme must be developed with milestones for institutions to work towards to upgrade curricula, develop capacity and acquire the resources required to achieve the requisite graduate attributes.

Graduate training

To address the ever-growing challenge of unemployed graduates a regional approach to developing graduates must be established and adopted. A committee composed of employers and professional bodies who have been successful with graduate training should be formed to develop guidelines.

Alignment of registration processes

Unless there is a uniform measure for assessing the competence of engineering professionals, mobility in the region will be restricted. A committee under the TCCA representing all registering bodies needs to be formed to agree on the outcomes to be measured when assessing applicants for registration, the assessment methods, and how to handle foreign applications.

Repopulation of public sector structures

A concerted effort is required to repopulate public sector structures with competent engineering professionals, with decision-making authority, and to set up systems for developing future generations.

Alignment of service provider conditions

The TNF needs to form a subcommittee to look at construction council Acts and agree on standards throughout the region for classifying contractors and the type of work they may be appointed to carry out. Harmonisation of training requirements and the use of local labour, materials and equipment should also be considered, and regional resolve will be required to enforce these conditions.

Localisation

The Industrial Development Forum to share knowledge and experiences on setting up offset agreements. Agreements should include not only the use of local labour, plant, equipment and developing local manufacturers but should include the training of engineering professionals.

Investment

Without investment in infrastructure and maintenance, growth cannot take place. Major projects must be prioritised, and the funds raised, but care must be taken that funds are largely spent on local staff, materials and equipment. Care must also be taken that appropriate solutions are selected which satisfy local conditions, offer value for money and address the needs of as many as possible.

Agricultural engineering solutions

Regional solutions need to be researched and shared to support countries with innovative ideas on how to assist smallholders to become more productive and contribute towards national food security.

Rural development

Infrastructure development has largely been focused in urban areas and industrial centres. Rural development programmes and support for rural communities is essential to grow rural economies and encourage de-urbanisation.

Data collection

Centralised reporting systems need to be considered for compiling reliable, but detailed labour, education, professional and service provider information for better planning. Countries must be encouraged to develop robust data management systems and feed high level information into centralised regional databases.

Part 1
Context

PART CONTENTS

Part I outlines the SADC development plans and rationale for the study. The need for engineering practitioners, how they are trained and standards the region should aspire to are outlined. The continuous flow of skills and the scope and performance of each engineering sector per country is considered to set the scene for understanding the assessments carried out, findings and recommendations. The research approach is outlined in Chapter 5.

The remaining parts are as follows:

Part II which looks at the overall findings for each stage of the engineering skills development pipeline and includes regional recommendations.

Part III which includes detailed reports and recommendations per country.

Chapter 1

SADC Plans

There has never been greater pressure on nations to improve economic growth to address the burgeoning challenges of poverty, food security, unemployment and climate change. Attendant with these is the need to improve the opportunities for health care and education.

AGENDA 2063 AND AGENDA 2030

Recognising these challenges, in 2015 African nations adopted Agenda 2063, which is a strategic framework for the socio-economic transformation of the continent over the next 50 years. Its builds on and seeks to accelerate the implementation of past and existing continental initiatives for growth and sustainable development.

The guiding vision for Agenda 2063 is the African Union (AU) Vision of *'An integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in the international arena'*.

The year 2015 was a watershed year for Africa, as not only was Agenda 2063 adopted, but the Sustainable Development Goals (SDGs), which replaced the Millennium Development Goals, were launched. The SDGs cover a range of social and economic development issues to end poverty, protect the planet and ensure prosperity for all. In more detail they address poverty, hunger, health, education, climate change, gender equality, water, sanitation, energy, urbanisation, environmental concerns and social justice.

The SDGs have become known as Agenda 2030 or *Transforming our World: the 2030 Agenda for Sustainable Development*. Each goal has specific targets to be achieved over the period to 2030.

Considering many of the initiatives on which Agenda 2063 was built, such as the Programme for Infrastructural Development in Africa (PIDA), the Comprehensive Africa Agricultural Development Programme (CAADP) and the need to address the SDGs, many regional and national plans and programmes have been developed. The Southern African Development Community (SADC) is one such regional body that has responded to both Agendas.

SADC DEVELOPMENT

The SADC region is blessed with abundant and diverse natural resources, but countries continue to export unprocessed goods, earning a fraction of the potential value of the products, and hunger and poverty persist. Agenda 2063 aims to optimise the use of Africa's resources for the benefit of the continent's people. In response to Agenda 2063, SADC countries have developed a suite of Vision documents and Action Plans for achieving SDG targets, and have adopted the **SADC Industrialisation Strategy (2015–2063)**.

The strategy is anchored on three pillars: industrialisation as the driver for economic and technological transformation; competitiveness as an active process to move from comparative advantage to competitive advantage; and regional integration. These are the context for industrial development and economic prosperity.

The strategic goals embodied in the industrialisation strategy include an increase in manufacturing and exports, a move to manufacturing more medium- and high-technology products, and doubling industrial employment. Industrial employment is expected to make up 40% of total employment by 2030. The growth areas identified include agro-processing, mineral beneficiation and related mining processes, pharmaceuticals, consumer goods, capital goods and services.

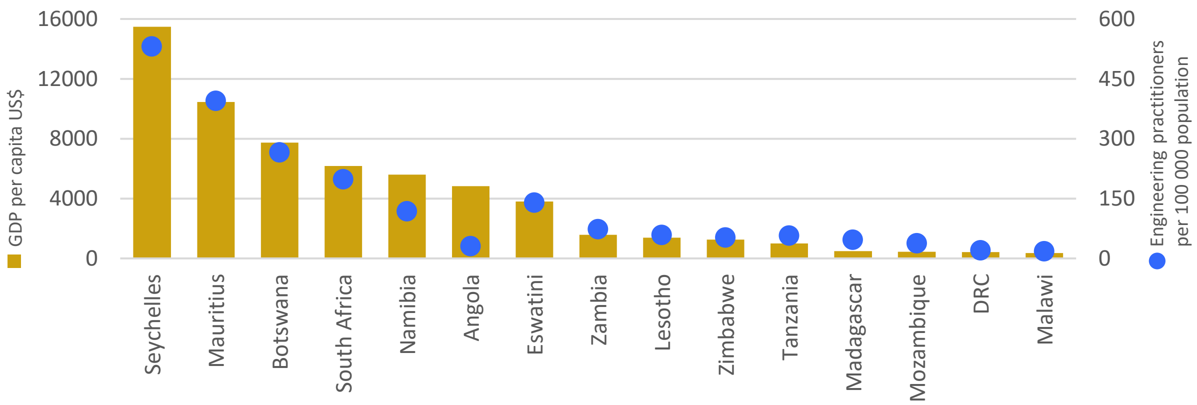

Figure 4: GDP per capita 2016 vs engineering practitioners per 100 000 population

Due to poverty levels and high unemployment in rural areas, there is a clear understanding that there is unlikely to be an industrial revolution in SADC without improved agricultural productivity, creating rural agro-processing clusters and making agro-processing careers attractive to the youth. To this end, in 2003 CAADP was established by the Assembly of the AU with the aim of raising agricultural productivity by at least 6% per year and increasing public investment in agriculture to 10% of national budgets per year.

Countries have recognised, however, that many of the goals cannot be achieved without developing economic infrastructure such as roads, rail, ports, airports, water and energy supplies, and telecommunication networks. Regarding regional integration, corridors are key to maximise trade opportunities. Many strategies and plans have been developed to support continental and regional development, the most significant of which are:

- **The Regional Indicative Strategic Development Plan (RISDP)** which calls on Member States to integrate their markets and work towards achieving peace, stability and wealth. In particular, it focuses on liberalisation, regional integration, food security and social and human development, and recognises the underlying need for infrastructure.
- **The Programme for Infrastructure Development in Africa (PIDA)** which promotes regional economic integration by building infrastructure which allows the flow of goods and associated trade between countries. Infrastructure investments in energy, transport, ICT and trans-boundary water are aimed at increased connectivity. Thirty-four PIDA projects were planned for the SADC region.
- **The Regional Infrastructure Development Master Plan (RIDMP)** which guides the development of key infrastructure in the region and acts as a framework for planning and cooperation with development partners and the private sector. The master plan is being implemented over three five-year intervals – the first (2012–2017) considered the short-term needs, the second (2017–2022) the medium term and (2022–2027) the long term.

Engineering professionals are key to many of these aspirations and are thus required to play a significant role in changing the fortunes of SADC countries. It is essential however, that they are adequately educated, trained and their skills are utilised to the full to deliver innovative solutions to agricultural production, manufacturing and mining output, and engineering service delivery. Figure 4 shows the relationship between GDP per capita and the number of engineering practitioners per 100 000 population. While it is tempting to suggest that more engineers will increase the GDP, this is not the case. Only when there is investment in infrastructure, manufacturing and mining can such skills be utilised and developed.

Nine of the 17 SDGs are reliant on engineering skills and several others require engineering facilities to be in place, such as health care and education infrastructure. Industrialisation, which will play a major role in transforming economies, can also not take place without adequate engineering capacity. The development and harmonisation of engineering skills and standards will be key to the implementation of both Agenda 2063 and Agenda 2030 and to the industrialisation strategy.

SADC NUMBERS AND NEEDS STUDY

To this end, the SADC Ministers of Science and Technology endorsed the *Engineering Numbers and Needs Study* to achieve a better understanding of the actual numbers of engineers, technologists and technicians in the SADC countries and the needs of SADC Member States in order to allow for better planning for the attainment of sustainable development in the region.

The overall objective of the study is to gain a better understanding of engineering numbers to determine whether there is adequate capacity for planning and implementing infrastructure programmes, and for enhancing output and productivity in the agricultural, mining and manufacturing sectors to support the SADC Industrialisation Strategy (2015–2063).

The Strategy identifies lack of adequate infrastructure and capacities in science, technology, engineering and mathematics (STEM) as among the binding constraints for industrial development. The outcomes of the study will serve as input towards the implementation of key SADC policies and frameworks such as the RIDMP, the Protocol on Education and Training, and the Protocol on Science, Technology and Innovation.

ECONOMIC GROWTH AND GDP

Economic growth is seen as the enabler for job creation and the reduction of poverty. Year-on-year changes in the GDP are considered to determine whether economies are growing or shrinking and to make regional and international comparisons. The GDP is a measure of the market value of all final goods and services produced. Given population differences and degrees of industrialisation, a more

useful measure for comparing the success of nations is to use the ratio of GDP to the total population, termed the 'GDP per capita'.

It is envisioned that by 2063, the SADC region will be fully transformed and will be an important player in the continental and global landscape, premised on the three growth phases:

1. **Phase I (2015–2020)** which constitutes a period of active industrial and infrastructure development, and market and services integration with industrialisation. During this phase, SADC countries should target income growth of about 6% per year to achieve a GDP per capita of US$2 000.
2. **Phase II (2021–2050)** which will focus on diversification and enhancement of productivity and competitiveness. By the end of this period, SADC aims to achieve GDP per capita of US$9 000 and a growth rate of 8% per year from 2020 onwards.
3. **Phase III (2051–2063)** during which SADC economies should move into the innovation-driven stage, characterised by advanced technologies and increased business sophistication. To achieve that status, GDP per capita needs to rise to US$17 000 by 2063, with an income growth of about 5% per year.

Although most SADC countries experienced high growth in the early 2000s, growth has since slowed significantly, as shown in Figure 5. This can be attributed to lack of decisive leadership, reduced international demand and the related reduction in commodity prices, policy changes, climate change and corruption, among others.

THE INFLUENCE OF POLICY CHANGES

Policy changes have been particularly devastating. The models for redistribution of wealth and indigenisation, although noble in ideals, did not consider the possible consequences of business failures and that the very people the new policies

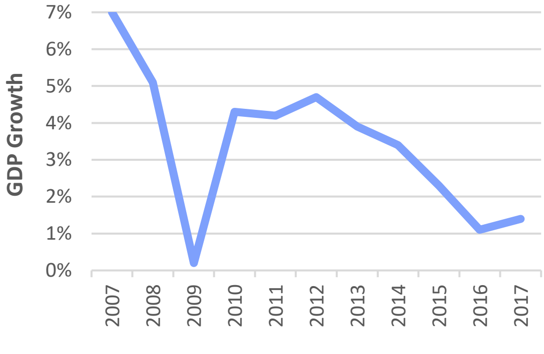

Figure 5: Percentage growth in GDP in SADC

were trying to serve would find themselves worse off due to job losses and reductions in food production, among other unintended consequences.

The nationalisation of mines or individual commercial farming operations, expropriation of land, and the indigenisation of many organisations in the interests of sharing wealth have generally resulted in loss of expertise and operational capacity, with an associated drop in production, lack of maintenance and the exit of investors.

An analysis of the 15 SADC countries at the time of their independence shows that several, such as Malawi, Lesotho, Madagascar, Mozambique, Botswana, Mauritius and the Seychelles, had limited resources and were among the poorest countries in the world. Most of the balance were prosperous and world players in one or more sectors or product lines, mostly in the mining sector and/or agriculture. These included South Africa, Namibia, Angola, Zambia and the DRC, with Zimbabwe being known as the *'Bread Basket of the World'* at the time of independence. Inappropriate policies, corruption, civil war and political instability have had a devastating effect. For instance, in the 1960s, before independence, the DRC was the second strongest economy in Africa, after South Africa. Today, it has one of the lowest GDPs per capita in the world. Zimbabwe went from being a strong economy with thriving manufacturing, mining and agricultural sectors, and a net exporter of food, to being a net importer of food and finding itself without currency in the second half of 2018.

Zambia at independence was among the richest countries in sub-Saharan Africa with copper being a substantial foreign currency earner, but after nationalisation, the lack of re-investment in those industries led to low production and inefficiency, with a devastating effect on the economy. Returning to privatisation brought the much-needed capital, and improved economic conditions. Tanzania followed a similar pattern and had to re-privatise to raise funding to cover rising debt.

Namibia's strong economy was based on fish, meat processing, karakul, base metals and diamonds. Overfishing has reduced that particular market and debt has mounted due to international funders carrying out the large infrastructure developments without harnessing local labour or resources. Namibia's debt deficit had reached 40% of the GDP by mid-2018.

Lesotho and Botswana's fortunes changed with the discovery of diamonds in the 1970s, which has led to substantial growth. More recently, the discovery of gas and oil in Tanzania and Mozambique, and of cobalt and ilmenite in Madagascar bodes well for these economies. Sadly, much of the benefit of the increased income is not realised by the general population, but by leaders and the foreign governments who have offered the capital to get new mining ventures off the ground and develop the associated infrastructure.

To their credit, Mauritius and the Seychelles have transformed their economies by developing their tourist industries and associated manufacturing industries, such as the food, beverage, herbs, handcrafts and textiles industries, to support tourism.

As a result of the changes in policies and approaches, today only three SADC countries appear in the top 10 list of economies in Africa – with South Africa holding second position, Angola the fifth and Tanzania the tenth position in 2017, according to the IMF. In terms of GDP per capita, only four countries are rated in the top 100 worldwide, namely the Seychelles at number 53, Mauritius 68, Botswana 87 and South Africa 96. The DRC, Madagascar, Mozambique and Malawi were at positions 189, 191, 193 and 195 out of 197 countries whose GDP per capita were determined and published by the World Bank.

Returning to Agenda 2063, which calls for *'An integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in the international arena'*, it is time for those with potential to claw their way back to prosperity. This cannot happen without enabling policies, strong, people-centred leadership and substantial private sector investment.

SKILLS DEVELOPMENT AND INTEGRATED PLANNING

One of the biggest injustices of the colonial era was the lack of local skills development at higher levels. Africans were largely excluded from highly skilled and managerial positions. Furthermore, infrastructure was generally built to service exports, rather than to promote internal trade.

In attracting investors and accepting loans, stringent skills development targets must be put in place and managed. These should not be limited to providing bursaries for students, but should span the skills pipeline from schooling, through tertiary education and graduate training, all the way up to the development of managers, technical experts and internationally recognised specialists.

As discussed, the highest earning country per capita is the Seychelles, which relies largely on tourism, a service industry. This service relies on excellent infrastructure, transport and communications to attract tourists from all over the world. It is interesting to note that when comparing the number of engineers, technologists and technicians per 100 000 population, the Seychelles boasts the highest ratio as shown in Figure 4. The Seychelles also boasts the highest Africa Infrastructure Development Index (AIDI) in the SADC region.

Infrastructure development is thus key to economic growth and its development is the foundation on which local skills can be developed with the assistance of international expertise. As the depth of local skills grows, the reliance on international expertise should reduce. Skills transfer is, however, not a short-term process. It takes many years to develop a seasoned professional, as outlined in Chapter 3, *Developing Professionals*.

When sources of funding are being considered, internal sources should not be forgotten. Although it is not a popular concept, payment for services must become part of the national psyche. A significant percentage of those receiving services can afford to make some contribution, but payments are not enforced, and countries' coffers are drained. The African Development Bank (AfDB) reports that tax revenue collection in Africa is below the threshold of 25% of GDP considered necessary to scale up infrastructure spending.

Multi-disciplinary and regional planning are essential to ensure that countries do not compete for the same markets or skills and that the use of resources is optimised. Locally, departments should collaborate to optimise construction activities. For example, when contractors are appointed to implement rural electrification programmes, it would be more cost-effective if they addressed rural water and upgraded local facilities at the same time.

When changes in policy and the approach to development take place, only then will countries need to consider increasing the size of their engineering workforce. Engineering education and training forecasts in this study consider 2017 growth rates and those projected by the IMF for 2018 to 2023 and give an indication of the requirements should the Agenda 2063 growth targets be met.

Chapter 2

Need for engineers

Without good infrastructure and transport, economies cannot develop. John F. Kennedy is widely quoted as saying 'It is not our wealth that built our roads, but it is our roads that built our wealth'.

The African Development Bank has recognised that the 'High 5s' are crucial for accelerating Africa's economic transformation – these are:

- Light up and power Africa
- Feed Africa
- Industrialise Africa
- Integrate Africa
- Improve the quality of life for the people of Africa.

The overall objective of the Numbers and Needs Study is to gain a better understanding of the engineer, technologist and technician capacity in the region. Without such skills, better planning and implementation of infrastructure programmes to support the SADC Industrialisation Strategy cannot proceed. It is thus necessary to understand where engineers are employed and what disciplines are required.

THE ENGINEERING SECTORS

Contributions to the GDP come from several industries and sectors of the economy. Sectors range from primary industries such as agriculture, in which produce is grown and sold without any value addition, to tertiary industries such as the manufacturing of motor vehicles, or services such as financial services. A comprehensive set of activities has been defined against which to measure and report on economic activities, known as the *International Standard Industrial Classification (ISIC) of All Economic Activities. Revision 4* is the current revision in use. There are 99 activities listed under 21 headings.

In the SADC region, many of these have been grouped under the following headings for purposes of uniform reporting:

- Agriculture
- Mining and Quarrying
- Manufacturing
- Electricity, Gas and Water
- Construction
- Wholesale and Retail Trade, Restaurants and Hotels
- Transport and Communication
- Finance, Insurance, Real Estate and Business Activities
- General Government Services
- Other Services.

As countries industrialise, the growth in GDP becomes more dependent on the development of skills and associated services than on the use of labour, machinery and supply of products.

The first five sectors above, plus transport and communications, rely on the availability of engineering skills in one way or another to plan, design, operate, optimise or maintain infrastructure, systems or processes.

Table 2 shows the GDP contributions of all sectors, by value for each country for 2015, while Figure 6 shows the contribution to GDP per engineering sector for each country over a number of years.

Most countries have one or two sectors that are stronger than the others, and many of these are primary industries such as agriculture or mining. Only a few have any significant manufacturing contribution. Eswatini is one of the notable exceptions, having developed an impressive sugar manufacturing sector, based on the near-perfect conditions for growing sugar cane in the Lowveld. The growth of the manufacturing industry has in turn created more demand and many smallholders have been able to benefit, selling their cane to the sugar mills to augment production.

The Mauritian manufacturing sector also relies on sugar and the production of electronic goods, which was a strategic move to diversify. Lesotho's textile industry is the backbone of that country's manufacturing sector.

Manufacturing is, however, not the only solution for improved economic performance. Many countries in the region are net importers of basic foodstuffs, although soil and climate conditions are such that local production should be adequate to meet their needs. In these instances, improved techniques need to be introduced, which rely largely on scientific and engineering innovations and know-how.

Throughout the region, development is required in each of the engineering sectors, all of which require engineering skills. For a better understanding of the engineering opportunities and needs, the scope of each engineering sector is outlined in this chapter.

Table 2: % Contribution to GDP per sector, 2015

COUNTRY	ENGINEERING CONTRIBUTORS						% ENG	OTHER CONTRIBUTORS			
	Agriculture	Construction	Electricity, Gas & Water	Manufacturing	Mining & Quarrying	Transport & Communication	% contribution of engineering GDP to total	Finance, Real Estate, Business	General Government Services	Other Services	Wholesale & Retail Trade, etc.
Angola	9.9%	13.0%	0.5%	5.3%	23.5%	4.5%	**56.8%**	6.2%	11.3%	9.3%	16.4%
Botswana	2.4%	7.2%	-0.4%	6.3%	20.2%	6.5%	**42.3%**	16.3%	16.9%	6.6%	17.9%
DRC	19.9%	4.7%	0.6%	17.7%	19.1%	11.9%	**73.9%**	8.6%	5.9%	-	11.6%
Eswatini	8.2%	2.9%	1.3%	34.3%	0.2%	5.1%	**51.9%**	16.3%	7.1%	8.9%	15.7%
Lesotho	5.6%	6.3%	6.4%	10.6%	8.3%	6.8%	**44.1%**	14.4%	13.7%	12.6%	15.1%
Madagascar	24.9%	3.2%	1.2%	13.8%	0.2%	25.1%	**68.5%**	2.5%	7.2%	11.3%	10.6%
Malawi	28.3%	3.4%	1.6%	7.8%	1.2%	6.9%	**49.2%**	17.6%	2.6%	10.3%	20.3%
Mauritius	3.5%	4.4%	2.3%	14.7%	0.2%	10.4%	**35.7%**	25.6%	6.1%	14.1%	18.5%
Mozambique	24.6%	2.5%	3.3%	9.8%	5.5%	11.3%	**56.9%**	11.1%	17.3%	0.7%	14.0%
Namibia	6.6%	6.6%	1.5%	8.9%	13.5%	5.3%	**42.4%**	13.9%	12.3%	16.3%	15.0%
Seychelles	2.7%	3.7%	3.4%	6.4%	0.0%	17.5%	**33.7%**	30.5%	7.4%	5.5%	22.9%
South Africa	2.4%	4.0%	3.7%	13.2%	8.0%	10.3%	**41.5%**	20.6%	17.0%	5.9%	15.0%
Tanzania	31.1%	14.6%	1.5%	5.6%	4.3%	6.7%	**63.8%**	11.1%	6.9%	5.5%	12.6%
Zambia	5.3%	10.7%	3.5%	7.9%	13.4%	7.2%	**48.0%**	11.6%	4.7%	10.5%	25.3%
Zimbabwe	13.3%	3.4%	4.3%	11.3%	8.8%	12.1%	**53.2%**	13.4%	3.6%	13.8%	15.9%

AGRICULTURE, FORESTRY AND FISHING

This sector consists of the growing of crops, raising and breeding of livestock, the harvesting of timber and other plants, and fishing and hunting. Agro-processing, however, falls under manufacturing.

The SADC region, and indeed most of Africa, consists of large rural populations, the majority of whom are involved in subsistence agriculture. To improve their livelihoods, the opportunity to grow and sell crops is important. This may rely not only on irrigation (including dams, canals, wells and boreholes) and energy supplies, but also on adequate transport infrastructure to get their products to market. Also essential is post-harvest support, such as drying, storage, refrigeration, freezing and packing facilities, to ensure that harvested products do not spoil.

Several engineering disciplines are to be found working in this sector: from chemical engineering practitioners involved in agro-processing; civil engineering practitioners involved in the development of dams, irrigation systems, roads and structures; electrical engineering practitioners largely involved in renewable energy; mechanical engineering practitioners involved in mechanisation, refrigeration and the manufacture and supply of equipment. Agricultural engineering practitioners have a combination of the knowledge of all disciplines described, plus have had training in crop production, livestock, post-harvest processing and agricultural systems and processes to equip them to develop innovative technological solutions to increase production and improve productivity. Industrial engineers are also used to enhance systems and process flows in terms of planning, harvesting and processing.

MINING AND QUARRYING

This sector covers mining and quarrying, including the extraction of minerals occurring naturally as solids (coal and ores), liquids (petroleum) or gases (natural gas). Extraction can be achieved by different methods, such as underground or surface mining, well operation, seabed mining, etc. This sector includes supplementary activities aimed at preparing materials for use, such as crushing, grinding, cleaning, drying, sorting, concentrating ores, liquefaction of natural gas and agglomeration of solid fuels (see Figure 7). These operations are often carried out by the units that extracted the resource and/or others located nearby. However, the sector excludes the processing of the extracted materials, which is covered under *Manufacturing*.

Mining, civil, electrical and mechanical engineering practitioners are required initially to plan and construct, and later to maintain and optimise operations.

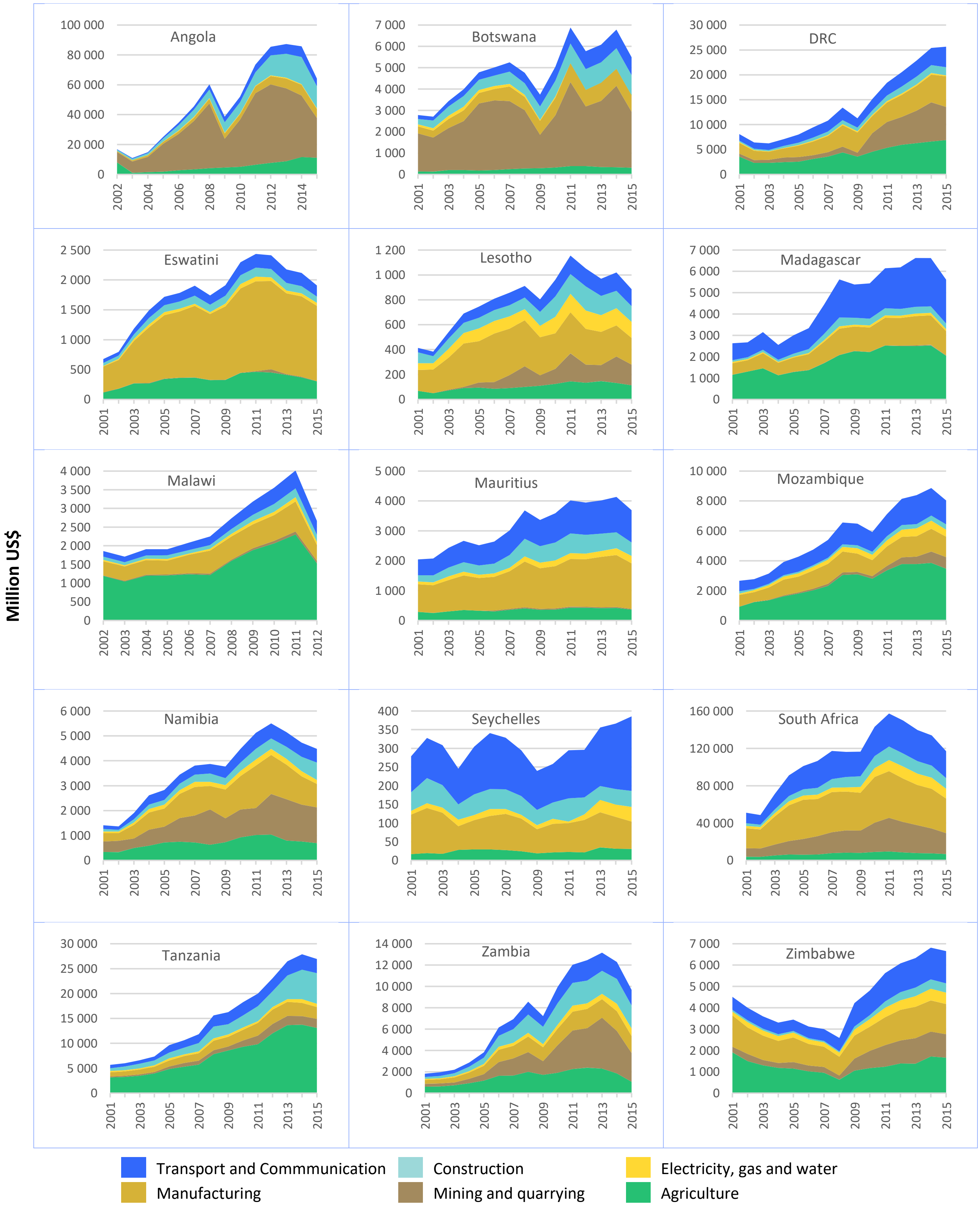

Figure 6: Engineering GDP per sector in SADC countries

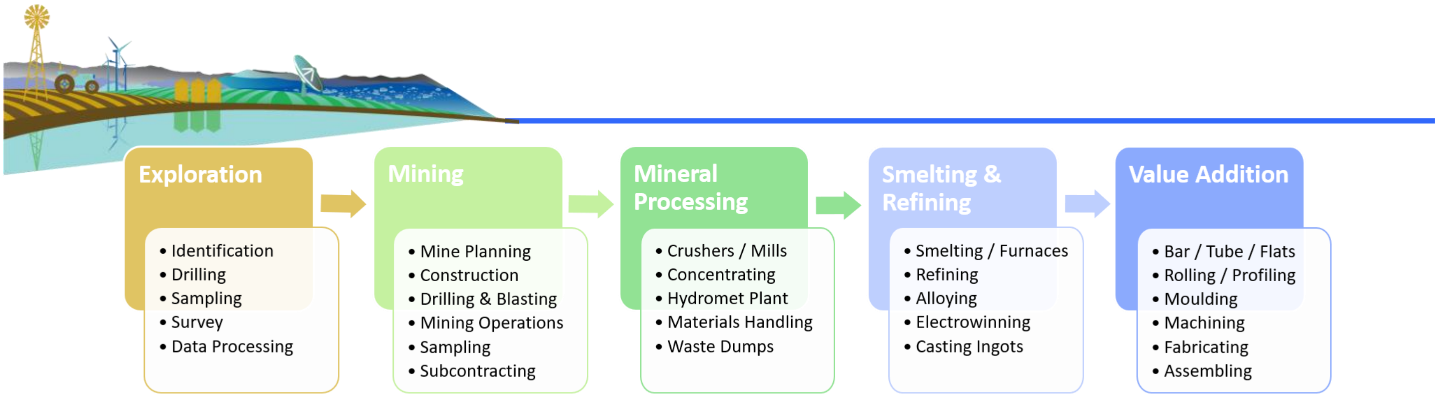

Figure 7: The mining and beneficiation process

MANUFACTURING

This sector covers 33 categories under ISIC which can be summarised as follows:

- Food products, beverages and tobacco products
- Textiles, clothing and leather goods
- Wood and wood products, paper, packaging, publishing and printing
- Furniture and other related manufacturing
- Petroleum, chemical products, rubber and plastic products
- Electrical equipment and electronics
- Machinery, motor vehicles, parts and accessories, and other transport equipment
- Glass and non-metallic mineral products
- Basic iron and steel, non-ferrous metal products, metal products and machinery
- Other.

Agro-processing

There has been considerable debate on the difference between agro-processing and manufacturing. Essentially, agro-processing is a subset of manufacturing which processes raw materials and intermediate products derived from the agricultural sector. ISIC categorises 11 divisions under agro-processing: food, beverages, paper and paper products, wood and wood products, textiles, wearing apparel, furniture, tobacco, rubber products, footwear, leather and leather products. Agro-processing minimises post-harvest losses of perishable produce, including fruit, vegetables, milk, meat and fish among others.

Secondary processing of farm produce is handled by many mills, such as flour, sugar and rice mills, etc. End products, such as cereals, baked and confectionary goods, processed foods and beverages, emerge after tertiary processing. Pickled, dried and frozen products also offer long shelf life. Given stringent health and safety requirements, the quality expected by consumers, and productivity demanded by shareholders, engineering skills are required to plan, oversee and optimise processes. Controlling feedstock, the quality of water, temperature and pressure, and minimising downtime are key elements which engineering practitioners must manage. Chemical engineers are important in this sector.

It is interesting to note that even those countries that claim not to have a manufacturing sector of any worth, all had at least one brewery and some plants producing international brands of carbonated drinks under licence, sweets and chocolates, all of which employed engineering practitioners.

The manufacture of tobacco products such as cigarettes, pipe and chewing tobacco, cigars and snuff is a substantial activity in several countries.

In terms of textiles and clothing, the US African Growth and Opportunity Act (AGOA) enacted to enhance market opportunities for sub-Saharan countries has resulted in growth in the textiles and garment sector, as goods imported from African countries by the USA are quota- and duty-free.

Sadly, over the years, the production of fabric has declined, with countries importing material from elsewhere in Africa and rather making clothing for export. Where cotton is still grown, ginning and weaving facilities require engineering skills.

Plants that manufacture pulp, paper and converted paper products are to be found throughout the region. The range of papers and packaging material has become an integral part of our daily lives. The list of paper products is extensive, from tissues and toilet paper to paper cups and plates, computer and copy paper, labels and envelopes, to name but a few. Packaging products include cardboard boxes, egg trays and other moulded pulp packaging products. There are many substantial manufacturers of paper and packaging materials which employ literally hundreds of engineers and technicians.

The manufacturing of wood products other than pulp also falls under this section. This includes the manufacture of plywood, veneers, wooden containers, flooring, trusses and prefabricated wooden buildings. Much of this work is carried out by artisans, but engineering skills are required for the design of roof trusses and buildings.

Need for engineers

The manufacture of wearing apparel, furniture and leather goods relates largely to handcrafts in the region, but the balance of production is generally the domain of large processing plants employing the full complement of engineering skills.

Petroleum, chemicals, rubber and plastic products

This industry includes the transformation of organic and inorganic raw materials by chemical processes into end-user products. A huge variety of products are covered under this heading, including motor fuels, oils, road surface materials, waxes, pharmaceuticals, fertilisers, plastics, rubber, paint, ink, gases and alcohol, to name but a few. Not only are chemical engineers required to design and optimise processes, but electrical, industrial and mechanical engineering skills are required to manage the range of complex equipment, pressure vessels and to maintain a controlled environment. .

Other non-metallic mineral products

This category includes the production of glass, clay and refractory bricks, and cement and cement products, among others. The sector would generally require civil and mechanical engineering skills.

Mineral beneficiation

The manufacture of basic iron and steel entails secondary processing by the mining sector, while tertiary processing involves machinery, vehicles and parts. The last two stages in the mining value chain shown in Figure 7 fall under *Manufacturing*. Smelting, refining and fabrication add considerable value to the original product and the fabrication phase offers substantial employment opportunities.

Once again engineering skills are critical for planning, overseeing and optimising processes. In secondary processing, metallurgists play a key role in extraction, while it is mainly mechanical and electrical engineering practitioners who operate and maintain tertiary processes, along with industrial engineers, who have become increasingly important for optimising and streamlining processes.

Electrical equipment and electronics

This industry includes the manufacture of computers, computer peripherals, control and communications equipment, and similar products, as well as the manufacture of components. Production processes are characterised by the design and use of integrated circuits, and the application of highly specialised miniaturisation technologies. By and large this sector employs electronic and systems engineers.

Machinery, equipment, motor vehicles and other transport equipment

This sector includes the manufacture of machinery and equipment and their mechanical components. Machinery may be fixed, mobile or hand-held devices used for industrial, building, construction and agricultural purposes, for home use or in passenger or freight transport.

In terms of transport the range of motor vehicles, trailers, rolling stock, ships, boats, floating structures, aircraft and spacecraft, military vehicles, motorcycles, bicycles, parts and accessories are covered in this sector.

The sector employs mainly mechanical and electrical engineering practitioners.

Hi-tech versus low-tech

It is important to note the classification of various goods into low-tech, medium-tech and high-tech categories. Generally, agro-processing activities and the manufacture of furniture are low-tech, while basic rubber, plastics, metal and petroleum industries are considered to be medium-tech. The manufacture of chemical products, machinery, electrical goods, electronics, motor vehicles, parts, medical precision and optical instruments are considered high-tech. The latter would require higher numbers of engineering practitioners, and the job multipliers increase. 'Job multipliers' refers to the number of people engaged in downstream industries.

ELECTRICITY, GAS AND WATER

This sector includes the generation of bulk electricity, and transmission and distribution to end users. It also includes water abstraction, treatment and distribution activities for domestic and industrial needs.

Without a continuous supply of clean energy and water, mining and manufacturing cannot take place. Engineering skills are thus critical, not only to supply these services, but also for other sectors of the economy to thrive. While electrical and civil engineering practitioners are key to the delivery of electrical and water services, the equipment associated with generation and treatment processes also requires chemical and mechanical engineering skills.

CONSTRUCTION

This sector covers construction activities for buildings and civil engineering works, including:

- **Building works:** residential buildings, estates and slum redevelopment; and non-residential construction, including commercial, retail and industrial structures, public amenities, hotels and tourist facilities. Public amenities would include hospitals, schools and other educational facilities, sports and recreation facilities and public sector buildings.
- **Transportation and communication:** roads, rail, bridges, airports, ports, telecommunication systems and related physical infrastructure
- **Water works and sanitation projects**: water supply, sanitation and sewerage schemes, dams, pumping and irrigation systems and related physical infrastructure
- **Energy:** power stations, transmission and distribution lines, schemes for producing renewable energy and related physical infrastructure
- **Other physical infrastructure:** defence, mining, agriculture and related infrastructure.

Construction covers new work, maintenance and repair, additions and alterations, the erection of prefabricated buildings or structures and construction of a temporary nature.

This sector largely uses civil engineering skills and construction project managers, but electrical and mechanical skills are required for equipment, lighting, heating and cooling, among others.

TRANSPORTATION AND COMMUNICATIONS

Transportation and communications are means of overcoming distance, either by moving goods or people, or by passing news and information from one person to another.

Transportation

The transportation sector includes the provision of passenger or freight transport by rail, pipeline, road, water or air, as well as associated activities such as terminal and parking facilities, cargo handling, storage, etc.

Mechanical and electrical engineering skills are required to design, manage, operate and maintain fleets. Aeronautical and marine engineering are subdisciplines of mechanical engineering, although in some countries they have become separate disciplines.

Civil and some electrical and mechanical engineering practitioners would be involved in the construction, operation and maintenance of the infrastructure networks.

Communications

The communications sector has become an integral part of our daily lives. From providing mainly voice services 30 years ago, communication has expanded to the transmission of voice, data, text, sound and video. Transmission facilities may be based on a single technology or a combination of technologies, with the use of satellite, wireless and extensive optical fibre networks having considerably enhanced transmission speeds. This sector transmits content, without being involved in its creation.

Electrical, electronic and systems qualifications are required in this sector. Some graduates would go on to complete a post-graduate qualification in telecommunications. More recently, dedicated telecommunications qualifications have been introduced in a number of countries.

The Internet of Things (IoT) will place further demand on the electronics and communications sectors, as the network of physical devices, vehicles, home appliances and other items are embedded with electronics, sensors and network connectivity which will enable these objects to connect and exchange data. Devices can be as diverse as heart monitoring implants, transponders on farm animals and links to security systems, among others. It is estimated that the IoT will consist of about 30 billion devices by 2020.

The positive and transformative effects the Internet of Everything (IoE) has had on government services, manufacturing, retail and health care have already been observed. It has allowed new customer and citizen experiences, improved operational efficiencies, breakthrough innovations and entirely new economic models for services and growth. At the city level, this includes smart grid solutions, traffic management, parking solutions and physical and cyber security. At the citizen level, the value comes from electronic payments and teleworking, among others. For enterprises, the IoE can be the deployment of sensors that provide real-time data, which when deployed with an overlay of data analytics, will allow proactive responses to changing conditions.

Need for engineers

THE ENGINEERING LIFE CYCLE

Developing infrastructure, products or processes is not a trivial exercise, but requires many steps to ensure that a cost-effective and sustainable solution is developed, utilised and maintained. The engineering life cycle is shown in Figure 8.

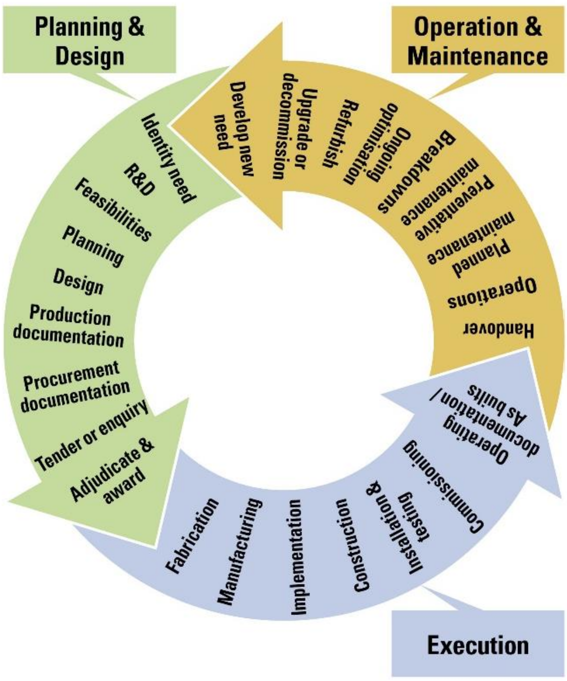

Figure 8: The engineering life cycle

Whether a road, a new mobile phone, a vehicle or a streamlined data processing system for a financial institution is being designed, it is necessary to investigate and identify the need, to carry out feasibility studies, planning and detailed design and to document the final solution before execution can begin. Once the development is complete, ongoing use, optimisation and maintenance must be managed. This cycle requires the dedication of engineering teams.

THE ENGINEERING TEAM

Engineering teams as we know them today have evolved into a multi-disciplinary hierarchy able to address all levels of engineering activities, from basic labour to the design of the most complex systems. The hierarchy has, however, evolved over time.

THE EMERGENCE OF THE ENGINEERING TEAM

Engineering has developed from a very rudimentary form of manual arts to a high level of science and research. Historically, engineering training was a hands-on, shop- or site-cultured process learned through various means of guilds, apprenticeships and simple on-the-job training.

The science of modern-day infrastructure, which includes surfaced roads, steam (and now fuel, diesel or electric) engines, railway networks, bridges, tunnels, water-borne sewage removal, piped potable water and the light bulb, only began to emerge in the 18th century and dominated the development of major cities such as London and New York. Masters such as Macadam, the Stephensons, Bazalgette, Babbage, Brunel, Telford, Edison *et al.* pioneered new technologies which needed to be shared with future generations to support growing populations and the dawn of urbanisation.

It was realised that much of the theoretical knowledge learned or developed by these masters could be shared through tuition. Many masters wrote material that became standard works in which design calculations replaced the rules of thumb on which decisions had previously been made. Engineering was formally introduced to academia in the 1700s, and a theoretical, school-cultured engineer emerged, whose role it was to expand the implementation of new technologies. Courses concentrated on implementation techniques and developing many practical skills, such as drawing, surveying, managing machine shops, etc.

When the Western World reviewed its technological successes after World War II, it was realised that engineers generally did not perform as well as physicists in solving unusual problems. Many engineers had been ignorant of the science underlying the breakthroughs, and so the need for engineers to understand principles and concepts was recognised. After much debate, two tiers of engineering instruction were finally recommended. The first tier, the training of the engineer, would concentrate on more science and engineering science, and the second tier on technology training.

Thus, the engineering technician was born. The technician was to be equipped with practical know-how to complement the academic knowledge of the engineer, thereby forming what Frederik Philips, who served on the American Society for Engineering Education's Committee on Evaluation of Engineering Education in 1955, considered to be an *'unbeatable team fit to tackle any project'*.

In time, it was realised that the practice of engineering required a broader spectrum of expertise and an additional team member, the technologist, emerged. Technology training was extended to a Higher National Diploma, or Bachelor of Technology. The engineering team as we know it today is shown in Figure 9.

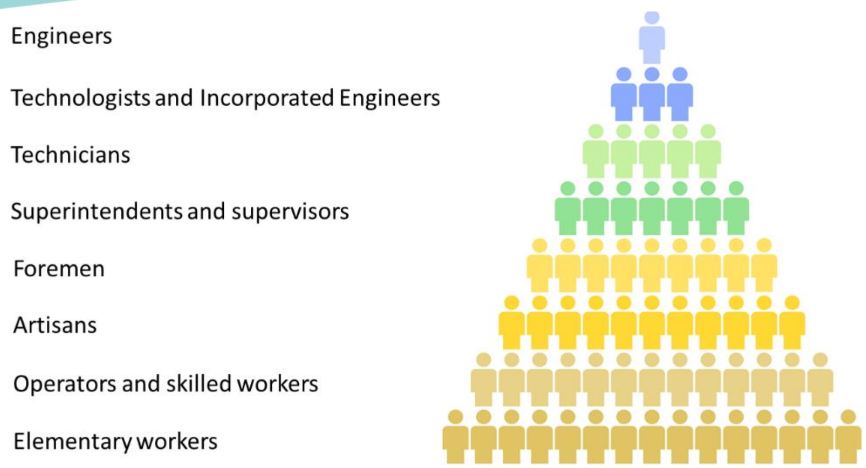

Figure 9: The engineering team

Considering Figure 10, broadly speaking, engineers should be 'innovators' responsible for complex tasks such as developing solutions to address new infrastructure or systems requirements, or enhancements to operations and maintenance. They may use engineering principles where necessary to develop unique solutions. They need to consider multi-disciplinary needs, overall resourcing and risks associated with the solutions.

Engineering technologists solve engineering problems by using proven techniques and are thus the 'implementers' who implement broadly defined tasks or projects proposed by engineers. They may also plan and oversee long-term strategies for implementation, operations and maintenance.

Engineering technicians are the backbone of infrastructure support, and are the 'doers' who carry out well-defined tasks such as managing safety, operations, maintenance, production, etc. They may source skills for operational activities and detect and respond to non-standard situations that arise.

In the planning phase, engineers and technologists play a major role, while in the implementation phase, technologists and many technicians, artisans, operators and elementary workers are required.

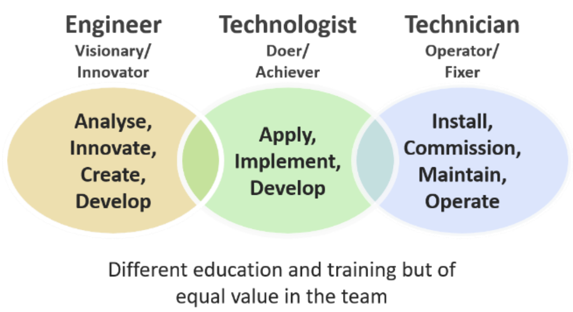

Figure 10: The role of engineers, technologists and technicians

There is no ideal ratio of engineer to technologist to technician. This varies per discipline and stage of the engineering life cycle.

ENGINEERING DISCIPLINES

The following are the main engineering disciplines covered in the study. Other occupations are derivatives of these. For example, an aeronautical or marine engineer would follow a similar programme to a mechanical engineer and would branch into the area of specialisation part way through the qualification. The descriptions are extracted from the Organising Framework for Occupations and the ECSA Discipline-specific Training Guidelines.

AGRICULTURAL ENGINEERING

An agricultural engineer performs and supervises engineering work concerned with planning, design, development, operation and maintenance of agricultural land, buildings, infrastructure, machinery, equipment, mechanisation, production and processing. Agricultural engineering practitioners generally concentrate on one or more of the following areas:

- Agricultural energy and renewable energy
- Agricultural product processing engineering
- Agricultural structures and facilities
- Agricultural waste handling and management
- Aquaculture engineering
- Mechanisation and refrigeration
- Hydrology, irrigation and water use management
- Natural resource and environmental engineering
- Post-harvest processes and food engineering
- Rural infrastructure engineering.

The use of technology is important in food processing and storage systems to add value to raw products to make them fit for human and animal consumption.

Need for engineers

CHEMICAL ENGINEERING

A chemical engineer designs and prepares specifications for chemical process systems, and for the construction and operation of commercial-scale chemical plants, and supervises industrial processing, fabrication and manufacturing of products undergoing physical and chemical changes. Typical tasks carried out by chemical engineering practitioners include:

- Conducting research, advising on and developing processes to refine crude oil and other liquids or gases to produce substances such as petroleum derivatives, explosives, food and drink products, medicines and synthetic materials
- Specifying chemical production methods, materials and quality standards and ensuring that they conform to specifications
- Establishing control standards and procedures to ensure the safety and efficiency of chemical production operations
- Designing chemical plant equipment for manufacturing chemicals and products
- Performing tests throughout the stages of production to determine the degree of control over variables, including temperature, density, specific gravity and pressure
- Monitoring and optimising production
- Performing laboratory studies to manufacture new products and testing proposed processes on a small scale in a pilot plant.

CIVIL ENGINEERING

A civil engineer plans, designs, organises and oversees the construction and operation of civil engineering projects. Typical tasks that civil engineering practitioners may undertake include:

- Conducting research and developing new or improved methods and materials
- Advising on and designing infrastructure such as roads, bridges, airports, ports, railways, dams, canals, pipelines, treatment works, waste-disposal and flood-control systems, and industrial and other large structures
- Determining, directing and specifying construction methods, materials and quality standards, and ensuring safety
- Organising and directing the maintenance and repair of existing civil engineering infrastructure
- Analysing soil conditions and designing structural foundations.

ELECTRICAL ENGINEERING

Electrical engineers are expected to plan, design, construct or manufacture, manage, operate and maintain materials, components, plants and systems for generating, transmitting, distributing and utilising electrical energy; electronic devices, apparatus and control systems for industrial systems, bio-medical and consumer products; computing, communication and software for critical applications; and instrumentation and control of processes, through the application of electrical, electromagnetic and information engineering sciences. Within the broad field of electrical engineering, practice areas or specialities include:

- **Electric Power Engineering:** comprising electrical systems, components, motors and equipment, control systems, illumination, signalling and communications, materials, products and processes
- **Electronic Engineering:** comprising electronic systems, instrumentation, computers and information systems, automation, materials, products or processes
- **Telecommunications:** comprising systems, devices and products, including broadcasting, digital signal processing, communications (fibre optics, radio, radar, satellite transmission) and telecommunications.

INDUSTRIAL ENGINEERING

Industrial engineers conduct research and organise and oversee the planning, design, implementation, operation and maintenance of industrial, manufacturing and production systems and operations, through systems engineering and supply chain management. They establish programmes for the coordination of manufacturing activities, assess cost-effectiveness and safety, and recommend improvements in the efficiency of operations in commercial, industrial and production environments. Practice areas include:

- Automation and control systems
- Enterprise resource management
- Industrial efficiency and machinery
- Manufacturing logistics and technology
- Operations research
- Process design
- Production
- Quality management
- Robotics and production automation
- Supply chain management.

MECHANICAL ENGINEERING

Mechanical engineers advise on and design machinery and tools for manufacturing, mining, construction, agricultural and other industrial purposes and the mechanical aspects of materials, products or processes. Machinery may include non-electric motors and engines; hulls, superstructures and propulsion systems; airframes, undercarriages and vehicles; mechanical plant and equipment for heating, ventilation and refrigeration; gears, pumps, pipework, valves etc. Practitioners generally concentrate on one or more of the following areas:

- Air-conditioning, heating and ventilation
- Automotive, diesel and transportation systems
- Fluid mechanics and thermodynamics
- Machine design and development
- Maintenance management
- Mechatronics
- Piping
- Power generation
- Pressurised vessels.

METALLURGICAL ENGINEERING

Extractive metallurgical engineers conduct research and plan, design, develop, construct, operate and maintain commercial-scale processes for the extraction of metals or intermediate compounds from ores by chemical or physical processes, including those at high temperatures. They are found in smelters, refineries and other processing plans. They may also develop, control and advise on processes used for casting, alloying, heat treating or welding refined metals, alloys and other materials to produce commercial metal products or to develop new processes.

Materials engineers investigate the properties of metals and alloys, develop new alloys and advise on and supervise technical aspects of metal and alloy manufacture, processing, use and manufacturing. They may also carry out residual life evaluations and predictions and failure analyses, and prescribe remedial actions to avoid material failures. Metallurgical engineering practitioners may be found in the following areas:

- Mineral processing
- Pyrometallurgy
- Hydrometallurgy
- Physical metallurgy
- Materials
- Welding
- Corrosion
- Quality assurance.

MINING ENGINEERING

Mining engineers involved in extraction and mining operations conduct research on and assess the feasibility, safety and productivity of mine locations. They also plan, design, develop, manage and optimise the extraction of surface and underground deposits. They ensure that underground resources such as minerals, metals, oil and gas are extracted safely and efficiently. Typical responsibilities include:

- Assessing the feasibility, potential and commercial benefit of new sites
- Ascertaining extraction risks
- Producing models or plans for possible mining sites
- Planning and implementing extraction systems
- Using specialist applications to maximise planning and production
- Monitoring and evaluating underground performance
- Managing construction projects
- Ensuring that equipment used and operations comply with health and safety requirements.

DERIVATIVE ENGINEERING QUALIFICATIONS

In countries with niche engineering requirements, several derivative or specialist engineering qualifications have emerged. The most notable are described below.

Textile engineering

Cotton is an important crop in several countries. To develop the value chain an interesting qualification, textile engineering, has emerged. This covers a combination of electrical, mechanical and process engineering, and courses in cotton growing, processing and yarn and fabric production.

Railway engineering

Given the major developments and upgrades required in the rail sector, the Instituto Superior de Transportes e Comunicações (ISTUC) in Mozambique has introduced a railway engineering degree covering aspects of civil, electrical, electronic and mechanical engineering to address the design, operations and maintenance of the perway, signalling, control systems and rolling stock. Due to its relevance in the region, the university is considering offering the qualification in English.

Aeronautical engineering

In countries involved in the design of aircraft or the maintenance of large fleets, a specific aeronautical engineering degree is offered. Essentially, it is a mechanical engineering degree, with specific subjects covering aerodynamics and flight mechanics.

Need for engineers

Environmental engineering

Environmental engineering qualifications include elements of civil and chemical engineering qualifications and the principles of soil science, biology and chemistry to allow graduates to develop solutions relating to recycling, waste disposal, and water and air pollution control, among others.

Marine engineering

In many coastal countries a marine engineering degree is offered. Essentially, it is a mechanical engineering degree, which considers the dynamics of wave action and the design, development, manufacturing, certification, maintenance and modification of ships and water-borne structures on the ocean, coastal waters, inland waters and underwater.

Mechatronics

A hybrid degree emerged from the 1970s combining mechanical and electronic engineering. However, given the level of automation that has become inherent in most devices and processes, mechatronics degrees today are multi-disciplinary and include a combination of mechanical, computer, telecommunications, systems and control engineering, electronics and robotics.

Software engineering

In several countries a stand-alone software engineering qualification is offered. Essentially, it is composed of electronic engineering with the addition of more software and systems subjects, to allow graduates to design, develop, test and evaluate software, operating systems, hardware systems and components, and computer networking. In other countries software engineering is offered as an elective in the final year of electrical and electronic engineering qualifications.

ESTIMATED NUMBERS

Detailed data per discipline and category was not readily available in many countries. However, estimates of the percentages and totals per discipline are shown in Figure 11 and Table 3.

Reliable data could only be gathered from some registration bodies, which often only represents a small percentage of the engineering workforce, as registration is not compulsory in many countries. Their data, in combination with graduation history, employment profiles, and consulting and contracting skills information, where available, has been used to estimate ratios and extrapolate the samples received to the overall engineering population. The data should be used with caution as many samples were small relative to the population and the engineering skills considered to be available.

The main disciplines, such as chemical, civil, electrical, mechanical, metallurgical and mining engineering, were well understood, but emerging and specialist qualifications such as mechatronics, telecommunications, textiles or industrial engineering, etc. were only evident in some countries. Where specialist qualifications are not offered, the sub-disciplines are covered in the qualifications of one of the main disciplines, but not necessarily to the same degree of complexity. Due to the inconsistency in approach from country to country, these specialisations are grouped under the main disciplines in Figure 11 and Table 3.

It is possible that the number of civil practitioners is overestimated, as this is the most regulated of the engineering disciplines in terms of public health and safety, hence more data was available about the number of civil engineering practitioners in most countries. Where more detailed data was available it was found that electrical engineering presented the largest group, as electrical practitioners are involved not only in infrastructure development, but mining, manufacturing, electronics, automation, system development and telecommunications among others. Mechanical engineering is the second largest

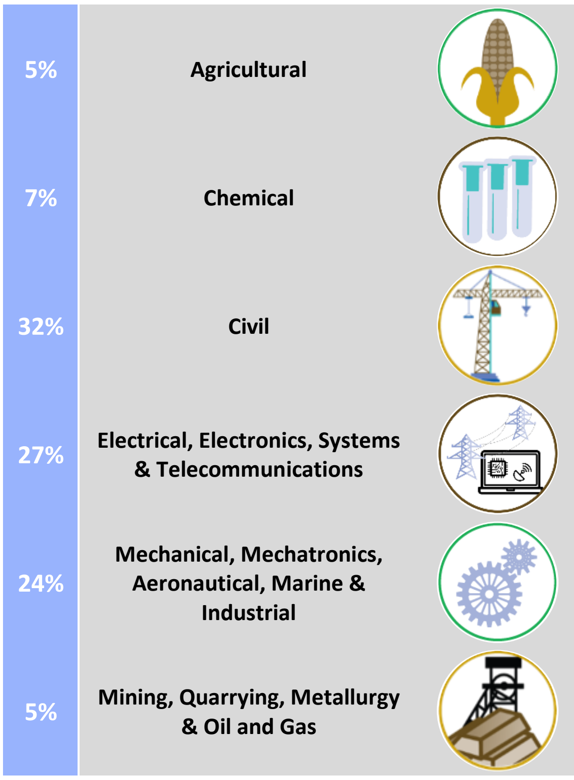

Figure 11: Percentage distribution of disciplines in the region

group in South Africa due to the extent of the manufacturing and mining sectors. Mechanical practitioners are required in all industries and should be factored into skills planning, as they also play a role in power generation (including renewable energy), water treatment (including desalination), agriculture, and heating, air conditioning and ventilation (HVAC) among others.

The extent of the use of agricultural engineers was difficult to gauge as there are few voluntary associations dedicated to agricultural engineering and agricultural engineers were not found in many registering body datasets.

In the French and Portuguese speaking countries, agronomy qualifications also include engineering subjects hence agronomists are classified as engineers, which is reflected in the higher numbers in those countries in Table 3.

Due to the emphasis placed on analysis and problem-solving in engineering qualifications, engineering practitioners are to be found not only in the engineering sectors as described in this chapter, but in many industries that are affected by or influence engineering decisions, such as in finance, insurance, investments, property development, asset management etc. Practitioners are also found in the tourism sector in some of the island states, where it is the responsibility of resorts to provide and operate their own water services and energy supplies.

Many practitioners, mostly civil, electrical and agricultural engineering are involved in the NGO sector, working on community projects to address the delivery of basic services and enhance agricultural production.

Engineering practitioners are also involved in delivering training and managing professional bodies.

It should be noted that the data relating to the total in Zimbabwe was taken from the 2014 Labour Force Survey, but the Zimbabwe Institution of Engineers suggests that by the end of 2018, the numbers would have been significantly lower due to the poor state of the economy, retrenchments, company closures, and engineering practitioners seeking work outside of the country.

Table 3: Disciplines in which engineering practitioners are employed per country

COUNTRY	Agriculture	Chemical	Civil	Electrical, Electronics, Systems & Telecomms	Mechanical, Mechatronic, Aeronautical, Marine & Industrial	Mining, Quarrying, Metallurgy & Oil and gas	Total
Angola*[1]	552	368	4 770	1 718	944	649	9 000
Botswana	27	92	2 194	1 880	1 421	386	6 000
DRC	6 270	550	2 660	3 370	3 400	1 750	18 000
Eswatini	120	35	685	520	230	10	1 600
Lesotho	25	20	500	350	195	60	1 150
Madagascar	1 110	400	2 900	3 040	2 700	850	11 000
Malawi	301	25	1 255	1 079	508	31	3 200
Mauritius	20	150	2 200	1 550	1 070	10	5 000
Mozambique*[1]*[2]	989	747	5 103	2 401	1 760	*[2]See note	11 000
Namibia	20	55	1 200	840	520	165	2 800
Seychelles	-	3	143	178	184	2	510
South Africa	900	10 175	30 950	32 350	31 325	4 300	110 000
Tanzania	1 550	1 475	12 350	7 400	6 375	850	30 000
Zambia	350	700	3 800	3 300	2 600	1 250	12 000
Zimbabwe	180	400	2 360	1 850	1 810	1 000	7 600
TOTAL	**12 414**	**15 195**	**73 070**	**61 826**	**55 042**	**11 313**	**228 860**

*[1]Only engineers are reported on in these countries
*[2]The Ordem dos Engenheiros de Moçambique reports civil and mining engineering as one total which is reflected under Civil

Chapter 3

Developing professionals

Prospective professionals follow a protracted development pathway of at least 8 to 10 years after leaving school before they are able to operate independently.

THE ENGINEERING SKILLS PIPELINE

The engineering skills pipeline is shown in Figure 12. The requirements to succeed are as follows:

- **Schooling:** Demonstrate an aptitude for mathematics and science as required by each programme in higher education.
- **Theory:** Complete an accredited professional degree or diploma through a university, polytechnic, university of technology or college.
- **Workplace:** Complete a workplace training phase usually over three or more years under supervision and mentorship. In terms of the various registration Acts throughout the region, during this phase the graduate is known as a candidate or graduate-in-training who is required to do the following:
    - Follow a prescribed range of activities or follow best practice guidelines, complete logbooks or reports as required by the professional body, and develop a portfolio of evidence.
    - Be exposed to an adequate range of increasingly complex activities and take increasing responsibility, until able to perform as an independent professional.
    - Submit logbooks, portfolios of evidence and reports as required, either during the course of development or when ready for assessment for the purpose of registration.
- **Assessment:** Be assessed through an examination or peer review or both to determine whether the required level of competence has been achieved.
- **Registration:** Be awarded a designation commensurate with their education, training and experience.
- **Professional practice:** Work in a professional environment which values engineering professionals and offers them opportunities to develop as experts or grow into management and leadership roles. Experienced professionals must:
    - Adhere to the Code of Conduct prescribed by the relevant Statutory Council and work within the practice area for which their education, training and experience has rendered them competent
    - Continue to develop and keep up to date by actively engaging in Continuing Professional Development (CPD).
- **Institutional commitment:** Work in an environment where appropriate staff, systems, processes, support and necessary service providers are in place or may be appointed.
- **Investment:** Work in an environment where investment in planning, development, operations and maintenance of infrastructure, products, systems and/or processes takes place.

There are numerous bottlenecks in each of these phases which need attention. Furthermore, regional standards and alignment are critical for countries to benefit from and support each other's development. The report will look at the challenges per phase, but

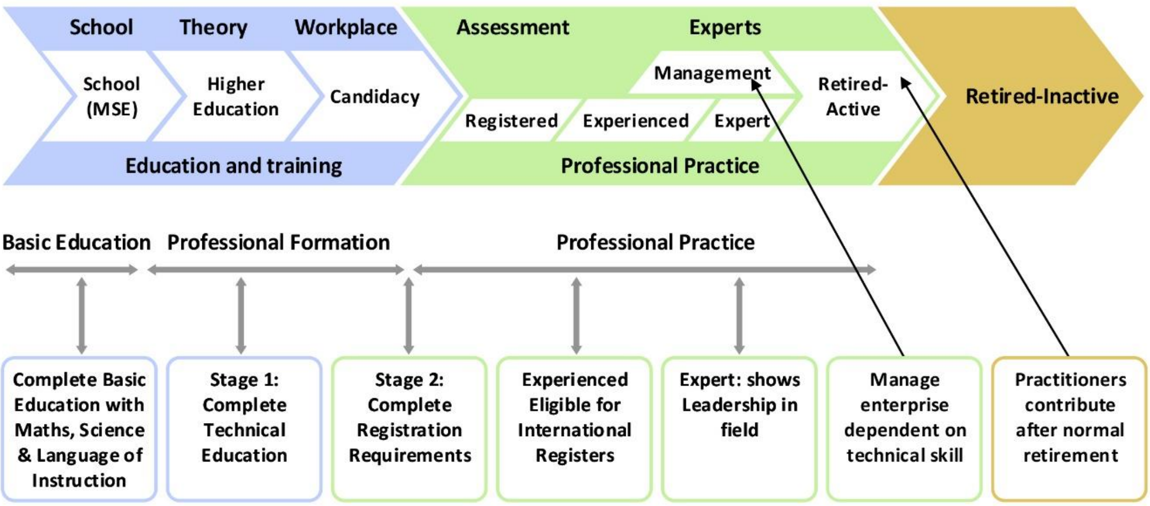

Figure 12: The engineering skills pipeline

to understand possible solutions, consideration of appropriate standards is necessary.

THE SADC QUALIFICATIONS FRAMEWORK

In the late 1980s the idea of a National Qualifications Framework emerged in the UK. Such a framework would measure qualification levels in terms of outcomes achieved, without prescribing learning pathways or programmes. Level descriptors were defined to determine the level at which a qualification should be pegged. South Africa, along with Australia and New Zealand, among others, embraced this thinking and South Africa was the first country in Africa to develop a National Qualifications Framework. Initially launched with eight levels, the framework was expanded to 10 levels covering all major exit levels from early secondary school to the award of a doctorate as follows:

- General certificate
- Elementary certificate
- Intermediate certificate
- National certificate
- Higher Certificate
- Diploma
- Bachelor's degree
- Bachelor Honours degree
- Master's degree
- Doctoral degree

In SADC, a committee known as the Technical Committee on Certification and Accreditation (TCCA) was constituted to:

- Facilitate mutual recognition of qualifications in all Member States
- Harmonise qualifications wherever possible
- Promote the transfer of credits within and among Member States, and even beyond, to facilitate the mobility of students, teachers and lecturers
- Create SADC regional standards where appropriate.

THE SADCQF

Emerging from the work of the committee, a regional qualification framework has been launched, known at the SADC Qualifications Framework (SADCQF) which countries are called upon to use for developing their own qualifications frameworks. The descriptors consider knowledge, skills, autonomy and responsibility.

All SADC countries have committed to developing frameworks and have progressed to a greater or lesser degree to date, using a 10-level framework, guided by the SADCQF. There is concern, however, that the lower levels are lower than those defined in the qualification frameworks of countries who have been using this approach for some time. It has also been found that the complexity of subjects at the school leaving level varies which poses a challenge when considering tertiary education entrance criteria. The TCCA still has much work ahead to ensure that different level descriptors per country are understood and aligned.

The descriptors consider knowledge, skills, autonomy and responsibility. The levels under discussion in this study are Levels 6 to 8, where:

- **Level 6** relates to the **engineering technician** who is expected to have specialist knowledge in a wide range of technical subjects and must be able to manage processes and personnel.
- **Level 7** relates to the **engineering technologist** who is expected to understand the principles relating to specialist areas, solve problems and design and manage processes and personnel.
- **Level 8** relates to the **engineer** who is expected to understand the principles relating to the entire discipline, be able to think critically, conceptualise and develop original solutions, and prepare strategic plans, taking complete accountability for the management of resources and the supervision of others.

QUALITY ASSURANCE AUTHORITIES

Each country has committed to set up a quality assurance authority to develop the local framework and take responsibility for assessing the levels of qualifications offered and ensuring that the standard of qualifications at each level is maintained, through various assurance methods.

Quality assurance authorities have been set up as stand-alone statutory bodies in several countries, while in other countries, assurance is handled through the ministries of education. In assessing and accrediting qualifications, many countries call on associated professional or industry bodies to participate in assessments, or to handle assessments formally on their behalf, as it would not be practical to build a set of expertise for each qualification within the assurance authority or body. In South Africa, three statutory bodies, covering general education, occupational qualifications and higher education, have been set up to handle the accreditation of qualifications which must satisfy level descriptors set by the South African Qualifications Authority (SAQA).

INTERNATIONAL STANDARDS

Ensuring substantial equivalence of standards for each of these stages in each country presents a challenge. For instance, is an engineering degree in one country equivalent to an engineering degree in another country, or does professional registration in one country demand the same level of problem-solving and complexity of work as in another?

TERTIARY EDUCATION

Recognising the challenges of qualification equivalence, several international best practice standards have been developed.

International Engineering Alliance (IEA)

Several countries agreed in 1989 to work towards aligning and accrediting engineering qualifications and to recognise their equivalence in signatory countries. The first agreement, known as the Washington Accord, was focused on the content and outcomes of engineering degrees, and has made a considerable impact in improving engineering education. Two further accords have been signed, known as the Sydney and Dublin Accords, which recognise the substantial equivalence of engineering technologist and engineering technician qualifications respectively.

The cornerstone of the agreements has been the development of agreed graduate attributes, which students must achieve when exiting each programme. Assessment of qualification equivalence requires the assessment of the programme design, the resources committed to the programme, the teaching and learning process, and of the student experience and results, including confirmation that the graduate attributes have been satisfied.

The theoretical requirement for each Accord is defined as follows:

- **Dublin Accord (Technician):** A descriptive, formula-based understanding of the natural sciences and a procedural understanding of mathematics, numerical analysis and statistics applicable to the subdiscipline.
- **Sydney Accord (Technologist):** A systematic, theory-based understanding of the natural sciences and a conceptually based understanding of mathematics, numerical analysis, statistics and aspects of computer and information science to support analysis and use of models applicable to the subdiscipline.
- **Washington Accord (Engineer):** A systematic, theory-based understanding of the natural sciences and a conceptually based understanding of mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modelling applicable to the discipline.

These reflect those of the SADCQF descriptors for levels 6 to 8, although there is some concern that the SADC level 6 requirements may not be as demanding as those defined in the Dublin Accord.

Rather than accrediting institutions, the approach is to accredit each qualification offered by an institution. It is conceivable that one discipline could be well resourced, and another not. There are rigorous rules in terms of accreditation to retain recognition, including reviews every five years by local reviewers, and reviews of one or more qualifications per country every six years by an international team of experts selected through the accreditation committees of the IEA.

By 2016, registering or professional bodies in Australia, Canada, Ireland, New Zealand, the United Kingdom, the United States, Hong Kong, South Africa, Japan, Singapore, Korea, China, Malaysia, Sri Lanka, India, Turkey and Russia had become recognised accrediting bodies, and several more, mostly from South-East Asia and Latin America, hold provisional status, while others, including Mauritius, are working towards provisional status.

Being the only signatory to the Accords in Africa, the Engineering Council of South Africa (ECSA) has been assisting higher education institutions (HEIs) in the region with assessments and recommending areas in which they need to strengthen their programmes to achieve recognition under the Accords.

European Network for Accreditation of Engineering Education (ENAEE)

The ENAEE is the European network which authorises accreditation and quality assurance agencies to award the EUR-ACE® label to accredited engineering degree programmes.

As with the IEA, a set of standards and guidelines for accreditation of engineering programmes covering student workload requirements, programme outcomes and programme management and resourcing are specified to ensure that quality programmes are offered. In the case of the ENAEE, only Licentiates and Master’s degrees are considered.

Registering bodies in the United Kingdom, Ireland, Austria, Belgium, France, Germany, Italy, Portugal, Spain, Switzerland, Denmark, Finland, Russia, Turkey, Romania, Poland, Slovakia and Kazakhstan have become authorised agencies able to award the EUR-ACE® label, while several others are associate members working towards full membership.

Best Practice in the accreditation of engineering programmes

In 2015, the ENAEE and the IEA agreed to develop jointly a Best Practice document. It serves both the ENAEE and the IEA in their ongoing operations and is of interest to bodies that are either forming new agencies or developing accreditation systems to the level required by either EUR-ACE® or the IEA Accords.

This is a significant achievement as it represents the agreement and common understanding of best practice in engineering accreditation by the 26 countries/accreditation agencies involved in the two organisations worldwide.

Conseil Africain et Malgache pour l'Enseignement Supérieur (CAMES)

CAMES (African And Malagasy Council for Higher Education) was formed soon after the independence of several French-speaking African states to address harmonisation of curricula, enhance mutual recognition of higher education qualifications and promote professional and student mobility between its members. The CAMES guidelines cover all qualifications, not just engineering.

Currently, CAMES member countries are Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, DRC, Gabon, Guinea, Guinea-Bissau, Equatorial Guinea, Ivory Coast, Madagascar, Mali, Niger, Rwanda, Senegal and Togo.

The Institut Supérieur de Technologie d'Antananarivo (IST-T) in Madagascar was delighted to have its accreditation renewed in January 2017.

A SADC Accord?

The disparity in engineering qualifications in the SADC region requires attention. Consideration needs to be given to using the guidelines developed by these bodies to set milestones for tertiary education institutions to work towards ensuring that their qualifications are eventually on par with international best practice.

It is critical that engineering degrees produce graduates who are able to solve problems and become the specialists and strategic thinkers of the future. For too long has it been necessary to harness international expertise to solve complex problems. Professor Clive Chirwa from the Copperbelt University in Zambian, among others, has recognised this need. He has expressed concerns that Zambian engineers were maintenance engineers and not innovative. He called upon them to move to a '… *higher level of excellence*' and come up with '… *the solution to whatever problems that this nation may have*'. It is important that local engineers should solve local problems, as often international service providers have come up with solutions that do not recognise the African context or needs.

Cost of accreditation and quality assurance

Alignment with tried and tested international standards is something for which the region should strive. However, substantial funding needs to be set aside, not only for supporting all institutions to enhance their offerings, but also to fund ongoing accreditation and quality assurance activities.

In a review of engineering education in Zambia it was recognised that there were neither robust accreditation nor adequate quality assurance processes in place, with one of the main reasons being the prohibitive cost of bringing external examiners from universities outside Africa.

It will be necessary to build regional accreditation and quality assurance teams.

PROFESSIONAL REGISTRATION

Worldwide, different measures have been put in place to determine when an engineering graduate is ready for professional registration.

Before listing and evaluating these approaches, it is necessary to consider briefly the need for registration. The intention is to recognise those who have achieved the competence to work as independent practitioners, able to analyse needs and develop sustainable solutions in the interests of public health and safety, among other considerations. This requires more than knowing the theory. It requires that graduates have learnt to apply their undergraduate theory in the context of engineering problem-solving.

In 1956, Dr Benjamin Bloom, an educational psychologist, developed a taxonomy to promote higher forms of thinking, such as analysing and evaluating, rather than just remembering. His original model has been modified to be more relevant to today's action learning approaches, but nevertheless captures the abilities that engineering professionals should develop. They are, in the context of engineering problem-solving:

- **Remember:** Recall facts and basic concepts previously learned.
- **Understand:** Comprehend and be able to explain the meaning of lessons and concepts.
- **Apply:** Use what was learned in the classroom in new situations in the workplace.
- **Analyse:** Examine something in detail, considering all the facts, variables and inferences, to discover more about it.
- **Evaluate:** Make judgement calls about options, needs, impacts and appropriate solutions.
- **Create:** Develop a sustainable solution unique to the situation.

Developing from a novice graduate to a competent professional takes time and support. The support suggested and the progression are described in Table 4 (published in the ECSA *Training and Mentoring Guide for Professional Categories* (see www.ecsa.co.za)).

Readiness for professional registration should test levels of thinking in Bloom's Taxonomy and the level of responsibility assumed when solving complex engineering problems.

Approaches to registration worldwide include:

- **Recognition of an accredited qualification** which allows graduates to operate independently as long as they have completed an engineering qualification accredited by the registering body. This approach does not ensure that graduates have gained meaningful practical experience under the guidance of seasoned professionals. It either results in graduates limiting themselves to simple projects and not developing to their full potential, or in graduates taking on work for which they are not sufficiently experienced, with the associated risk of developing unsafe or costly solutions.
- **Set time to registration** which allows graduates to register professionally after completing a specified number of years in the workplace. This does not measure the range or complexity of experience gained, or the level of responsibility taken.
- **Professional exam** which generally has the disadvantage of testing more theory along the lines of undergraduate exams and the graduate's ability to perform processes, rather than assessing his or her critical thinking and problem-solving abilities. In cases where the professional exam is a day-long applied exam requiring graduates to complete a detailed design or develop a solution, results are generally low, as the range of design questions set in the exams are generally too limited to cover the range of the types of project on which graduates may have been involved.
- **Professional report and peer interview** which is a competence-based assessment that allows reviewers to determine the range and complexity of work undertaken and the ability to solve problems and take responsibility.

Several of the above do not test the development of all the Bloom's levels of thinking. The final registration assessment model as listed above is the most reliable approach, as reviewers can be matched to the subdiscipline areas in which graduates have practised and can test that they have mastered problem-solving and decision-making in these areas. This approach should be adopted as a standard in the region.

International Engineering Alliance (IEA)

The IEA also considers registration alignment. Over and above the Accords, it has developed agreements to ensure alignment of competency standards and equivalence of the level of practice for professional

Table 4: Increasing responsibility levels assumed during graduate development and training
(Source: ECSA R-04-P)

LEVEL	Nature of candidate work	Responsibility of candidate	Level of supervisor/ mentor support
A. Being exposed	Undergoes induction, observes work of competent practitioners	No responsibility	Mentor explains challenges and forms of solution
B. Assisting	Performs specific processes under close supervision	Limited responsibility for work output	Supervisor/mentor coaches, offers feedback
C. Participating	Performs specific processes as directed with limited supervision	Full responsibility for supervised work	Supervisor progressively reduces support
D. Contributing	Performs specific work with detailed approval of work outputs	Full responsibility to supervisor for immediate quality of work	Candidate articulates own reasoning and compares it with those of supervisor
E. Performing (responsible but not accountable)	Works in a team without supervision, recommends work outputs	Responsibility to supervisor is appropriate to a registered person	Candidate takes on problem-solving without support, at most limited guidance

registration, based on experience, the complexity of work and responsibility carried. These agreements are known as the:

- International Professional Engineers Agreement (IPEA)
- International Engineering Technologists Agreement (IETA)
- Agreement for International Engineering Technicians (AIET)
- Asia-Pacific Economic Cooperation (APEC) agreement, which is in place with a number of Asia-Pacific countries for purposes of recognising the 'substantial equivalence' of professional competence in engineering in those countries.

International Registers have been set up for engineers and technologists. These are known as the International Professional Engineers Register (IPER) and the International Register of Professional Engineering Technologists (IRPET). Each signatory country manages its part of the register. The requirements are more stringent than professional registration, requiring at least seven years of experience after graduation, and having had at least two years in responsible charge of engineering work. Applicants must hold an accredited engineering qualification, must be professionally registered in their home country and must demonstrate that they are keeping up to date through CPD activities. The postnominals for the international engineer and technologist are Int PE and Int ET respectively.

Registration on the registers ensures that professionals can have their professional standing recognised by signatory countries, thereby contributing to the globalisation of professional engineering services. This is of particular benefit to organisations that are providing services in many countries, but it also adds value to individuals who may wish, at some stage, to work outside their country.

European Federation of National Engineering Associations (FEANI)

FEANI is a federation of professional engineers that unites national engineering associations from 34 European Higher Education Area (EHEA) countries. It is striving for a single voice for the engineering profession in Europe and wants to affirm and develop the professional identity of engineers.

FEANI has defined a quality professional title 'European Engineer' (EUR-ING) for professional engineers based on a sound education and assessed professional experience. The FEANI proprietary professional title is a *de facto* quality standard recognised in Europe and worldwide, and particularly in those countries that do not regulate the profession.

FEANI uses a competence standard to assess applicants which is very similar to the competences expected by the frameworks of the IEA. A comprehensive written submission is required outlining experience, and rigorous assessments take place against the competences required. The standard applies only to engineers.

THE SADC IMPERATIVE

In SADC, considering the number of regional projects in which multinational engineering teams need to participate, it is important that education and professional practice standards are aligned to allow articulation and mobility throughout the region. The region should set its sights on attaining the standards developed by the IEA for each category of engineering.

Chapter 4

The flow of skills

It is often assumed that self-regulation mechanisms in a market economy ensure the necessary supply to the labour market, but there is evidence of this not being the case in the SADC region. Experienced engineering professionals are reported to be in short supply and vacancies exist in many public sector structures. At the same time, reports indicate that engineering graduates are unable to find employment, leading to the growing phenomenon of the 'unemployed graduate'.

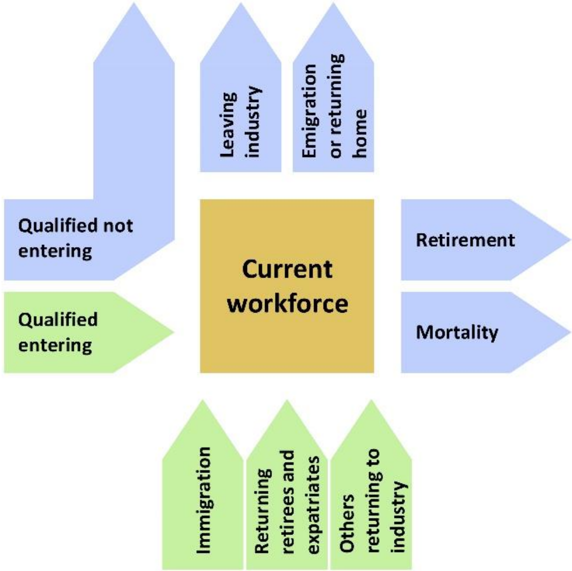

Figure 13: The flow of skills
(Acknowledgement: IMechE. Demand and supply of engineers in the UK)

To understand and address the mismatch, overall data on demand and supply is required. Adequate data on the demand for and supply of skills in the region is not available and a combination of approaches has been adopted to build a picture of the current engineering skills base, and the future potential capacity and requirements. Figure 13 captures the flow of skills. The current workforce is not static, but rather reduces over time as people exit the workforce for various reasons, and others enter. Given that there is ongoing growth, methods of increasing the inflow need to be considered to grow the workforce on an ongoing basis. To build a comprehensive picture, economic growth, demand, and current and future supply must be understood.

ECONOMIC GROWTH AND DEMAND

Despite many grand plans, SADC countries have not succeeded in achieving the growth targets considered necessary to address poverty and inequality. As shown in Figure 14 few countries had achieved the SADC target of 7% by 2010.

Growth to 2015 improved, but 2016 saw a drop in several countries, as shown in Table 5. Projections to 2023 estimated by the IMF show a positive movement in many countries.

Conventional wisdom suggests that economic growth creates more job opportunities and will address unemployment. The difficulty, however, is determining the magnitude of employment opportunities.

It is important for growth to occur in sectors that have the potential to absorb labour on a large scale. Some sectors and activities are more employment-intensive than others, such as manufacturing and construction.

The impact of GDP growth on employment in agriculture is found to be limited as growth often has more to do with improvement in productivity than

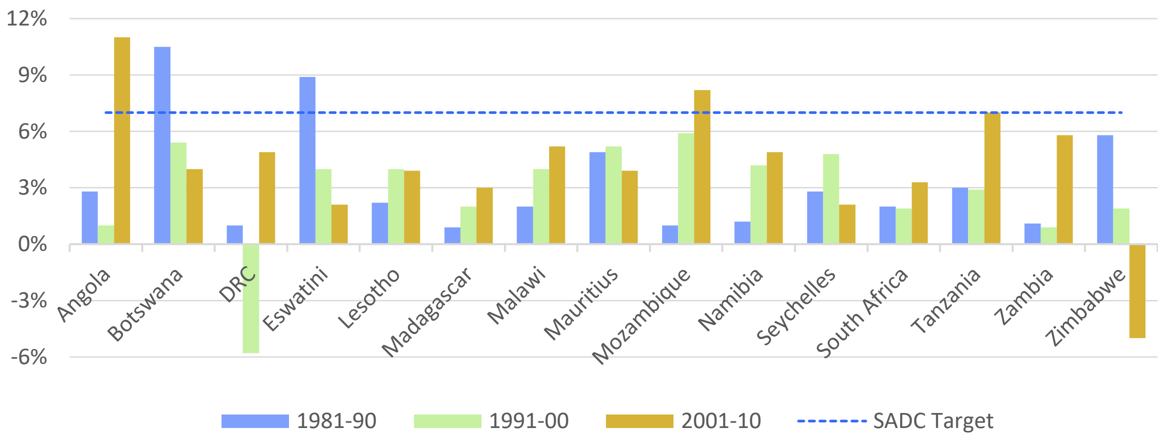

Figure 14: Real GDP growth rate in SADC countries
(Source: IMF, 2015)

employment. The agro-processing sector, however, has a relatively larger impact on employment. Furthermore, when economic conditions improve, companies often invest more in technology than in taking on an increasing number of employees, or they extend the working hours of existing staff as a low-risk approach to coping with growth.

A study carried out by Khan in 16 developing countries showed that no country's employment growth equalled its economic growth. He found the elasticity of employment with respect to GDP growth to be 0.7. Another study showed that for every 1% of GDP growth, total employment grew between 0.3 and 0.38 percentage points.

Data from the International Labour Organisation (ILO) and the World Bank suggest that elasticity ratios in the SADC region range from 0.2 in Mozambique and Lesotho to 1.6 in Madagascar. However, the ratio in most SADC countries is between 0.3 and 0.7, with an average of 0.48. Given the focus on industrialisation and growing the manufacturing sector, an elasticity ratio of 0.7 has been used for projections in this study, i.e. for a projected growth in GDP of 5%, an increase of 3.5% is included for the growth in the number of engineering skills required in the workforce.

According to the AfDB, 0.7 represents the desirable value for developing countries and is based on the elasticity in the Republic of Korea during the 1970s, when the country had a level of development and resource endowment comparable to that of some African countries.

EXPANSION DEMAND

Expansion demand refers to the increasing demand required to accommodate growth. To estimate expansion demand, the current number in the workforce is used and projections are based on percentage growth recorded in 2017. A second projection that could be used to estimate expansion demand is the growth projections suggested by the IMF for 2018 to 2023. A third set of expansion demand projections could be based on the Agenda 2063 growth projections of 6% from 2015 to 2020 and of 8% from 2021 to 2050. In most countries the latter growth seems unrealistic, given the limited growth that has taken place in recent years.

REPLACEMENT DEMAND – LOSSES

Replacement demand relates to replacements required in the workforce for those who are likely to retire, emigrate, change jobs or pass away. Percentages for each variable per country were established to calculate the number necessary to replace the losses.

Retirement

Retirement was calculated using the age profiles from 25 to 65 per country, and assuming that the age group over 65 had retired.

Migration

Net migration is the difference between the number of persons entering and leaving a country during the year per 1 000 persons (based on the mid-year population). An excess of persons entering the country is referred to as 'net immigration' and was added to the gains (discussed under *Supply*). An excess of persons leaving the country is referred to as

Table 5: Summary of percentage economic growth in SADC 2012 to 2023

COUNTRY	Actual growth						Projected growth						
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2018 - 2023
Angola	5.2	6.8	4.8	3.5	3.5	-2.5	-0.1	3.1	3.2	3.2	3.7	3.8	2.8
Botswana	4.5	11.3	4.1	-1.7	4.3	2.4	4.6	3.6	4	4.1	4.2	5.5	4.3
DRC	7.1	8.5	9.2	9.2	8.5	3.4	3.8	4.1	4.3	4.4	4.6	4.7	4.3
Eswatini	3.5	4.8	3.6	1.1	0	1.6	1.3	0.4	0.4	0.4	1.6	2	1.0
Lesotho	4.9	2.2	2.2	3	2.5	-1.6	0.8	1.2	1.1	4.8	4.3	1.3	2.3
Madagascar	3	2.3	3.3	3.1	4.1	4.2	5	5.4	5.3	5.2	4.9	4.9	5.1
Malawi	1.9	5.2	5.7	3	4.5	4	3.3	4.7	5	5.5	6	6.5	5.2
Mauritius	3.2	3.2	3.6	3.4	3.8	3.8	3.9	4	4	4	4	4	4.0
Mozambique	7.2	7.1	7.4	6.6	3.8	3.7	3.5	4	4	4	4	11.1	5.1
Namibia	5.1	5.1	4.5	4.8	5	-0.8	1.1	3.1	3.7	3.4	3.3	3.4	3.0
Seychelles	3.7	6	4.5	5	4.5	5.3	3.6	3.3	3.3	4.1	4	3.3	3.6
South Africa	2.2	2.5	1.7	1.3	0.3	1.3	0.8	1.4	1.7	1.8	1.8	1.8	1.6
Tanzania	5.1	7.1	7	7	7.1	6	5.8	6.6	6.6	6.4	6.4	6.4	6.4
Zambia	6.8	6.7	5.6	5.6	6.2	3.4	3.8	4.5	4.5	4.5	4.5	4.5	4.4
Zimbabwe	10.6	3.3	3.1	3.2	3.9	3.7	3.6	4.2	4.7	4.8	5	5	4.6

'net emigration' and was added to the losses. Migration statistics from the United Nation's Population database were used. The sources used are detailed in Chapter 5, under *Demographics and the economy*.

Mortality

Mortality rates for the age profiles from 25 to 65 per country were used.

Leaving the industry

There are no studies giving an indication of the rate at which professionals leave the industry. This tends to vary, depending on the state of the economy. Alumni research gathered from a number of South African universities, and anecdotal evidence from 30- and 40-year graduate reunions, suggests that some 0.5%, on average, per year have left their original field and have moved into other industries.

The number required to replace those no longer in the industry is the total of the above four factors which must be accommodated by way of additional supply coming into the industry.

SUPPLY

Supply is made up of the current workforce and, in time, those entering the industry from various sources, namely tertiary education, nationals returning from overseas, retirees re-entering the industry, those returning who had previously left the industry and net immigration as discussed under *Migration*.

THE WORKFORCE

Determining the number in the workforce was not a trivial exercise. Theoretically, each country's Labour Force Survey should provide this data, but only in South Africa and the Seychelles was it possible to extract data down to occupation level. That being so, the sample used for carrying out labour force surveys is very small, and the Seychelles National Bureau of Statistics warned that using values down to occupation level was not exact but would offer an indication. Data from three years of the South African Quarterly Labour Force Surveys (QLFS) was used to give an average, as data varies significantly from quarter to quarter, depending on the locality of the sample.

All other countries simply show the total number employed under the major occupational groups, namely:

- Legislators, senior officials & managers
- Professionals
- Technicians & associated professionals
- Clerks
- Service workers, shops & market sales workers
- Skilled agricultural & fishery workers
- Craft & related trades workers
- Plant & machine operators & assemblers
- Elementary occupations
- Armed forces

Each category covers many other disciplines such as medical, teaching, legal, financial and religion in the case of professions, and the range of technicians covers not only engineering technicians but hairdressing, catering and entertainment technicians, among others. It was thus necessary to work with the engineering institutions and associations in each country to understand the make-up of their membership and solicit an estimate of the percentage of engineering practitioners they represented. Where there were several such bodies in a country, comfort was found when several estimates agreed.

Some countries, notably Namibia and Botswana, had carried out detailed research in the past few years, which was used to provide a more accurate picture. In other countries, it was necessary to try to establish the total workforce by gathering data from the major employers such as water, electricity, transport and telecommunication utilities, and major manufacturing companies and mining houses.

Where regulations existed for construction and consulting companies to be registered, it was possible to estimate the number of engineering practitioners in the construction sector using the company category and associated criteria.

The numbers in the workforce for all countries are estimates. The only way to be sure of the numbers is to carry out a complete census of all engineering sectors and employers per country. Botswana, harnessing a large team of students, has carried out such an exercise, which has given a good idea of the spread of disciplines per sector. With a relatively small population, and industry and government located mainly in Gaborone and a few smaller centres, this was possible. In countries with large populations, several major centres and large manufacturing sectors, this would be a huge task.

As national labour force and household surveys do not gather data down to the level required, alternative methods of accurately determining the active labour force need to be considered. An option could be to expand online personal tax return systems to ask tax payers for comprehensive occupation data. This would offer an annual snapshot of the employment of all who are in formal employment.

TERTIARY EDUCATION

It was necessary to establish the total number graduating each year and the numbers projected from newly opened private institutions or new courses being offered by existing universities. This task proved extremely difficult as only South Africa and Mozambique could provide the full sets of data for the period in question from central management systems. It is still not certain whether every institution per country offering engineering qualifications matching the scope of this study has been identified. A list of institutions and the numbers qualifying in 2015 is included in each country report.

Where large numbers of students were known to graduate in other countries and return to their home countries as part of their bursary contracts, they were included in the graduate inflow estimates. This data was not always forthcoming. In many instances returning graduates could not find work as their foreign qualifications were not recognised, hence the inflow figures are an estimate at best.

Graduates joining the workforce are gains but, in time, some may also be lost to the industry as noted in the discussion above, choosing to move to other sectors or to emigrate. A similar allowance has been made for losses in this group each year, but the loss has been subtracted from each year's student inflow.

GAINS – THOSE RETURNING TO THE INDUSTRY OR IMMIGRATING

A small percentage allowance was included in the overall supply estimate to allow for those:

- **Returning from other industries** who, for example, had left when construction was quiet, but returned when the industry picked up
- **Returning nationals** who, for example, may have worked on contracts abroad and returned when their contracts ended, or when local development opportunities became more attractive
- **Retirees** who were encouraged to stay on or return to the workforce for a period.

Migration was also considered as a gain when net migration was positive.

The handling of inflows from foreign countries on major contracts is very variable. Some countries insist that all engineering staff entering the country must seek temporary registration, others insist on full registration and others do not make any demands on foreign companies working locally. Hence, it could be that the workforce in some countries is higher than estimated, as there may be large groups of foreign engineering practitioners working on large contracts.

IDENTIFYING THE GAP(S)

Determining skills requirements is not a once-off exercise, but rather requires ongoing attention to the needs and a long-term view of the flow of skills. Figure 15 shows the philosophy adopted for determining the actions that need to be taken to ensure long-term supply. The elements are as follows:

- **2018 workforce** is the workforce in place at the end of 2017, shown as the orange bar, and which will reduce over the years as people leave.
- **Accumulated losses** from the 2018 workforce are shown in red, below the axis. These take retirement, mortality, those leaving the industry and net migration into account.
- **Graduates** represents those graduating who are available to enter the workplace. Only the inflow from degree courses and national diplomas are shown. Those completing post-graduate qualifications such as a BTech, Higher National Diploma or similar are not included as they do not represent additional entrants into the workforce, but rather existing capacity with post-graduate qualifications. In countries where the technologist qualification is a stand-alone qualification and does not follow the diploma, a third inflow of technologists or incorporated engineers is shown. In Angola and Mozambique, only engineers were analysed as these countries do not train technicians and technologists in a manner equivalent to the categories in this study. The model assumes a 2% increase in graduations per annum. It should be noted that in several tertiary education institutions, graduations have more than doubled since 2015. As a result, the oversupply of graduates may be higher than reflected in the flow models for some countries.
- **Accumulated gains** cover an allowance made for those returning to the industry from retirement or having been out of the local industry for a period and the net migration if positive.
- **Demand based on the 2017 GDP growth rate** is the blue dotted line, which suggests the increase that should take place to 2035 based on 2017 growth.
- **Demand based on the 2018–2023 GDP projected growth rate** is the green dotted line,

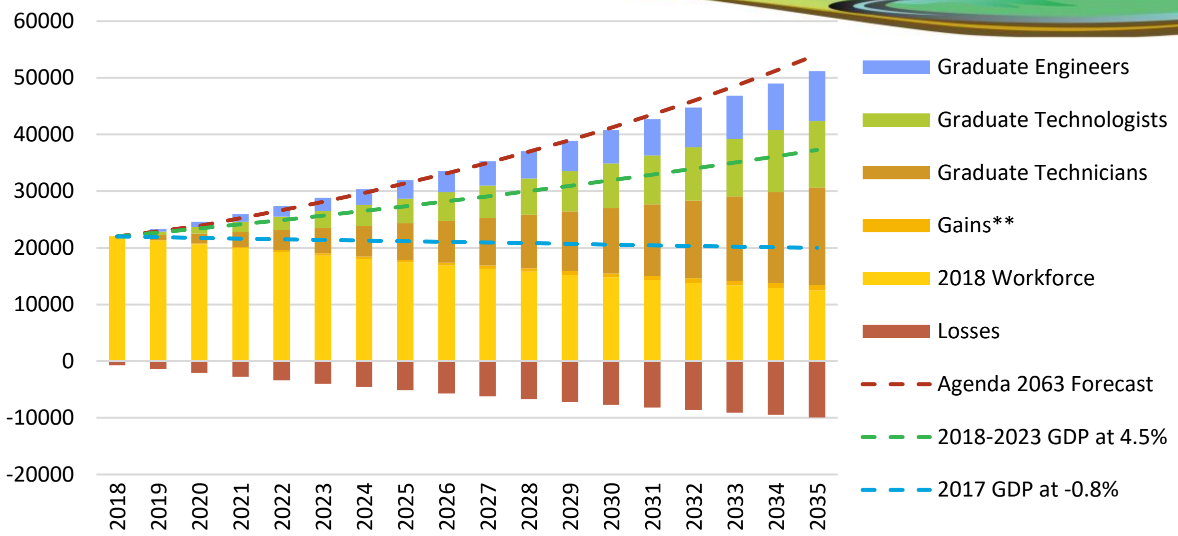

Figure 15: The projected flow of skills

which suggests the increase that should take place to 2035 based on the projected average growth for 2018–2023.

- **Demand based on the Agenda 2063 growth rate** is the red dotted line, which suggests the increase that should take place to 2035 based on the projected growth rates for Vision 2063, namely 6% to 2020 and 8% thereafter.

From Figure 15[1] it can be seen that if the graduate growth rate remains at 2%, the number of graduates coming into the system will exceed the demand, if the GDP growth is only 4.5% for the 2018-2023 period. If, however, Agenda 2063 growth can be achieved, the flow of graduates and gains will be slightly below demand by 2032.

Some countries advise that they currently require several thousand more engineering practitioners. Projections should therefore not be based on the current workforce, but on the number required at present to determine how many years it will take to achieve the desired number. Figure 16 shows a modified model assuming that the hypothetical country required 30 000 in the workforce. If increasing graduations alone are relied on, then the deficit will have been addressed by 2024 if there is no increase in demand. However, as the number required should also increase at the growth rate, the demand will only be met by 2034.

If aggressive targets are set for increased graduations, then dedicated capacity for the training of incoming graduates will be required, as the ratio

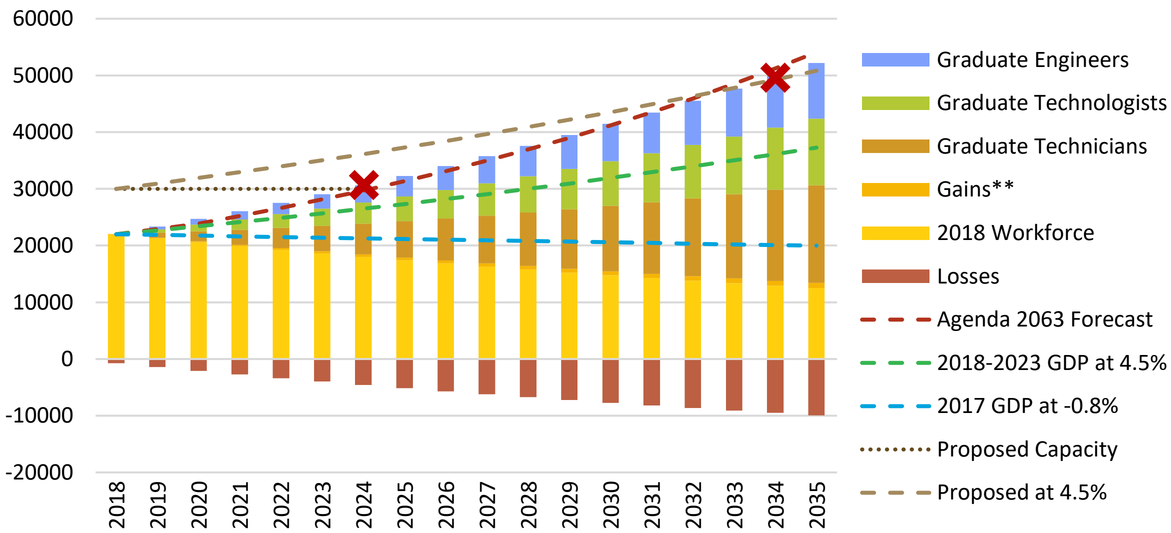

Figure 16: The projected flow of skills considering a specific target

[1]The skills flow diagram in this format was conceptualised by Allyson Lawless and Henk Langenhoven for the 2005 publication, *Numbers and Needs: Addressing imbalances in the civil engineering profession.*

of junior staff to the existing workforce will be high. Few countries have achieved growth rates of the order suggested in Agenda 2063, and countries are cautioned not to develop large numbers of engineering graduates without adequate investment in projects on which to train them.

All country models have been generated assuming the current workforce as the base for projections. Should countries already have a sense of the additional numbers that they can absorb immediately, then they should superimpose the projected growth line on the existing model to determine the year by which graduations would have addressed the shortfall. If this is found to be many years in the future, consideration needs to be given to purposefully selecting and appointing expatriates to assist with current strategic and development requirements, but understudies must be identified and assigned to such experts to be coached so that they are ultimately able to take over the work carried out by expatriates.

In South Africa in the 1960s and 1970s when there was huge investment in economic infrastructure, a conscious effort was made to source expert project developers worldwide in parallel with increasing the graduation rates and training graduates on all the large projects. The engineers retiring at present are those who were absorbed and trained on the large projects. Ghana also made a conscious effort to train local graduates on the Volta Dam project in the early 1960s, after which the number of Ghanaian engineers grew steadily.

Considering the need to increase the number in industry by 3% to 5% per year for growth, and to accommodate replacement demand of some 2% to 3%, suggests that graduations should be around 5% to 8% of the workforce per year, up to a maximum of 10% in countries experiencing high growth.

In the model shown in Figure 15 the number graduating each year represents 7% of the workforce, which is a reasonable number to absorb. In some countries the model looks completely different and there are insufficient tertiary education programmes in place to address the demand. Graduation percentages of only 3-4% imply that an increase in the number of graduates is required. In these cases, until more programmes are put in place, the other options under *Gains* need to be considered, including use of retired personnel, increasing immigration and funding students to study outside the country etc.

In other countries, the percentage of graduates to workforce has reached as high as 30%. In these cases, graduates complain of not being able to find work, and industry complains of pressure to employ many more graduates than they can absorb, based on the availability of work.

Chapter 5

Research approach

To determine the numbers and needs required a detailed approach. The research harnessed several methods using qualitative and quantitative research techniques. This was necessary to triangulate input and results in order to ensure the reliability of the final numbers and recommendations.

RESEARCH PROCESS

The research phases were planned as shown in Figure 17. Although it was expected that they would be sequential, delays in receiving data, and ideas gathered after interaction with stakeholders in the first six months resulted in several changes of approach, which are discussed under the phase headings.

Phase 1 System Design

- Identify engineering sectors
- Identify stakeholders
- Identify major datasets
- Design questionnaires
- Develop communication platform

Phase 2 Research

- Desktop research
- Analysis of existing datasets
- Stakeholder engagement
- Workshops and conferences
- Gather data

Phase 3 Analysis

- Analyse data
- Interpret trends
- Develop the report

Phase 4 Review

- Stakeholder input
- Validation workshop
- Receive final data

Phase 5 Finalise Report

- Finalise report
- Present findings
- Handover

Figure 17: The research process

PHASE 1 – DESIGN

During this phase several activities took place.

Identifying engineering sectors

The engineering sectors in which engineering practitioners are employed needed to be identified. With the help of the South African Sector Education and Training Authorities (SETAs) responsible for the funding and developing of skills, it was possible, by analysing their data, to determine the many sectors in which engineering practitioners were employed. Although they are found in the financial sector and other sectors not directly linked to engineering, the majority of engineering practitioners were employed in agriculture; construction; energy, gas and water; manufacturing; mining; and the transport and telecommunications sectors. These sectors were used as the major themes for research, although tourism and the Blue Economy were later added for the island states.

Identifying stakeholders

It was necessary to decide on the major stakeholders with whom to engage. Voluntary associations, registering bodies and major employers in both the public and private sectors were recognised as being important, and a substantial database for the entire region was developed.

Identifying major datasets

Over and above the datasets to be collected from stakeholders, many national sets of data needed to be accessed. These included labour force surveys, economic data, migration, and mortality and age data to determine gains to and losses from the workforce. It was also necessary to understand the engineering services currently supplied, the targets to be achieved and the projects planned. Sources of graduation data were also investigated, but very little data was available in central systems and it needed to be accessed from each tertiary education institution offering engineering qualifications. Data from voluntary associations and registering bodies was also requested, but data structures varied considerably.

Designing questionnaires

Once an understanding of the sectors to be interrogated and the data available had been established, questionnaires in English, French and Portuguese were developed to elicit further data. These covered:

- **Tertiary education institutions** to offer graduation data, gender and nationality of students, details of the qualifications offered and information on staffing and vacancies
- **Organisations** to understand the number employed per sector, training offered, vacancies, disciplines, categories, gender, education, nationalities and growth planned
- **Voluntary Associations (VAs):** to understand the numbers, categories, gender, ages, nationalities, disciplines, and, where available, country of study and qualifications of members

- **Registering Bodies (RBs)** to understand the numbers, categories, gender, ages, nationalities and disciplines of those registered.

In some instances, the place of work was available from VAs and RBs, which was useful to get a sense of the range of sectors in which people worked and the trends in terms of registration, and membership of VAs per sector. In some instances, data from VAs and RBs also offered insight into where people had studied, with many older practitioners having studied abroad.

Results from the organisation questionnaire provided excellent triangulation in terms of tertiary education, as employers were asked to list the institutions at which most of their staff had studied, and also gave insight into in-house training taking place, mostly in the large organisations.

Developing a communication platform

To communicate with all stakeholders, establish more contacts and gather input, the website www.numbersandneeds.co.za was set up. It was also used to share information, documents and presentations, and to involve stakeholders in online surveys.

PHASE 2 – RESEARCH

The detailed research covered a long period of desktop research; analysing existing datasets; field research, including in-depth interviews with relevant stakeholders; and presentations and discussions at major industry workshops. The research activities are outlined below:

Desktop research

During the desktop research phase, data was gathered from many sources. Activities included:

- Reviewing SADC strategy documents and plans
- Reviewing national development plans, policies and strategies
- Searching for and reviewing studies per sector, per country and reports covering trends in the SADC region and Africa
- Reviewing the annual reports of ministries, utilities, major employers, VAs and registering bodies
- Reviewing economic trends and forecasts
- Searching for and reviewing education data and reports per country and in the region.

Analysing existing datasets

This covered the analysis of data sourced in Phase 1. Sadly, many labour force surveys were very out of date and did not drill down to the occupation levels required. When occupation data was available, it generally did not agree with the actual membership data received from various organisations, and little reliance could be placed on the data.

Migration proved equally difficult to determine as data is limited or not available and, where available, does not drill down to professional and specifically engineering level. Using the United Nations Population Division statistics and superimposing the views from various studies, estimates of the movement of professionals were determined.

The studies used to determine the movement of professionals included the *Southern African Migration Programme* report in which it was estimated that 10% of migrants from the SADC region and 25% from the rest of Africa had post-secondary qualifications and could be considered as professionals.

With regard to immigration and emigration, other research exercises suggest percentages which, when combined, agree roughly with the overall migration percentages estimated in the above study. They indicate that, on average, around 4% of those who immigrate to developing countries are professionals.

Sources on emigration indicate that over the period 1990 to 2009 around 16% of those who emigrated were professionals. Since 2010, 17.1% of those who emigrated from Africa had tertiary qualifications and since 2013, this has increased to 18.6%.

National and international datasets were interrogated for demographic and economic data which, when combined with the country sector studies, offered a sense of the challenges each country was facing in terms of funding and possible development. Using this information, draft reports, presentations and questions were prepared for engagement with each country.

Stakeholder engagement

All countries were visited, and many calls, Skype sessions and emails took place before and after the meetings to collect as much data and gain as much insight as possible.

During country visits, meetings were held with most infrastructure ministries, major employers, education institutions, VAs, RBs, consulting, manufacturing and mining associations, and contractor registering councils, where they existed.

As part of the preparation for each trip and meeting, the SADC introductory letter, some background information and the appropriate questionnaire were sent to allow stakeholders time to prepare for the discussions. In some cases, completed questionnaires were received at the time of meetings, and in other cases, they were submitted later.

Some stakeholders were diligent about providing the detailed data, but estimates discussed at the time of meetings have been used to develop the overall models where data was not forthcoming. In many instances, the questionnaires were not completed in full, but totals were supplied.

Many different approaches were eventually used to make contact and set up the country visits. No single approach proved to be more effective than another. The final results depended on the capabilities and willingness of the organisations that participated in the meetings and workshops. In the DRC, Angola and Tanzania, the South African Embassy assisted with making initial contacts and in the case of the latter two, the local foreign office became involved. In other countries, the SADC focal point coordinator either assisted with the names of contacts in each sector or made the appointments, while in other countries, it was necessary to contact each institution and department directly to set up appointments. The latter was the case in ten countries. In these instances, the RBs and VAs were very helpful in providing contacts.

Sadly, there are no countries from which a full set of data, covering all sectors, Professional Bodies Institutions (PBs) and tertiary education was obtained.

Workshops and conferences

The research team has attended and presented at many workshops and conferences. The presentation outlined the project and data required, and delegates were asked to engage with researchers during breaks or to download questionnaires from the website; there were many follow-up emails.

Where the nature of the event allowed audience participation, valuable input was received, and consensus was reached on various topics. Workshops or conferences in the following countries were addressed:

- Angola
- DRC
- Eswatini
- Ethiopia (attended by many SADC countries)
- Lesotho
- Malawi
- Namibia
- Seychelles
- South Africa (several local, regional and African conferences)
- Zambia

Data gathering

The gathering of data proved to be the most challenging activity. Although several sets of data are prepared each year by national statistics departments, as outlined under Phase 1 and 2, data relating to tertiary education and employment in specific sectors, down to engineering practitioner level, is not available Much engagement was therefore necessary. Engineering professionals involved in water, energy and transport were generally to be found in the public sector. Information for the other sectors needed to be established by engaging with the private sector.

- **Tertiary education:** Centrally managed graduation data from ministries of education was only available from South Africa (2000 to present), Angola (2013 to 2015), Mozambique (2005 to 2015, although 2015 appeared to be incomplete) and Madagascar (2014). The Ministère de l'Enseignement Supérieur et Universitaire in the DRC gathered data for the study for the period 2013 to 2017. In all other countries, it was necessary to contact each tertiary institution offering engineering qualifications. The study commenced in the first half of 2017, when education data had only been audited and published officially to the end of 2015, hence the decision to gather data from 2005 to 2015. However, with the difficulty in collecting data, the project took substantially longer than expected, but time did not permit contacting all tertiary institutions again to gather data to 2017. Anecdotally, graduations have continued to increase since 2015.
- **Professional bodies (PBs):** While most countries had VAs, several countries did not have registering bodies. Most countries made data available from their databases, but some did not have comprehensive data. For instance, some institutions did not have gender information, while others did not have nationality, age or discipline data. Data was received from all countries, but in some cases the detail available or the sample size was inadequate for the data to be meaningful.

- **The public sector:** It was hoped that full sets of data from infrastructure ministries would be available. However, the inadequacy of data structures or, in some cases, lack of cooperation, resulted in gaps in the data in all countries. Profiles of neighbouring countries of similar sizes and economic activities were used to estimate numbers.
- **Agriculture:** Very few countries have VAs in this sector, making it difficult to determine the number of agricultural engineering practitioners. Where a sense of the number was available, it was still not possible to determine how many were working in agriculture and how many had moved to other sectors. Furthermore, many other disciplines are involved in the sector, as discussed in Chapter 2. The number shown in most countries is a rough estimate at best. In the French-speaking and Portuguese-speaking countries, the training of agricultural engineers includes substantially more agricultural science than in English-speaking countries. There are large numbers of agronomic engineers covering animal husbandry and nutrition; crop production; plant, soil, environmental protection and water resource management; horticulture; and agricultural management and marketing. Data from agronomist VAs in these countries was available.
- **Construction:** In most countries it is a requirement for contractors to register with a construction council or with the Ministry of Public Works or similar, most of which made contractor data available, although few could estimate the number of engineering practitioners. Contractors are graded according to their capabilities and experience. Considering the criteria and the number of contractors per grade, it was possible in many countries to estimate the number of engineering practitioners in the sector. However, contractors do not always retain the number stated once they have been registered, hence the numbers may be overstated in some countries.
- **Consulting:** Many associations of consulting engineers were able to make data available or to estimate the number of engineering practitioners based on their member organisations. In those countries with no associations, estimates were developed when engaging with the major consulting firms.
- **Manufacturing:** Manufacturing data was the most difficult of all to gather, as associations of manufacturing in each country were focused on providing corporate, marketing and export support to their member companies. Information relating to engineers is not collected by any of these organisations. In some countries, major manufacturing companies such as breweries, confectioners and food manufacturers provided details on their considerable engineering workforces and assisted with estimates of the numbers likely to be employed by manufacturers. Values are therefore an estimate at best. In South Africa, data from the SETAs, the QLFS and online surveys allowed a slightly more accurate estimate to be determined, but it is still only an estimate.
- **Mining:** The Chambers of Mines in each country represent the interests of their member companies and, as with manufacturing, they do not collect information relating to engineers. In some countries, ministries provided data and in other countries, mining houses provided their data. Numbers were estimated using the models provided and considering the type and volume of each commodity extracted. Once again, this represents an estimate only.

It must be emphasised that the data presented throughout are only estimates, some more accurate than others, due to the paucity of data. This study has certainly served to highlight the lack of, and inconsistency of, statistics and indicators relating to engineering practitioners.

An allowance of 5% has been made for *Miscellaneous* to cover those engineers working in the financial and insurance sectors, advising on infrastructure developments, investments, loans, risks, etc., and those working in other sectors requiring engineering input or knowledge.

Many engineers also work for NGOs involved in water, sanitation, health, safety, education and community development programmes, and professional bodies, to name a few. For this reason, a further 5% allowance has been made for engineering practitioners working in the many NGOs distributed throughout the region. The percentage has been increased slightly in countries with limited or failing social infrastructure, such as Madagascar, and has been reduced where lower levels of NGO support are required.

PHASE 3 – ANALYSIS

Analysis and interpretation of data is the interesting part of any research project. Seeing numbers triangulate, views agree and trends emerge is most gratifying.

Research approach

Analysing data

Analysing the data received was a critical activity. In many instances, incomplete submissions required follow-up calls and discussions to ensure that the data received included the range of variables that needed to be analysed. Often, data included information on operators and craft- or tradespeople, which had to be removed. In other instances, variables were missing, requiring further follow-up. As outlined above, many institutions have never built complete sets of data. This required follow-up discussions to estimate values.

Interpreting trends

From an early stage trends began to emerge. To ensure that trends were being correctly interpreted, additional desktop research was carried out and stakeholders were contacted to confirm our interpretation or offer additional insight.

Gaps emerged from which many recommendations flowed.

Developing the report

Developing the report was a long, slow process. A report for each country was prepared under specific headings to ensure consistency of the reports. This approach led the research team to review all reports several times as new topics and ideas emerged in specific countries which were found to be relevant to all. Once the country reports had reached some degree of maturity, the overview document and overall findings were developed.

PHASE 4 – REVIEW

This phase covered the gathering of outstanding data and verifying the data and views expressed.

Stakeholder input

Once in their draft form, country reports were issued to those stakeholders with whom researchers had engaged for their input on the validity and relevance of the content, and in particular on the recommendations. Once the reports were nearing completion, stakeholders were able to gain a better feel of the intention of the study and some countries offered valuable further input.

Validation workshops and engagements

Two validation workshops were held, one in June 2018 and a further workshop in November 2018. Eswatini, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe participated in one or other of the workshops. The intention was for countries to understand the approach taken, review the reports to date and return to their countries to test the accuracy and acceptability of the report, and to collect missing data. Two DRC nationals living in South Africa who attended the second workshop to offer their views also committed to chasing up more data and soliciting views. The Association of Engineers of DRC Origin in South Africa (AEDOSA) later gave input.

Outside of the validation workshops, the Botswana report was commented on by the Botswana Institution of Engineers (BIE) and the Engineers Registration Board in September 2018, and the Angola report by the Ordem dos Engenheiros de Angola. The Seychelles report was finalised with the help of the National Institute for Science, Technology and Innovation (NISTI) in late 2018.

The Malawi report was presented to a delegation from Malawi, consisting of representatives from the Ministry of Transport and Public Works, the National Construction Industry Council and members from academia in December 2018, after which corrections were received.

Input or edited reports from the remaining countries were received from individuals or the professional bodies in those countries.

Receive final data

After the workshops many missing pieces of data were received and consolidated into the reports. Participants had similar challenges accessing data to the research team, hence validation workshops served only to enhance the reports to some extent, rather than ensure their completeness.

PHASE 5 – FINALISE THE REPORT

The final phase covered consolidating the final input, editing the document, finalising the design and presenting and handing it over to the client.

DATASETS USED

Data was compiled from many sources. The data continues to change as annual reports are published and more up-to-date research is carried out. The references therefore do not include each URL visited, as many that were visited in early 2017 had already been replaced with later information, named differently, by the end of 2018. The reader is referred to the sites listed below for the latest information. Specific references will be made available on request. Please email info@numbersandneeds.co.za with your request.

Where relevant country and sector-specific research was available, these references are given under the section *Sources of Information* in each country report.

DEMOGRAPHICS AND THE ECONOMY

As much demographic data as possible was extracted from the *SADC Statistical Yearbook 2015*. Where information required was not available, the following sites or sources were used:

- Africa Development Bank
- *Africa Economic Outlook*
- *Africa on the Rise*
- African Advisor
- African Business Communities
- *African Business Review*
- *African Review*
- African Volunteer.net
- Democracy Africa.org
- Export.gov
- IMF – International Monetary Fund
- Index Mundi
- International Labour Organisation
- *Knoema's World Data Atlas*
- Labour Force and Household Surveys carried out by national statistical departments
- Mbendi
- Mongabay
- *Nations Encyclopaedia*
- PwC reports
- Southern-African German Chamber of Commerce and Industry
- Statista
- *The CIA World Factbook*
- *The World Folio*
- Top 10 Exports
- *Trading Economics*
- TRALAC – Trade Law Centre
- UNICEF – United Nations International Children's Emergency Fund
- *World Atlas*
- World Bank Reports
- *World Finance*
- *World Population Review*
- World's Top Exports

AGRICULTURE

Many international sets of data were consulted, along with region plans. These included:

- ACTIF – Cotton Africa, African Cotton & Textile Industries Federation
- *Africa Essays*
- AgDevCo – Investment and project developers
- AQUASTAT – water database of the FAO
- CAADP – Comprehensive Africa Agriculture Development Programme
- FAO – Food and Agriculture Organization of the United Nations
- Global Forest Watch
- Global Partnership
- Global Yield Gap Atlas
- IAEA – International Atomic Energy Agency
- ICID – International Commission on Irrigation and Drainage
- IFAD – International Fund for Agricultural Development
- *New Agriculturist*
- Trading Economics
- UNDP – United Nations Development Programme
- United Nations Sustainable Development Goals
- USAID – United States Agency for International Development

MINING

Many datasets and reports are published in this sector which were referred to, including:

- AZO Mining Reports
- Chambers of Mines reports per country
- EITI – Extractive Industries Transparency Index Reports
- *Mining Review*
- Mining.com
- NASA Earth Observatory
- Rigzone.com
- US Geological Survey

MANUFACTURING

The United National Industrial Development Organisation (UNIDO) holds the most comprehensive set of data on manufacturing and publishes the *International Yearbook of Industrial Statistics* annually, covering select countries in each edition. Where available, data from national banks is the most accurate, but is generally considered to be confidential at the level of manufacturing subsector detail.

The Yellow Pages or equivalent were consulted in each country to gain a sense of the type and range of manufacturing industries, in the absence of comprehensive research reports. Where manufacturing associations or the Chamber of Commerce carried out research, these results were used.

ENERGY, GAS AND WATER

- AMCOW – African Ministers' Council on Water
- EIA – US Energy Information Administration
- Energy for Africa
- SE4ALL – Sustainable Energy for All
- USEA – United States Energy Association

- *ESI Africa* (Africa's Power Journal)
- SADC regional and country energy master plans
- SADC regional and country water master plans
- Energy-pedia.com
- WASHwatch – a site monitoring the progress with water, sanitation and hygiene facilities

TRANSPORT AND COMMUNICATIONS

- *Africa Ports*
- *African Telecoms News*
- Cross Border Road Transport Agency country profile reports
- FTTH Council Africa reports
- ITU – International Telecommunications Union
- Liquid Telecom
- Logistics Cluster
- Ports of Entry
- *Railways Africa*
- SADC regional and country communications master plans
- SADC regional and country transport master plans
- *Transport World Africa*
- WRA – World Road Association (also referred to as PIARC – Permanent International Association of Road Congresses (PIARC))

CONSTRUCTION AND HOUSING

- CAHF – Centre for Affordable Housing Finance Africa
- Commonwealth Local Government Forum information
- *Construction Review*
- PIDA – Programme for Infrastructure Development in Africa
- SADC regional and country infrastructure master plans
- UN–Habitat

EDUCATION

- HEMIS – Higher Education Management Information System (South Africa)
- SACMEQ – The Southern and Eastern Africa Consortium for Monitoring Educational Quality
- SARUA – Southern African Regional Universities Association
- UIS – UNESCO Institute for Statistics for student mobility
- UNESCO literacy and enrolment data
- *University World News*

GENERAL

A range of reports are available from several international players. These include:

- NEPAD – New Partnership for Africa's Development policies and reports
- Deloitte country and sector reviews
- PwC sector reviews
- UNESCO: National Commission reports covering all GPD sectors of interest
- MONGABAY: A non-profit provider of conservation and environmental science news.

COUNTRY METRICS

Table 1 in each country report covers a range of metrics to give a sense of the demographics, services and regional or international indicators. Table 6 shows the sources used for each set of data.

Table 6: Sources of data for country metrics

Population	
Total	*SADC Selected Indicators 2017*
Urban and rural split	*SADC Statistical Yearbook 2015*[*1]
Poverty, HIV, Unemployment	
Below the international poverty	World Bank
HIV-positive	World Health Organization
Unemployment	*SADC Statistical Yearbook 2015*[*2]
Human Development Index	*SADC Statistical Yearbook 2015*
Electricity	
Production kWh	*CIA World Factbook*
Consumption kWh	*CIA World Factbook*
Airports and Ports	
Airports – paved and unpaved	*CIA World Factbook*
Ports	Individual references
Kilometres of	
Roads, rail, pipelines and waterways	*CIA World Factbook*[*3]
Africa Infrastructure Development Index	African Development Bank
Services	
Access to safe drinking water	*SADC Statistical Yearbook 2015*[*4]
Access to improved sanitation	*SADC Statistical Yearbook 2015*[*4]
Access to electricity	*CIA World Factbook*[*5]
Telephones	ITU 2016 [*6]
Mobile phones	ITU 2016 [*6]
Internet users	ITU 2016 [*6]

[*1] Except Seychelles (CIA World Factbook)
[*2] Except Mozambique (CIA World Factbook)
[*3] Except Botswana (Economics Africa), Mozambique and Tanzania (Road data from Roads Authorities)
[*4] Except the Seychelles (Own data)
[*5] Except Mauritius (SADC 2015)
[*6] Except DRC (2014) and Seychelles (2018)

SADC DATA

Until 2015 SADC annually published a comprehensive set of data covering country demographics, economics and services, etc. in the *Statistical Yearbook.* The detailed spreadsheets and written reports per year are available on the SADC website. Budgets have not been available to continue with the detailed research required. Since 2016, only SADC *Selected Economic and Social Indicator* reports have been published. The research team were advised to use the *2015 Statistical Yearbook* as the most consistent and reliable source of data for as many of the required metrics as possible.

INDICATORS

Several indicators have been developed to compare the status of many variables per country. Three indicators were considered, as discussed below.

International Poverty Line

Poverty lines serve as a measure of the minimum level of income considered adequate per country to satisfy the basic need for food, water, clothing and shelter. In 2015, the World Bank set the international poverty line as US$1.90 PPP (purchasing power parity). National poverty lines vary according to costs in each country and are usually published with country census data. The values suggested by the World Bank for different income countries are:

- International poverty line – US$1.90 PPP
- Lower middle income class poverty line – US$3.20 PPP
- Upper middle income class poverty line – US$5.50 PPP

For purposes of comparison, the international poverty line has been used for all countries in this study. This gives a sense of the extent of poverty, and the investment and development required to stimulate growth and address poverty.

Human Development Index

The Human Development Index is a measure of life expectancy, education and per capita income. The index will result in similar rankings to the international poverty line, but will vary where the standard of education is higher than in countries with similar infrastructure and economic indicators.

Africa Infrastructure Development Index

The African Infrastructure Development Index (AIDI) is a measure of infrastructure development. It considers the extent and condition of water, sanitation, electricity, transport and ICT infrastructure. It is explained in more detail in Chapter 4.

TIMEFRAMES

The project commenced in April 2017 and was expected to take 18 months. Phase 1 to 3 were to be completed during 2017, but due to lack of data and poor responses it became necessary to spend time in every country. Most country visits took place from January to September 2018 and the final validation meeting took place in November 2018. Unless otherwise noted, data and views quoted relate to 2018.

Chapter 6

Sector performance

The development of significant services sectors is considered critical for countries to transition from low- and medium-income economies to high-income economies. Strong service sectors are not possible without developing the engineering-related contributors to the economy. Resources in each SADC country are plentiful and therefore the potential exists to increase secondary and tertiary production, but this requires investment and engineering capacity.

The contribution and status of each engineering sector is outlined below.

AGRICULTURE

Table 7 shows the contribution of agriculture to the economy in each country; the estimated percentage of the population involved in agriculture; and the area of arable and irrigated land. Details on the cultivated and irrigable potential were not available from all countries. However, from information available, it was evident that there is significant potential in many countries to expand production.

The percentage of rural communities eking out a living is alarming and does little to encourage people to remain on the land. Given the large percentage of young people, this must be addressed to prevent mass migration to the cities which is unsustainable. The need for good local education, health and basic services is critical and extensive agricultural support for smallholders and rural communities is required.

Although it was not part of this study, it was evident that in many countries, agricultural extension capacity has declined, and where young people are being trained, they have had limited hands-on experience, hence their advice is not valued by mature farmers. Community engagement with experts who can demonstrate the value of change is essential before new approaches such as diversification, conservation agriculture or cooperative farming will be adopted. Where comprehensive extension support has been in place, there are many success stories of improved output using improved seed, fertilisers, controlled watering and other techniques.

To expand the areas that families can farm effectively, the introduction of small-scale mechanisation has proved successful in India and China. Mauritius is following their example in the quest to become self-sufficient in food production – the Ministry of Agro-Industry and Food Security makes equipment available to farmers who cannot afford the capital cost.

Many innovations require engineering skills or input of some sort. In many countries, getting produce to markets is cited as a challenge due to the poor condition of the roads. There are also limited post-harvest facilities for processing, packing and storing excess crops. Transport network development plans are normally based on the needs of the mining and manufacturing sectors. Expanding outlet opportunities for agricultural production and growing sustainable rural communities should be factored into these plans.

Table 7: Agricultural metrics

(Malawi GDP 2012, Agricultural data from Trading Economics)

COUNTRY	Contribution to GDP 2015 (US$ million)	Agricultural % of GDP 2015	% contribution to engineering GDP	% relying on agriculture	Arable 1000 ha	Permanent cropland 1000 ha	Land equipped for Irrigated 1000 ha	Smallholder ave size ha	Country area 1000 ha
Angola	$11 184	9.9%	17.4%	66%	4 900	332	86	1	124 670
Botswana	$313	2.4%	5.7%	70%	399	2	2	5	58 173
DRC	$6 895	19.9%	26.9%	70%	7 100	931	11	2	234 486
Eswatini	$301	8.2%	15.8%	70%	175	15	50	1	1 736
Lesotho	$113	5.6%	12.7%	66%	272	5	3	3	3 036
Madagascar	$2 042	24.9%	36.4%	78%	3 500	628	1 086	1	58 704
Malawi	$1 532	28.3%	57.4%	80%	3 800	175	104	1	11 848
Mauritius	$362	3.5%	9.8%	8%	74	4	20	0	204
Mozambique	$3 464	24.5%	43.1%	73%	5 650	305	118	5	79 938
Namibia	$697	6.6%	15.5%	70%	800	9	8	2-7	82 429
Seychelles	$31	2.7%	7.9%	4%	3	1.4	0.3	1	46
South Africa	$6 672	2.4%	5.7%	17%	12 500	415	1 601	1	121 909
Tanzania	$13 110	31.1%	48.7%	67%	13 500	2302	184	0.2-2	94 730
Zambia	$1 060	5.3%	10.9%	56%	3 800	36	156	5	75 261
Zimbabwe	$1 666	13.3%	25.0%	70%	4 000	101	174	5-10	39 076

MINING AND QUARRYING

When one considers mineral wealth, the region is a treasure trove. Angola is the fourteenth-largest oil producer in the world and the second-largest in Africa, after Nigeria. The DRC has the second-largest reserves of diamonds in the world, with Botswana in fourth position and South Africa in fifth. The DRC also holds the world's largest reserves of cobalt, by a large volume, with Zambia in fourth position and Madagascar in eighth position. South Africa has the world's largest reserves of manganese, platinum (with Zimbabwe in third position) and chrome. Namibia has the fourth-largest reserves of uranium in the world, with South Africa in fifth position. Zimbabwe has the eighth-largest reserves of lithium and Tanzania is the only country in which tanzanite is found. Lesotho produces the largest diamonds in the world and the discovery and development of the gasfields off the shore of Mozambique will change the fortunes of that country. This leaves only the Seychelles and Mauritius with no mineral wealth, and Malawi with limited reserves.

The mining contribution to GDP varies considerably per country, depending not only on the mineral wealth of the country, but also on the general state of the economic infrastructure, the economy and investment levels. The GDP contributions and main activities are shown in Table 8. Several countries, namely Angola, Botswana and the DRC, are highly dependent on their income from minerals and need considerable diversification to protect them from the shocks experienced when commodity prices and associated demand drop. In several other countries, the mining GDP exceeds 15% of the engineering-related GDP earners, indicating the need for significant engineering skills in this sector.

The lack of infrastructure restricts the development of vast mining potential in many countries. Power is essential for mining and particularly smelting, as is a good transport network. In Mozambique, for instance, the mining of coal from the Tete area only became viable once the SENA railway line had been constructed.

As discussed in Chapter 1, investment in and the use of cutting-edge technology is essential for the mining sector to continue to be competitive. The number of countries which nationalised their mines to access the capital, and subsequently experienced significant economic downturns, should ring warning bells for others considering following this practice. Imposing high levies on the sector is also detrimental to

Table 8: Mining commodities and potential

*(*Malawi GDP data 2012)*

COUNTRY	Contribution to GDP 2015 (US$ million)	Mining % of GDP 2015	% contribution to engineering GDP	Key commodities (Output could generally increase with investment)	Additional potential subject to investment and infrastructure
Angola	$26 512	23.5%	41.3%	Oil, gas, diamonds, iron	Gold, copper
Botswana	$2 625	20.2%	47.8%	Diamonds, coal, nickel	Gold, copper, iron
DRC	$6 647	19.1%	25.9%	Oil, copper, cobalt, diamonds, zinc	Lithium, niobium, manganese, zinc, cobalt, iron, cassiterite, gold
Eswatini	$6	0.2%	0.3%	Coal	Iron, gold, diamonds
Lesotho	$167	8.3%	18.8%	Diamonds	Uranium, coal, iron
Madagascar	$20	0.2%	0.4%	Nickel, cobalt, ilmenite, chrome, sapphire	Coal, bauxite, oil
Malawi*	$68	1.2%	2.5%	Uranium, coal, ruby, sapphire	Bauxite, graphite and heavy minerals
Mauritius	$25	0.2%	0.7%	Quarrying	-
Mozambique	$772	5.5%	9.6%	Tantalum, ilmenite, zircon, coal, gas	Gold, graphite, iron
Namibia	$1 428	13.5%	31.9%	Diamonds, gold, uranium, zinc, lead, copper, iron	
Seychelles	-	-	-	-	-
South Africa	$22 431	8.0%	19.2%	Gold, PGMs, iron ore, chrome, coal, silver, diamonds, uranium	
Tanzania	$1 821	4.3%	6.8%	Gold, uranium, gas, nickel, copper, diamonds, tanzanite	Iron
Zambia	$2 697	13.4%	27.9%	Copper, cobalt, coal, uranium	
Zimbabwe	$1 098	8.8%	16.5%	PGMs, gold, chrome, coal, iron, nickel	

national economies in the long term, as mining operations become unviable, or unattractive to investors. The multiplier effects of the sector are considerable given not only the beneficiation and manufacturing opportunities, but also the economic and employment opportunities in mining towns in providing goods and services to local communities.

Policies that are a deterrent in many countries need to be reviewed to attract investors and grow the potential that exists. With the mineral wealth in the region, no country should be struggling with a failing economy, rising debt, poverty and hunger.

MANUFACTURING

Although most countries proclaim themselves not to be manufacturing countries, there are many basic products manufactured in each country. Typically, food processing and the production of soft drinks and brewing take place, all of which require engineering skills. Due to the high cost of freight for large-volume products, plastic products tend to be made in each country, even if the raw material needs to be imported. Likewise, paper and packaging products, paints, cleaning materials and other chemicals are generally manufactured locally. Quarrying and the production of associated building materials are also local activities.

Many countries have created manufacturing opportunities based on their unique or local resources, which, although small in some cases, require highly specialised skills. Table 9 shows that manufacturing contributes 10% or more to the GDP in almost half the countries, and represents more than 20% of the engineering GDP in nine of the SADC countries. The climate in many countries lends itself to growing sugar, fruit, cotton, tobacco and spices, each of which offer manufacturing opportunities as listed under Potential and Growing Markets.

Currently heavy and advanced manufacturing are generally limited to a few countries but have the potential to be developed in many countries. Moving from low-tech industries which largely require artisanal skills to high-tech will require the range of engineering skills. These include, in the main, chemical, electrical, industrial and mechanical engineers, and these must be available in adequate numbers.

The absence of engineering associations in manufacturing made is impossible to determine accurate engineering numbers and needs. Another approach to understanding the mix required, would be to study the manufacturing value added (MVA) per industry, but MVA data was not readily available in detail in many countries. Descriptions of the range of manufacturing activities have therefore been included in each country report to create awareness of the need to continue developing engineering disciplines relevant to each industry. The numbers estimated for manufacturing must be taken as rough estimates at best.

Table 9: Manufacturing metrics

*(*Malawi GDP data 2012)*

COUNTRY	Contribution to GDP 2017 (US$ million)	Manufacturing % of GDP 2015	% contribution to engineering GDP	POTENTIAL AND GROWING MARKETS
Angola	$6 015	5.3%	9.4%	Fuels, fish processing, coffee, alcoholic beverages
Botswana	$824	6.3%	15.0%	Diamond cutting, batteries, meat processing, leather goods
DRC	$6 154	17.7%	24.0%	Quinine, cocoa, coffee
Eswatini	$1 259	34.3%	66.0%	Sugar, soft drink concentrates, wood pulp
Lesotho	$214	10.6%	24.1%	Textiles and clothing
Madagascar	$1 133	13.8%	20.2%	Coffee, tea, spices, fish, textiles, perfumes
Malawi*	$422	7.8%	15.8%	Cotton, tobacco, sugar
Mauritius	$1 526	14.7%	41.3%	Textiles and clothing, sugar, medical equipment, electronics, fish, coffee, tea, spices
Mozambique	$1 379	9.8%	17.2%	Aluminium, tobacco, nuts, fish processing
Namibia	$945	8.9%	21.1%	Armoured vehicles, fish and meat processing
Seychelles	$73	6.4%	19.0%	Fish processing
South Africa	$37 215	13.2%	31.8%	Vehicles, machinery, weapons, explosives, aluminium, electronics, wines, spirits, rooibos, other beverages
Tanzania	$2 373	5.6%	8.8%	Coffee, tea, fish processing, cotton, tobacco, safari vehicles
Zambia	$1 600	7.9%	16.5%	Sugar, tobacco
Zimbabwe	$1 413	11.3%	21.2%	Tobacco, meat processing, sugar

ENERGY, GAS AND WATER

Without an adequate supply of energy and clean water, beneficiation and industrialisation are not possible. Poor sanitation and unsafe water are major health hazards and cost countries significant amounts in terms of health care. The time involved in walking to collect water reduces productive time available for cottage industries or farming activities.

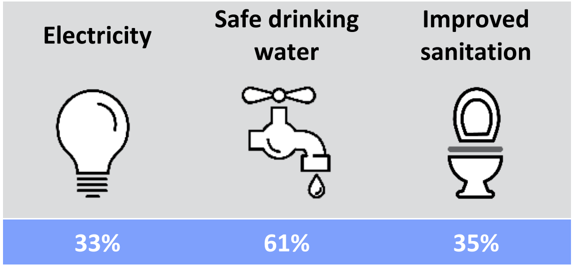

Figure 18: Average percentage with access to services

(2011 to 2016, depending on data availability)

Figure 18 shows the overall percentage access per service achieved in the region up to 2015, while Table 10 shows that many countries still have a long way to go to achieve universal access to these services. (It should be noted that access data for a set year is not available – the data is based on the latest information available from 2013, 2014 or 2015.)

The whole process of long-term planning, prioritising projects, scoping, raising funds, designing, developing and implementing solutions to increase capacity, or to rehabilitate neglected infrastructure, requires significant engineering capacity. In most government departments throughout the region, vacancy levels are high or non-technical staff occupy technical posts. In some countries there is a moratorium on employing staff in public sector structures, which is resulting in capacity declining as employees leave the sector.

Extremely ambitious targets have been set to achieve universal access, many of them requiring the development of large bulk capacity and substantial networks. If these targets are indeed to be achieved, it is critical that capacity requirements for maintenance teams should be determined, and that the education, training and expansion of maintenance teams should commence in the short term to ensure that there is capacity to operate and maintain new infrastructure.

Some governments suggested that they would be outsourcing their maintenance to subcontractors. Expansion and training of the subcontracting network will need to be managed to ensure that subcontractors are adequately equipped, and have appropriate staff, trained to the standard required by for each service.

Table 10: Access to basic services

(2011 to 2016, depending on data availability)

COUNTRY	ACCESS TO SAFE WATER	ACCESS TO IMPROVED SANITATION	ACCESS TO ELECTRICITY	YEAR TO ACHIEVE UNIVERSAL ACCESS		
				SAFE DRINKING WATER	IMPROVED SANITATION	ELECTRICITY
Angola	44%	60%	30%	>2030	>2030	2030
Botswana	97%	74%	66%	2030	2030	2030
DRC	46%	31%	9%	>2030	>2030	2050
Eswatini	74%	68%	27%	2022	2022	2025
Lesotho	78%	26%	17%	2030	2030	>2030
Madagascar	52%	12%	15%	None set	None set	2040
Malawi	87%	55%	9%	2025	2030	>2030
Mauritius	100%	100%	99%	-	-	2020
Mozambique	51%	27%	39%	2030	2030	2030
Namibia	92%	32%	32%	2020	>2030	2030
Seychelles	96%	98%	97%	2030	2030	2030
South Africa	91%	80%	85%	2030	2030	2030
Tanzania	55%	14%	24%	2030	2030	>2030
Zambia	68%	25%	26%	2030	2030	>2030
Zimbabwe	76%	62%	40%	2030	2030	2030

TRANSPORT AND COMMUNICATIONS

Good transport and communication networks are essential to grow any economy.

TRANSPORT

Due to the size of many countries, an extensive road and rail network, in good condition, is required. Furthermore, to ensure the flow of produce, material and manufactured goods to address food security and grow economies, corridors connecting countries are required.

Data relating to the lengths of rail and paved and unpaved roads are shown in Table 11. Many railway lines and paved roads are in poor condition and many unpaved roads serve as the main access to markets, taking days instead of hours to traverse. Major upgrades to roads and rail are required to achieve the smooth flow envisaged.

Table 11: Lengths of rail and road network

COUNTRY	RAIL LENGTH	PAVED ROAD	UNPAVED ROAD	YEAR
Angola	2 852	5 349	46 080	2001
Botswana	888	7 892	20 260	2011
DRC	4 007	2 794	150 703	2004
Eswatini	301	1 078	2 516	2002
Lesotho	1.6	1 069	4 871	2011
Madagascar	836	6 103	31 373	2010
Malawi	767	4074	11378	2015
Mauritius	-	2 379	49	2015
Mozambique	4 787	7 365	23 718	2018
Namibia	2 628	6 387	37751	2010
Seychelles	-	514	12	2015
South Africa	20 986	158 124	591 876	2014
Tanzania	4567	11 202	134 002	2018
Zambia	3 126	9 403	31 051	2005
Zimbabwe	3 427	18 481	78 786	2002

The corridors identified for development are the:

- **Bas Congo Corridor** from the Port of Matadi to Kinshasa in the DRC
- **Beira Corridor** from Zambia and Malawi through Zimbabwe to the Port of Beira in Mozambique
- **Central Corridor** from Burundi, Rwanda, Uganda and the eastern part of the DRC through Tanzania to the Port of Dar es Salaam
- **Dar es Salaam Corridor** from Walvis Bay in Namibia through Zambia, the DRC and Malawi to the Port of Dar es Salaam in Tanzania
- **Limpopo Corridor** from Zimbabwe to Mozambique
- **Lobito Corridor** from the DRC through Zambia to the Port of Lobito in Angola
- **Malanje Corridor** from the Malanje Province to the Port of Luanda in Angola
- **Maputo Corridor** from the Gauteng Province in South Africa to the Port of Maputo in Mozambique
- **Maseru–Durban Corridor** from Maseru in Lesotho to the Port of Durban in South Africa
- **Mtwara Corridor** from Malawi to the Port of Mtwara in Tanzania
- **Nacala Corridor** from Zambia through Malawi to the Port of Nacala in Mozambique
- **Namibe Corridor** from Namibia to the Port of Namibe in Angola
- **North–South Corridor** through the DRC, Tanzania, Zambia, Zimbabwe and Botswana to Gauteng and the Port of Durban in South Africa
- **Trans–Caprivi Corridor** from southern DRC through Zambia to the Port of Walvis Bay
- **Trans–Cunene Corridor** from central and southern Angola to the Port of Walvis Bay
- **Trans–Kalahari Corrido** from the Gauteng Province in South Africa through Botswana to the Port of Walvis Bay
- **Trans–Orange Corridor** from the Northern Cape Province of South Africa to the ports of Walvis Bay and Lüderitz in Namibia.

Many corridors will be multi-modal, including road, rail and waterways. These corridors are aimed at connecting centres to each other and to ports and airports. However, the road and rail network along these corridors is currently not continuous, requiring more development over and above the upgrading of existing roads. The need to build multi-lane highways and rail lines at acceptable grades will require the construction of many bridges, but several countries complain of the lack of bridge-building expertise.

Furthermore, many coastal and waterway ports need to be upgraded and new ports need to be built. Modern cargo-handling equipment will also need to be designed and installed. Rail and port engineering expertise has declined over the years and needs to be redeveloped as part of construction programmes to ensure that there is sufficient capacity to operate and maintain the new or upgraded infrastructure.

Many airports also require expansion to handle both increased passengers and increased freight.

Transport refers not only to the networks and infrastructure, but also to the vehicles, whether cars, heavy earthmoving or freight vehicles, rolling stock, aircraft, boats, ships, tugs, etc. Considerable engineering expertise is required to manage such fleets, optimise their usage and handle maintenance programmes. Public transport is also important and several major cities are busy implementing Bus-Rapid-Transport (BRT) systems.

Several countries have large maintenance facilities for rolling stock and lament the shortage of engineering management skills to manage maintenance programmes. Aeronautical and marine engineering skills are also required, given the number of airlines in the region and the length of coastline. Furthermore, aviation and maritime navigation systems need to be upgraded.

COMMUNICATIONS

The status of the communications sector in the SADC region is summarised in Table 12, showing the percentage of each service available, relative to the population. Fixed-line communication is slowly decreasing in popularity as wireless systems offer more flexibility and functionality, and are more universally accessible.

Table 12: Percentage connected to services, 2016
(Eswatini 2012)

COUNTRY	FIXED LINE %	MOBILE %	INTERNET %
Angola	1	45	13
Botswana	6	137	63
DRC	0	44	6
Eswatini	3	74	29
Lesotho	1	103	27
Madagascar	1	32	5
Malawi	0	40	10
Mauritius	30	143	52
Mozambique	0	52	18
Namibia	8	107	31
Seychelles	20	175	87
South Africa	8	147	54
Tanzania	0	72	13
Zambia	1	72	26
Zimbabwe	2	80	23

The majority of international bandwidth is carried to and from Europe and Asia using fibre optic undersea cabling. Links which serve the SADC region, from the oldest to the most recent, are:

- **SAT-2 (South Atlantic Telecommunications)** which runs along the west coast of Africa from South Africa to Portugal and Spain, and was the first undersea fibre cable to the region, replacing the coaxial telephone cable laid in 1968
- **SAFE (South Africa Far East)** which links South Africa to Malaysia, with landing points in Mauritius, Reunion and India
- **SAT-3 (South Atlantic Telecommunications)** which runs along the west coast of Africa from South Africa to Portugal and Spain
- **SEACOM** which runs along the east coast of Africa and links South Africa to Egypt and India
- **LION (Lower Indian Ocean Network)** which connects Reunion, Mauritius and Madagascar
- **EASSy (Eastern Africa Submarine System)** which runs from South Africa to Sudan, with landing points in Mozambique, Madagascar, the Comoros and Tanzania, among others
- **WACS (West Africa Cable System)** from South Africa to the UK, which connects countries along the west coast of Africa, including Namibia, Angola and the DRC, to one another
- **ACE (African Coast to Europe)** which is an additional link connecting west coast countries to one another from South Africa to France
- **SEAS (Seychelles to East Africa System)** which connects the Seychelles to Africa through Tanzania
- **SACS (South Atlantic Cable System)** which connects Brazil to Angola. As it links the MONET fibre cable from Brazil to the USA, it gives Angola a more direct connection to the USA.

Further cables being installed or planned are:

- **METISS (MEltingpoT Indianoceanic Submarine System)** which will connect South Africa to Mauritius, Madagascar and Reunion
- **IOX (Indian Ocean Exchange)** which will connect South Africa to India through Mauritius
- **MARS** (**Mauritius and Rodrigues Submarine Cable System**) which will connect the islands of Mauritius
- **SABR (South Africa Brazil)** which will connect Brazil to South Africa
- **PEACE** (**Pakistan and East Africa Connecting Europe)** which will connect the Seychelles to Europe
- **Africa-1** which will connect South Africa to France and the Middle East
- **SAex-1 (South Atlantic Express)** which will connect South Africa to the USA through the South Atlantic islands
- **SAex-2 (South Asia Express)** which will connect South Africa to India and Singapore.

Connections to landlocked countries have been developed to allow them to access international connectivity.

Connectivity within the SADC community is generally accomplished using a fibre optic backbone, as it supports long distances and high bandwidth. It has been costly to implement in towns and cities due to the cost of laying cables. Overhead installations have also been used to reduce costs. Fibre optic networks allow for faster and more reliable access to services such as communication, wireless internet and fixed-line broadband services.

Fibre To The Premises (FTTP), which consists of two subsectors – Fibre To The Home (FTTH) and Fibre To The Business (FTTB) – is slowly becoming the new benchmark for connectivity, providing faster access, lower consumer and operating costs, as well as environmental benefits.

The implementation of FTTP requires bandwidth to be available in the national infrastructure and several countries have started or have already implemented FTTP services, including South Africa, the Seychelles, Zimbabwe, Mauritius and Tanzania.

One of the primary providers across the African continent is Liquid Telecom which has over 50 000 km of fibre optic networking and connects to five major submarine fibre cables linking Africa to Europe and Asia. This vast network requires constant expansion and overhauling to maintain uninterrupted connectivity.

Mobile connectivity is widely used as the primary means to access the internet as it is easily accessible throughout most of the SADC countries. The most widely used providers are MTN and Vodafone. However, wireless distribution stations depend on the national networks to be reliable and have sufficient bandwidth, but, in most cases, this is where the sector falls short.

An expanded team of electronic, telecommunications and systems engineers and technicians is needed to harness the opportunities that current connectivity offers, to expand connectivity and to maintain the infrastructure and networks.

Several communication projects are taking place in the SADC region, such as the Square Kilometre Array (SKA). It consists of a series of telescope dishes covering a square kilometre which will search for signatures of life in the galaxy. The project aims to revolutionise science and exploration in areas such as gravitational waves, pulsars, relativity and investigating black holes. It will provide a jump in capability, providing four times more resolution, five times more sensitivity and will be able to map the sky 60 times faster than the Karl G. Jansky Very Large Array (VLA), currently the best telescope at similar frequencies. It will also bring together people, processes and data, and will pioneer research in optical transport and big data. The countries involved include South Africa, Botswana, Madagascar, Mauritius, Mozambique, Namibia and Zambia.

CONSTRUCTION

The value and structure of the construction sector in the region can be seen in Table 13. The sector is very sensitive to the state of the economy and suffers boom and bust cycles largely linked to government spending. The sector is characterised by three types of organisation, namely consulting engineers, contractors and construction materials suppliers. The manufacturers of construction materials fall under *Manufacturing*.

As major projects can pose serious threats to public health and safety, in terms of both the design of the final product and the dangers associated with the construction phase, many countries have taken to setting up construction industry boards or councils which are usually statutory bodies set up to regulate the appointment of service providers. In some countries, this control is exercised within the Ministry of Public Works or Construction.

The approach taken is to determine the capacity and skills set of each organisation to determine what size and type of project it is capable of taking on. Normally, contractors are categorised into four to six levels, depending on the capital they have access to, the extent of their plant and equipment, and their professional skills. A minimum number of engineering and construction professionals are specified per category. As companies gain experience and grow, they may apply to be moved up into the next category to take on bigger and more complex projects. Of concern is the fact that some countries, although regulating, have not prescribed skills sets.

Other countries have not set any requirements but do require consultants and contractors to apply for licences. At the time of applying for the licence, they must prove that they have adequate public liability cover in case of accidents. In those countries where there are no national controls, it was not possible to determine the exact number of consulting engineering practices or contractors – the estimates provided reflect the numbers which belong to VAs and are therefore less than the total number.

The dominance of foreign contractors in many countries limits the opportunities to grow local capacity. Chinese construction companies are said to dominate the construction sector in many countries, with India, Portugal, Brazil, South Africa and others

Table 13: Construction metrics

*(*Malawi GDP data 2012)*

COUNTRY	Contribution to GDP 2015 (US$ million)	Construction % of GDP 2015	% contribution to engineering GDP	No. of consulting practices	Registration of consultants	No. of contractors	Registration of contractors**	COUNTRY OF ORIGIN OF MAIN FOREIGN CONTRACTORS
Angola	$14 729	13.0%	23.0%	~30	R	1 812	R	Brazil, China, Portugal, South Africa, Spain, UAE, UK, USA
Botswana	$940	7.2%	17.1%	45	-	>2 000	-	China, Egypt, Korea, South Africa
DRC	$1 614	4.7%	6.3%	>30	L	>286	L	Brazil, China, France, Netherlands, South Africa, Spain, USA
Eswatini	$106	2.9%	5.5%	26	C	440	C	South Africa, Taiwan
Lesotho	$127	6.3%	14.3%	50	-	1 400	-	China, South Africa
Madagascar	$258	3.2%	4.6%	>5	-	~2 000	-	China, France, UK
Malawi*	$184	3.4%	6.9%	50	C	850	C	China, Portugal, South Africa
Mauritius	$457	4.4%	12.4%	70	B	1 154	B	China, India
Mozambique	$349	2.5%	4.3%	~63	R	>5 000	R	Brazil, China, India, Italy, Portugal, South Africa
Namibia	$695	6.6%	15.5%	90	-	>450	-	China, Italy, South Africa
Seychelles	$43	3.7%	11.1%	20	-	80	L	China, India, Mauritius, UAE
South Africa	$11 398	4.0%	9.7%	600	-	122 890	B	Many international equipment suppliers and JVs
Tanzania	$6 157	14.6%	22.9%	205	-	9 300	C	China, Egypt, India, Japan, South Africa
Zambia	$2 163	10.7%	22.3%	76	C	5 650	C	China, Egypt, India, Italy, Korea, Lebanon, Portugal, South Africa
Zimbabwe	$429	3.4%	6.5%	60	-	>600	-	Brazil, China, India, Korea, Portugal, South Africa

**B=Registration Board C=Registration Council L=Licence from government R=Registration by government

also competing for work. The list shown in Table 13 is not comprehensive but gives a sense of the spread of countries competing for work.

Local contractors complain that they cannot compete against foreign contractors which are able to price below them, due to support from their governments. Other complaints include the use of foreign labour and materials on projects awarded to international companies, when local construction skills are unemployed and local manufacturers are looking for business. Controls on international contracts are needed to ensure the maximum use of local skills, material and equipment.

In South Africa, the labour laws and requirements for Broad-based Black Economic Empowerment generally preclude the direct appointment of international contractors. Where specialist skills are required, joint ventures are formed between local and international specialist companies.

Construction contracts are the perfect setting for training. Conditions should be set in all contracts for the training of local graduates and apprentices on public sector projects. Contracts should include guidelines and controls must be put in place to ensure that all trainees are given a suitable variety of tasks and are challenged and coached.

Throughout the country reports it will be evident that major projects have been identified, but few can proceed without funding. There is a limited number of bankable projects, i.e. those that are financially viable and that will not pose a risk to investors. Thorough research and assurance of return on investment are required before many projects can proceed. For this reason TBD ('to be determined') is shown under the cost and date columns associated with many projects in the country reports.

THE AFRICA INFRASTRUCTURE DEVELOPMENT INDEX (AIDI)

The Africa Infrastructure Development Index (AIDI), is a good indicator of the extent and quality of infrastructure in Africa. It is a measure out of 100. The Seychelles is ranked the highest, with an index of 94.324, followed by Egypt at 85.847.

INDICATORS

The AIDI is based on four major components, namely transport, electricity, ICT and water and sanitation. These components are disaggregated into nine indicators that have a direct or indirect impact on productivity and economic growth. They are summarised as follows:

I. Transport

- **I.a Total Paved Roads (km per 10 000 inhabitants):** The country's total road length surfaced with crushed stone (macadam), hydrocarbon binder or bituminised agents, concrete, or with cobblestones. The indicator is measured in km per 10 000 inhabitants to give an indication of access to paved road network.
- **I.b Total Road Network in km (per km^2 of exploitable land area):** The total road length (both paved and unpaved roads) relative to the exploitable area of the country, where exploitable area is the total area minus the surface area of deserts, forests, mountains and other inaccessible areas.

II. Electricity

- **Net Generation (million kWh per hour per inhabitant):** The total electricity production of a given country, including the energy imported from abroad. This includes both private and public energy generated.

III. ICT Composite

- **III.a Total Phone Subscriptions (per 100 inhabitants):** This refers to both fixed-line and mobile.
- **III.b Number of Internet Users (per 100 inhabitants):** The estimated number of internet users using any device (including mobile).
- **III.c Fixed (wired) Broadband Internet Subscribers (per 100 inhabitants):** Total internet subscriptions using fixed-line (wired) broadband technologies, excluding access through mobile cellular networks.
- **III.d International Internet Bandwidth (Mbps):** The sum of capacity of all internet exchanges offering international bandwidth (if incoming exceeds outgoing, incoming capacity is used).

IV. Water and sanitation composite

- **IV.a Improved Water Source (% of population):** Access to an improved water source able to supply at least 20 litres per person per day from a source within 1 km of the dwelling.
- **IV.b Improved Sanitation Facilities (% of population):** This refers to access to facilities in which the disposal of excreta can prevent human, animal and insect contact with excreta.

RANKING

Many countries in the region rate very poorly on the Index, with Mozambique at 44, Madagascar at 46 and the DRC at 50 out of 54. Somalia held 54th position with an index of just 3.36 out of 100. Table 14 shows the overall index for 2018. The low ranking in many countries indicates the extent of upgrading and development of both economic infrastructure and water and sanitation services required. This, however, cannot take place without investment.

It is interesting to note that the Index has more than doubled in Angola, Madagascar and Tanzania over the 15-year reporting period. In each case this can be attributed largely to investment in major mining projects and the development of associated infrastructure.

Table 14: AIDI values per country, 2018
(Source: African Development Bank)

COUNTRY	RANKING 2018	AIDI 2003	AIDI 2018	% INCREASE	WSS	ICT	ELECTRICITY	TRANSPORT
Angola	29	7.3	19.04	161%	40.14	11.78	6.4	1.87
Botswana	10	24.73	36.79	49%	80.82	30.63	21.51	22.28
DRC	50	4.02	8.15	103%	31.93	6.99	1.85	1.64
Eswatini	17	13.22	25.76	95%	61.6	18.32	5.78	8.36
Lesotho	35	12.83	16.01	25%	54.56	16.35	4.11	7.41
Madagascar	46	3.14	10.73	242%	23.42	6.45	0.95	3.01
Malawi	25	11.51	21.02	83%	65.84	7.02	2	4.83
Mauritius	5	42.1	76.79	82%	97.51	58.67	39.86	38.39
Mozambique	44	5.88	12.49	112%	27.11	11.18	12.04	2.02
Namibia	13	24.72	28.65	16%	63.34	22.09	10.54	15.49
Seychelles	1	47.43	94.32	99%	96.87	59.78	63.81	50.32
South Africa	4	46.07	78.53	70%	79.99	76.94	74.86	21.91
Tanzania	43	5.17	12.54	143%	28.16	10.43	1.82	3.27
Zambia	23	14.42	22.29	55%	48.74	14.93	14.08	4.71
Zimbabwe	19	22.48	24.52	9%	53.97	16.36	10.38	11.69

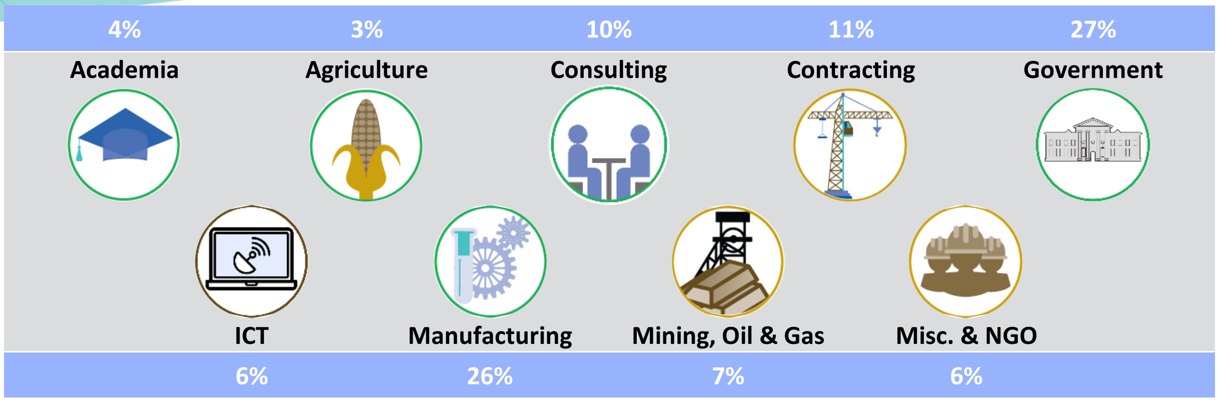

Figure 19: Percentage of engineering practitioners employed per sector

NUMBERS PER SECTOR

The distribution of disciplines employed in each country was shown in Chapter 2. Figure 19 shows the percentage split of practitioners in each sector and Table 15 shows the estimated numbers per sector.

Construction has been split into consulting and contracting, as they have significantly different employment profiles. Since the bulk of employment relating to energy, water, transport and communication is in government, the two sectors have been combined under government, which, in this case, represents all spheres of government.

With the spread of information technology, automation and telecommunications, major private sector activities have emerged, hence a separate measure of ICT in the private sector. Typically, this would include staff in mobile service provider, systems, software and communication companies.

Mining requires specialist skills, including mining and metallurgical, mechanical and electrical engineers. More recently, specialists in oil and gas have become necessary, not only in Angola, but in several countries that have discovered coastal reserves.

Engineering skills are also to be found in many industries that are not directly related to engineering, but are affected by or influence engineering decisions, hence a category for Miscellaneous. Many practitioners are also involved in the NGO sector, working on community projects to address the delivery of basic services, enhance agricultural production, training, etc.

It must be emphasised that these numbers represent an estimate only, based on limited responses and data availability throughout the region, as discussed under *Estimated Numbers* in Chapter 2.

Table 15: Number of engineering practitioners employed per sector
(Engineers only)*

COUNTRY	Academia and research	Agriculture	Consulting	Contracting	Government	ICT, systems and telecoms	Manufacturing and suppliers	Mining, oil, gas and quarrying	Miscellaneous and NGOs	Total	% in government
Angola*	500	300	300	1 000	3 250	300	1 700	1 200	450	9 000	36.1%
Botswana	300	50	500	550	2 500	400	500	750	450	6 000	41.7%
DRC	800	2 000	400	1 000	5 000	1 000	5 000	1 000	1 800	18 000	27.8%
Eswatini	50	50	200	280	650	50	150	10	160	1 600	40.6%
Lesotho	50	20	150	160	350	80	150	80	110	1 150	30.4%
Madagascar	700	1 000	400	1 000	1 850	700	3 500	750	1 100	11 000	16.8%
Malawi	140	250	300	700	1 200	100	300	50	160	3 200	37.5%
Mauritius	350	50	400	1 400	1 400	500	600	50	250	5 000	28.0%
Mozambique*	500	550	700	1 300	3 500	600	2 500	800	550	11 000	31.8%
Namibia	150	50	500	400	650	60	450	400	140	2 800	23.2%
Seychelles	20	20	50	90	170	30	90	10	30	510	33.3%
South Africa	2 000	500	14 000	9 000	28 000	9 000	34 000	8 000	5 500	110 000	25.5%
Tanzania	1 800	700	4 000	6 000	8 000	1 000	6 000	1 000	1 500	30 000	26.7%
Zambia	400	300	700	1 100	3 000	500	3 800	1 600	600	12 000	25.0%
Zimbabwe	400	100	400	700	2 000	400	2 000	1 200	400	7 600	26.3%
TOTAL	**8 170**	**5 940**	**23 000**	**24 680**	**61 520**	**14 720**	**60 740**	**16 900**	**13 200**	**228 860**	**26.9%**

Part 2
Findings and Recommendations

PART CONTENTS

Many trends have emerged which are impacting on the development of engineering skills in the region. Countries have many ambitious plans, which will require large numbers of experienced engineering professionals. However, the funds are simply not available for many projects to be considered. Furthermore, few countries have sufficient expertise for the current workload, and public sector structures struggle to maintain existing services, let alone expand services and deliver new solutions. Many of the bottlenecks will require policy decisions, funding or both to be addressed.

The bottlenecks and recommendations are considered under the headings relating to development, employment and appointment of professionals, and investment in infrastructure, as follows:

Chapter 7

Theory

The theoretical training of engineering professionals is not limited to tertiary education, but starts from childhood, with adequate exposure to the concepts, thinking and theory that build engineering problem-solving capabilities. From early childhood all the way up to post-doctoral studies, the phases to develop engineering experts are theoretical training phases. It was not within the ambit of this study to cover the full education life cycle, but the importance of each phase must be considered when developing national policies.

The critical elements on which the engineering profession must comment, and in which it must play a role, are schooling and tertiary education.

SCHOOLING

There are several areas of concern in the schooling system with regard to the development of engineering practitioners. Access to education is still a major barrier, as can be seen in Figure 20. This means that many with aptitude will never have the opportunity to enter the engineering space. Coupled with this, the teaching capacity and inadequacy of infrastructure and resources present further challenges which impact on developing the potential of those in the system.

INADEQUACY IN SCHOOL MATHEMATICS AND SCIENCE

The quality of teaching and access to high school education presents a problem in the region. The numbers achieving the required pass marks are inadequate to meet the need of the technical, scientific, actuarial and other professions requiring high-performance school leavers who have excelled in mathematics.

In the attempt to extend education to the entire population, the complexity of mathematics and other subjects has been reduced to accommodate large classes and make teaching easier for underqualified teachers. Furthermore, the move to the outcomes-based approaches to education in several countries has, due to the size of classes, meant that process, rather than principles, have been taught. This has had a detrimental effect on engineering education.

As far back as 1998, Prof. Les Clarke, Dean of Civil Engineering at Birmingham University, complained that due to the change in the school teaching approach, it had become necessary to teach mathematics and physical concepts at university level. This required more teaching time which was problematic considering the already demanding content of engineering degrees.

Angola's rationale for opening many more universities is to '*better skill and create employment opportunities*', which is the view adopted by many countries. However, engineering students with an inadequate foundation in mathematics and science have little hope of succeeding. Emphasis should rather be placed on improving teaching at school level.

In many countries, the Y model of choosing a technical or academic stream after Grade 9 offers the opportunity for technical mathematics to be taught for the last three years of secondary education, and emphasis should be placed on developing those with an aptitude for engineering at this stage, rather than expecting universities to teach principles which should have been learnt at school.

Bridging or foundation courses have been introduced to assist those entering higher education to 'catch up' on poor school teaching. However, if there has been no grasp of the basic principles early on,

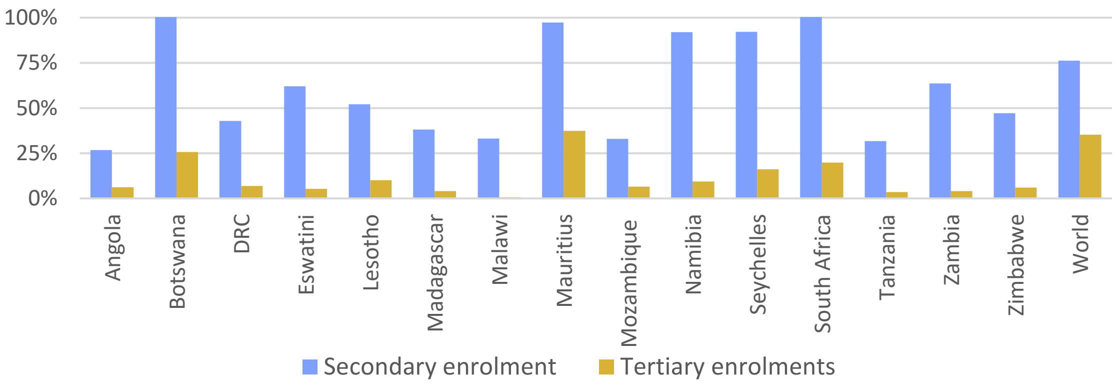

Figure 20: Percentage enrolments in secondary and tertiary education
(UNESCO from 2012 to 2016)

understanding subsequent concepts is difficult. As a result, those arriving at university with poor school results require years to catch up, rather than being able to do so in the short period offered as part of bridging.

Detailed analyses of the challenges have been carried out in many countries. The temptation is always to provide more books and teachers, but without adequately qualified teachers, the concepts and principles so vital for engineering students cannot be developed. Teacher development is therefore one of the important elements for developing engineering skills for the future.

The Centre for Development and Enterprise (CDE) in South Africa has carried out ongoing research in this field for many years. In an early publication, *From Laggard to World Class*, they suggested that scholarships for learners with an aptitude for mathematics should be considered to stream them into stronger schools to develop their potential from an early stage. In a later publication, they cautioned that addressing the emotional and social difficulties faced by such learners was essential as the transition from a weak school to a high-performance and highly competitive environment can be very challenging.

Although the CDE approach will make a difference to individual performance, the sheer numbers requiring access and better resourced schools will require years of intervention. In the absence of adequately trained teachers, technology should be harnessed. YouTube has proved to be a useful tool for teaching. Organisations such as the Kahn Academy, and many others, have created online learning material for all grades. Group work should be encouraged, to allow those who have grasped concepts to assist those who are struggling.

A young South African wishing to study biotechnology proved this approach to the research team. Although earning a First Class pass in science in Grade 12, his mark of 53% for mathematics precluded him from entry into studying biotechnology. On investigation is was found that his school mathematics teacher had only passed Grade 10, and the class did not cover the full syllabus. The young man was given access to a laptop, Wi-Fi and YouTube and after three weeks of self-study, rewrote his mathematics exam and earned 69%. This allowed him to enter biotechnology studies. He is thriving at university, getting good results in all his subjects.

A massive campaign to roll out online learning, to supplement the inadequacy of teaching capacity and material, needs to be mounted. This would require setting up hotspots and acquiring appropriate technology such as tablets or screens per classroom to access available material among others. Changes in teaching approaches need to be considered to allow teachers to be facilitators of online learning. Mobile technology and mobile applications have proved themselves throughout Africa. It is said that here are more mobile phones in Africa than taps. Many school goers in the most remote areas are connected to the extensive mobile networks throughout the region. This was witnessed by the researchers when visiting rural communities far removed from main roads or urban centres.

Donor Agency and corporate commitment to sponsor technology and the support of mobile operators to include remote schools in their development planning is also required.

CAREER GUIDANCE

Several countries have suggested the need for more career guidance to attract high-calibre candidates into the field. A range of methods need to be considered, including presentations at schools, taking stands at career shows, including engineering and built environment examples in mathematics and science textbooks, creating career portals and providing detailed online material.

Young professionals should be encouraged to act as the role models by delivering presentations and making themselves available to counsel potential entrants into the field. VAs should be working with education ministries to identify schools with high-potential learners at which to carry out engineering career guidance.

ENCOURAGING FEMALE SCHOLARS

Large numbers are entering engineering studies, but the number of women is still very low in many places. *WomEng* has developed a suite of support programmes for women in engineering, including high school STEM awareness. Funding should be raised to expand the *WomEng* programmes throughout the region.

TERTIARY EDUCATION

There are many challenges in tertiary education, including

- High enrolments
- Inconsistencies in qualifications
- Poor throughput
- Excessive numbers graduating
- A proliferation of higher education institutions of varying calibre
- Inconsistent accreditation regimes.

HIGH ENROLMENTS NOT JUSTIFIED

Although Figure 4 shows correlation between the GDP per capita and the number of engineering practitioners employed in a country, it is important to understand that engineers on their own do not raise the GDP per capita, but it is rather engineering development that is the key driver of growth. There has been the mistaken belief that by increasing the number of engineering graduates, growth will take place of its own accord.

For engineering development to take place, investment is required, along with experienced engineering personnel to investigate, plan and manage developments. The demand to increase dramatically the number of students enrolling in engineering classes cannot be justified until long-term investment is committed and projects are being rolled out. Development will offer internship and training opportunities for graduates, without which the prospects of employment will be limited. Growing the engineering team should be a slow, deliberate process linked to development and increasing demand.

It would seem that a directive has been issued throughout the region to increase the number admitted for engineering studies without the matching demand. The stretch targets have resulted in large classes and high student-to-academic ratios. This affects both the throughput and quality of graduates. Best practice should be considered, and numbers limited to ensure a higher throughput and calibre of graduates.

INCONSISTENCIES IN QUALIFICATIONS

The tertiary approach to educating engineers, technicians and technologists varies considerably across the region. In most countries, only one or two universities were in place in the 1960s and 1970s, modelled on universities in the colonial power at that time. Usually at least one offered an engineering degree. Students would apply for entry and would either receive a bursary or be funded by their family. As there were limited places and graduate numbers were small, students would generally have no difficulty in finding employment on graduation.

In parallel, technical colleges offered the theoretical and practical training associated with the development of a trade- or craftsperson. This was demand-led training, whereby a young employee on the shop floor with aptitude was sent to night school or on block releases to learn more advanced theory and processes, associated with the work being carried out at the time. With the advent of polytechnics, the theory was offered on a semester basis, and students could apply to enter such courses without being employed. The extent and duration of theory taught was extended. A national diploma or equivalent was awarded which normally included two years of theory and a third year spent in industry gaining practical experience. In many instances, as the student was not a permanent employee, investment into the extent and quality of practical training was limited. Furthermore, one year in practice was substantially less practical experience than had previously been gained in the workplace when the student was employed and studying part-time. Industry complains that technicians have had inadequate practical training, but without their commitment to invest in the process or without a change in the structure of technician training, this situation will persist.

With the more recent emergence of universities of technology, technician training has been enhanced to that of technologist or engineer, reducing the number of technicians being trained in several countries. In other countries, the colleges have expanded the levels that they cover, offering Level 5, 6 and, in some instances, level 7 qualifications.

Table 16 compares the types of training approaches and Figure 21 shows the range of models found in the region. The detailed differences are outlined under each category heading below.

Engineers

The approach to educating engineers is reasonably similar throughout all countries. Four- or five-year professional degrees are offered at traditional universities, or the more recently formed private universities. The initial years include mathematical and scientific subjects to develop a sound theoretical base and problem-solving capabilities, after which applied subjects in a range of subdisciplines are taught.

Most degrees tend to span all the subdisciplines within a discipline, rather than focus on narrow subdisciplines. Exceptions have been the emergence of irrigation engineering degrees, rather than agricultural engineering degrees including irrigation, and renewable energy degrees, rather than electrical engineering degrees including consideration of renewable energy. While the specialisation may be good for the specific topic, the question needs to be asked whether these specialisations should not be taught at post-graduate level after completion of a generic engineering degree in the discipline.

Table 16: Comparison between types of training approach

COUNTRY	TECHNICIAN	TECHNOLOGIST	ENGINEER
Angola	Technical Schools **Diploma** From craft training after Grade 9 Complete two years after craft qualification	Universities **Bacharelato** Known as Technical Engineers	Universities **Licenciatura** Five years Third year in industry
Botswana	Colleges and Universities **Diploma and Advanced Diploma** Varies	Colleges **BSc** Three years	Universities **BEng or BSc(Eng)** Four years Vacations in industry
DRC	Institutes **Gradué en Techniques Appliquées** Three years (excl. foundation)	Institutes **Licencié en Techniques Appliqués** Two years after Gradué	Universities **Ingénieur Civil** Five years (excl. foundation)
Eswatini	College **Diploma** Three years Six months in industry	N/A	Universities **BEng** Four years – Biosystems Five years – Electrical
Lesotho	College **Diploma**	N/A	University **BEng** Four-and-a-half years Six months in industry
Madagascar	Universities **Licentiate** Three years	N/A	Universities **Master's** Five years Fourth year in industry
Malawi	Polytechnic **Diploma**	N/A	Universities **BEng** Five years Six months in industry
Mauritius	Institutes, Colleges and Universities **Diploma, HND or C&G Advanced diploma** (Entry O levels)	Universities **BSc** Three years (Entry A levels)	Universities **BEng(Hons)** Three years (Entry A levels)
Mozambique	Technical Schools **Diploma** From craft training after Grade 9	N/A	Universities **Licenciatura** Four or five years
Namibia	Universities of Technology **National Diploma (ND)** Three years One year in industry	Universities of Technology **BTech** One year full-time or two years part-time after ND	Universities **BEng or BSc(Eng)** Four years Vacations in industry
Seychelles	College **C&G Advanced Diploma** Part-time	N/A	N/A
South Africa	Universities of Technology **National Diploma (ND)** Three years One year in industry	Universities of Technology **BTech** One year full-time or two years part-time after ND	Universities **BEng or BSc(Eng)** Four years Vacations in industry
Tanzania	Universities, Institutes and Colleges **Diploma**	Universities, Institutes and Colleges **BEng**	Universities **BSc(Eng)** Three to four-and-a-half years Six to 18 months in industry
Zambia	TVETA Colleges **Advanced certificate**	Universities or Colleges **Diploma**	Universities **BEng** Four years, 3rd and 4th year vacations in industry
Zimbabwe	Institutes and Polytechnics **National Diploma (ND)** Three years One year in industry	Institutes and Polytechnics **Higher National Diploma (HND)** One year full-time or two years part-time after ND	Universities **BTech(Hons), BEng, BSc(Hons)** Five years One year in industry

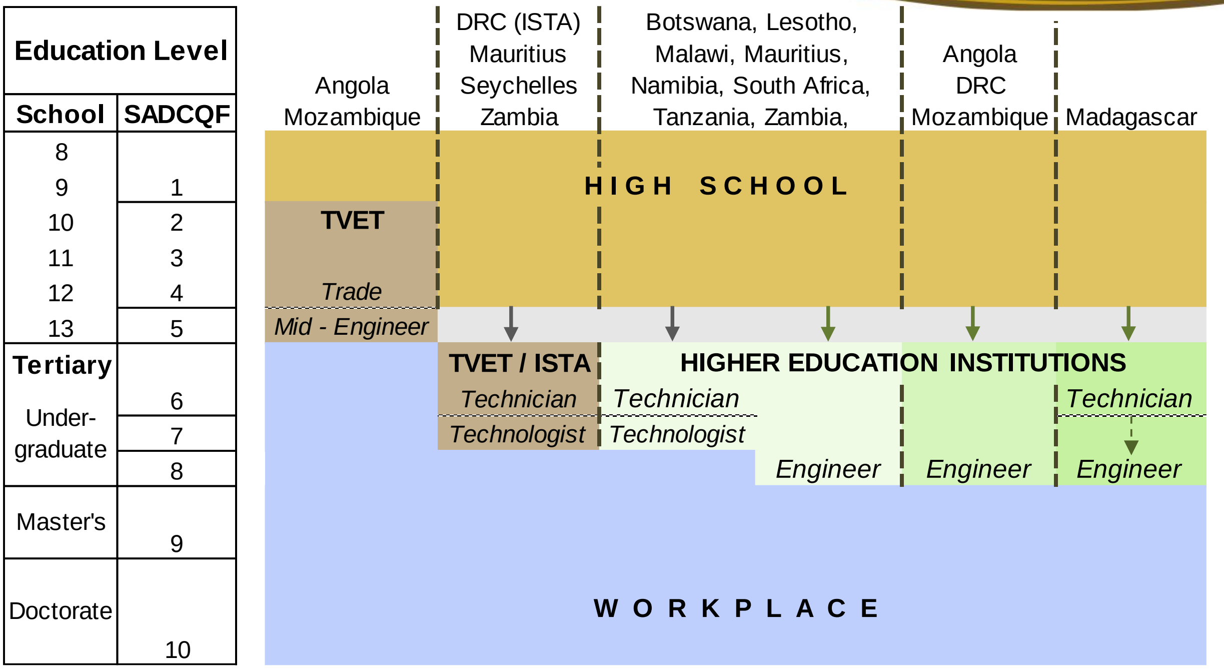

Figure 21: The structure of education models in the SADC region

The English-speaking countries have largely modelled their qualifications on British degrees. It is necessary to complete all years of study before graduating as an engineer. There are no exit points in earlier years. The engineer qualification is known as a Bachelor’s degree, with the nomenclature varying from BEng, BSc(Eng), BEng(Hons) or BSc(Eng)(Hons) or BTech(Hons), depending on the country, institution and duration of study.

Most degrees require that some time is spent in industry, but usually no more than six months, and in several countries only the summer vacations each year.

The engineer qualification in French- and Portuguese-speaking countries is also a four- or five-year professional degree, but it is possible for students to exit after two or three years and work as technicians or graduates – the terminology varies from country to country. In Madagascar students completing the full qualification offered by all types of institutions are recognised as engineers, while in the DRC only those completing qualifications offered by universities are considered to be engineers.

Historically, the training of engineers in universities versus polytechnics was different in these countries, resulting in university-trained graduates being called engineers and polytechnic-trained graduates being known as technical engineers. In Angola public and private universities offer different structures and content in their degrees, which makes accreditation difficult, but graduates from both are now recognised as engineers. The need for alignment is acknowledged.

In the DRC qualifications span six years, the first year being a foundation year. The structure of each qualification is presented in the DRC country report.

The introduction of LMD

With the advent of the Bologna Accord between European countries to ensure comparability in the standards and quality of higher education qualifications, the structure of qualifications has been changed into three cycles – the Bachelor’s degree of 180 to 240 credits, known as the Licentiate, the Master’s degree of 90 to 120 credits, and the Doctoral degree – hence the acronym LMD.

The shortening of the first cycle has raised concern about the reduced time to present the required content for training of engineers and several French- and Portuguese-speaking SADC institutions have expressed the need rather to align with the higher education models adopted by the other countries in the region.

The World Bank has, however, funded several universities to develop the new curricula for the LMD system, hence there is now a mix of the old and new systems in these countries.

To be recognised as an engineer, students must complete a Master’s degree. Students may leave after completing the Licentiate and return to complete their Master's at any stage. Of concern is the fact that students often do not return.

Technicians and technologists

The approach to the training of technicians and technologists varies enormously throughout the region.

In Botswana, Namibia, South Africa and some institutions in Zambia and Zimbabwe, technician training is offered at polytechnics or universities of technology. The training covers the full range of subdisciplines in any given discipline and is a mix of mathematical and applied subjects. The theory is less complex than that of the engineer qualification and is offered over two- or two-and-a-half years. The balance of the qualification is devoted to industrial attachment. These are stand-alone qualifications, which do not require an applied qualification to be completed first, such as with a trade.

In other countries and some instances in Zambia and Zimbabwe, technician and technologist training is offered by vocational colleges which are part of the Technical Vocational Education and Training (TVET) system in those countries. The qualifications may be locally developed, or the City and Guilds qualifications may be used. Qualifications may be stand-alone or may be a top-up to trade theory. In the case of the latter, the qualification will be narrowly focused, for example in automotive engineering rather than mechanical engineering in general.

In terms of City and Guilds qualifications, some countries consider Level 3 as technician and Level 5 as technologist training, while other countries do not recognise Level 3 for technicians but use Level 5 for technician training. The City and Guilds Level 6 qualification is not available in Africa, so theoretically their qualifications cannot be used for training technologists in the SADC region.

Not all countries recognise or offer training for technologists.

The need to review the approach to technician training

The change from the demand to the supply approach to technician training has made the qualification available for entry by school leavers. As a result, students are no longer linked to industry and do not get sufficient relevant practical experience during industrial attachments. As students are temporary staff, few companies have developed structured training for them to ensure that they become hands-on practitioners. The duration of industrial attachments is now far shorter than the period that technicians of the 1960s and 1970s spent in the workplace before graduating. Industry currently complains that graduates are not career ready and cannot be utilised once they have graduated without considerable training and associated investment on their part.

There is a need to revisit the structure and content of technician training to make it more relevant to industry and to return to demand-side training. In terms of the many different qualification structures at technician level in the region, and the definition of competence expected for qualifications recognised by the Dublin Accord, technician training may need to become more applied rather than being general theoretical training.

A possible SADC approach

The different structures and names of qualifications will make alignment difficult. However, recognising the philosophy of the qualification frameworks, a set of exit-level outcomes or graduate attributes needs to be developed per level for assessment of the knowledge gained, the complexity of problem-solving and the degree of autonomy and responsibility developed.

POOR THROUGHPUT

The quality of graduates is poor and the dropout rate is high at many tertiary institutions due to inadequate staffing and poor facilities and support. The bottlenecks that require attention include the following:

Infrastructure

- Facilities, laboratories and teaching space are limited and have not been expanded to cope with the increased enrolments in recent years. Most lecture venues were built for smaller classes and enlarging them is not always an option, as venues become audio-visually compromised.
- Many universities reported having antiquated equipment, some dating back to the 1970s, as well as not having enough sets of equipment for the large numbers enrolled.
- In many instances there is also a shortage of computers and up-to-date software.
- Library facilities cannot cater for the number of students enrolled and have not been modernised to include access to online research materials and books.

Staffing

The staff:student ratios present a challenge in many institutions. Ivy League and top universities in the UK tend to have ratios of 1:10 or less. In 2016 the average ratio for all universities in the USA was 15.2 and 16.9 in the UK. The ratio in South Africa was 1:30.3, which was lower than in most SADC countries.

In South Africa the ratio applies to institutions as a whole, but the number of students per lecturer generally increases in engineering courses due to the difficulty in attracting lecturers from higher paid opportunities outside of academia. Reports of ratios of 1:75 and higher were not uncommon in many countries.

The SADC region is not alone in its struggle with lecturer numbers. In Kenya, the pressure to admit more students in the 'double intake programme' exceeds the capacity of public universities. The number of lecturers being newly hired does not match the number of students being enrolled. The quality of education is now said to '*raise serious concern*'.

Returning to the findings from the region, the following should be noted:

- Academic staffing is the core of what it takes to make a meaningful impact to ensure the success of students. Staffing shortages, high vacancy rates, unsatisfactory staff:student ratios and staff attrition are evident across the system and severely compromise the ability to supply the necessary support to individual students.
- Institutions repeatedly advertise the vacancies and get few, if any, applications. The main reason for lecturing staff leaving or not wanting to enter the sector is the heavy load due to the large number of students and the lack of competitive packages.
- The existing lecture venues are not designed to accommodate large classes. They are at times split into two groups which doubles the teaching load.
- In some countries lecturing staff are expected to undertake research and supervise post-graduate students without a decrease in their lecturing load.
- University policies in some cases preclude the use of external specialists or retired professionals to supplement the teaching staff and act as mentors.
- The qualification levels of lecturing staff are not always appropriate for the qualifications being offered and there is insufficient funding to support them to continue with post-graduate studies.
- To fill posts, recent graduates are employed, many of whom see these jobs as a temporary measure until they find something more suitable. Without post-graduate knowledge, work experience or lecturer training, they can contribute very little to the development of their students.
- Few academics have had practical experience and cannot adequately contextualise the theory.
- Traditionally, lecturers were selected based on expertise in their field, and there was no requirement for them to have formal teaching qualifications. With the increasing load, the changing student profile and generational learning differences, they are not equipped to engage today's students in new and contemporary ways.
- There are not enough dedicated laboratory technicians to ensure that equipment is adequately set up, calibrated, operated and maintained, and to assist with practical sessions to achieve optimum results.
- Many universities do not have enough administrative staff to remove the burden of routine paperwork and reporting from overstretched academics.
- Professional registration and keeping up with the latest technology are important, but few institutions cover annual professional registration fees or membership of voluntary organisations.

Curricula

Re-curriculation and modernisation of many courses and associated material should be considered. At many institutions, course content is still Eurocentric and does not consider rural or local challenges and solutions. According to a Zambian report, design and analysis training is weak and little time is spent on solving problems and developing new and creative ways for value addition.

Content should be presented to, and debated with, industry, governments and educational specialists to ensure that it is fit for purpose, and sufficiently challenges students to meet the requirements of the Accords. To ensure that graduates can work in teams and cope with the ever changing environment, skills in critical thinking, problem-solving, creativity and being able to manage people should be developed.

Teaching and learning

Teaching methods have not been adapted for the 21st century student and should include problem-based learning, blended learning and the use of clickers and the like to ensure engagement. The use of the 'flipped classroom' is proving successful where it has been introduced. Where students watch lectures online and attend classes to discuss topics and undertake associated activities, scores are seen to be higher than those of students who attend traditional courses. In their thought-provoking report entitled *Academically adrift: Limited learning on college campuses* relating to student success in the USA, the authors report that after two years at college, 45% of students show no progress with critical thinking, complex reasoning and writing – skills that are so critical for engineering students to develop. They attribute much of this to colleges not adapting to today's life and learning styles.

The learning environment is also important. Millennial learners tend to absorb more information and develop problem-solving techniques through dialogue. Open spaces for engagement and group work is important but is not always available.

Figure 22: Group work at ISUTC in Mozambique

Student support

In the early years of study where classes are very large, lecturers cannot identify and support all the students who are struggling for various reasons. These include:

- A poor foundation in mathematics and science
- Writing difficulties due to a large proportion of students' studying in their second language
- Lack of career and course guidance at school, resulting in students not being suited to the qualification chosen
- Challenges with living conditions due to inadequate funding
- Adjustment to university life, particularly for those transitioning from rural areas
- Lack of family and community support.

Funding

Making funding available for tertiary education is an ongoing challenge and there are never enough funds to cover all the shortcomings. Governments need to prioritise investment in engineering departments, and industry needs to be encouraged to subvent salaries or contribute to investment funds. Where industries require specialist knowledge and research to be carried out, they should be encouraged to fund professorial chairs and research students.

Although industry and funders are often happy to make funds available, funds are frequently diverted into other budgets. It is important that mechanisms are put in place to ensure that funding given to universities for specific initiatives are ring-fenced so that they are used for the chosen purpose.

Practical training

Industrial attachments allow students to understand the context in which they are learning. However, finding willing employers and monitoring progress is expensive and funding is no longer adequate to cover these activities. Without completing time in the workplace, students cannot graduate. In South Africa, to overcome this problem, the three-year national diploma has been repackaged into a two-year advanced certificate, which simply covers the theory. Once graduates enter the workplace, they need to work for a minimum of four years before they can apply for professional registration, as opposed to three years, which was the minimum requirement with a national diploma.

GOOD PRACTICE

The weaknesses in teaching, practical experience and resourcing have been recognised and there are interventions aimed at supporting tertiary education in various ways.

HEPSSA support

The Royal Academy of Engineering has recognised the need for academic support. Accessing funding from the Anglo American Group Foundation and the UK Government through the Global Challenges Research Fund, it launched the Higher Education Partnerships in sub-Saharan Africa Programme (HEPSSA) in 2016. This initiative focuses on strengthening relationships between academia and industry to produce academics and engineers with the skills and knowledge required to tackle local challenges.

To maximise impact, the programme is implemented through a 'hub and spoke' model. The hub universities are funded to undertake secondments with local industry partners, and in turn, share their experiences with a larger number of spoke universities through knowledge-sharing activities.

Additional sponsorship should be raised to expand this type of support to many more institutions.

The SAICE Code of Best Practice

In 2017, the South African Institution of Civil Engineering (SAICE) carried out a detailed study to develop a best practice guideline for civil engineering departments. The study sought industry's views on the acceptability of graduates, identified gaps in curricula, laboratory and practical training, and interrogated academia on the challenges they faced. Predictably, the range of challenges outlined above emerged. Researchers quantified the optimum structures, including academic staff and administrators; facilities, equipment, systems and other support required; as well as the teaching approaches that should be considered.

State-of-the-art equipment was identified for each type of laboratory and SAICE is currently drawing up a tool for civil engineering departments to use to determine appropriate staffing levels and equipment for their class sizes and subject mixes. The plan is to update the information each year. The intention of the best practice guideline and the schedules that will be generated from the tool is to assist faculties to motivate for additional funding and to give less-experienced academics a guide on which to build their departments. Using the guide will be important to ensure that institutions are not stretched beyond acceptable levels. The model should be expanded to all disciplines and developed for the region.

TOO MANY GRADUATES

The number graduating has increased substantially since 2005 as shown in Figure 23. Furthermore, the graphs do not represent the total number graduating in countries marked 'partial', as only partial datasets were received. This suggests that graduations could be higher.

The number graduating exceeds the number that can be absorbed, giving rise to the phenomenon of the unemployed graduate. The continued supply-side approach to education and training needs to change and become more reflective of demand. As outlined in Chapter 4, an increase of 5% to 8% of the workforce is required to accommodate growth and replacement demand per year. In some countries, graduations have exceeded 20%, and even higher percentages when stratified to levels of qualifications, as shown in Table 17. Graduates in these situations have limited prospects of employment.

Rationalisation of the numbers being admitted is critical in terms of throughput and graduate training. When selecting where to cut, countries need to

Table 17: The number and percentage of graduates to engineering practitioners

COUNTRY	IN THE WORKFORCE		GRADUATES		%	
	Engineer	Technician/ Technologist	Engineer	Technician/ Technologist	Engineer	Technician/ Technologist
Angola	9 000		1 200		13%	
Botswana	3 319	2 681	117	345	4%	13%
DRC *1	6 700	11 300	1 176	2 500	18%	22%
Eswatini *2	550	1 050	139	127	25%	12%
Lesotho *2	450	700	20	347	4%	50%
Madagascar	4 000	7 000	896	757	22%	11%
Malawi	1 750	1 450	202		12%	0%
Mauritius	2 000	3 000	501	304	25%	10%
Mozambique	11 000		767		7%	
Namibia *3	1 550	1 250	99	129	6%	10%
Seychelles	310	200	16	16	5%	8%
South Africa *3	48 000	62 000	2 772	5 577	6%	9%
Tanzania	15 500	14 500	1 044	3 354	7%	23%
Zambia	5 200	6 800	351	575	7%	8%
Zimbabwe *3	5 250	2 350	575	1 576	11%	67%

*1 Including 3 700 agricultural engineers/agronomists

*2 Limited disciplines offered at local institutions. Overall numbers including those graduating outside the country will be higher

*3 Technologists not included – in these countries the qualification is offered at post-graduate level

Legend: % OK | % a little high | % excessive

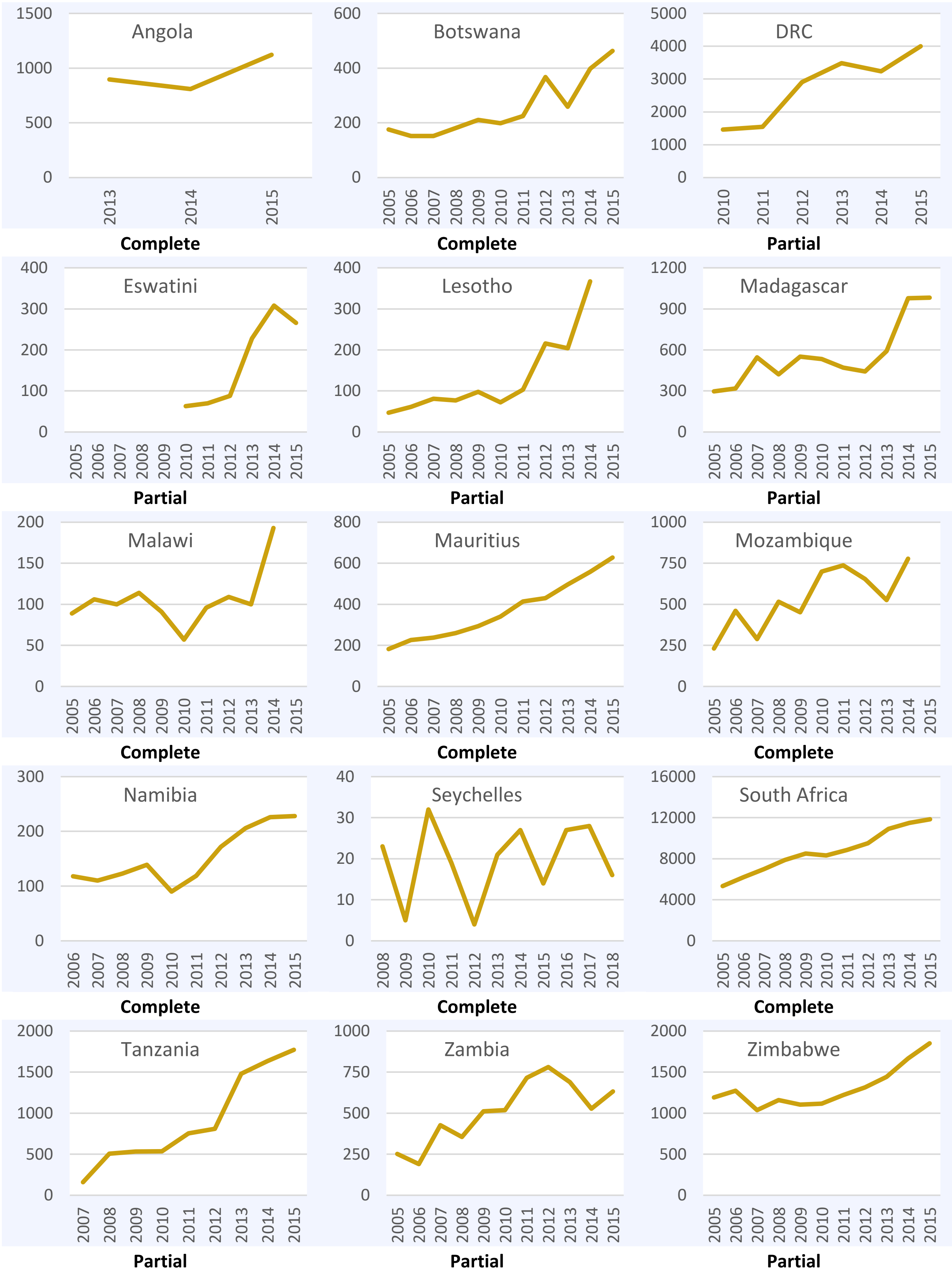

Figure 23: Graduation trends

consider their development priorities and retain those disciplines and qualifications that will address their needs. These are outlined in country reports.

In those countries with inadequate numbers of experienced local engineering professionals, external expertise and capacity may be required in the short to medium term, but such appointments must be linked to training and skills transfer to build an adequate base of local engineering skills, able to solve local problems in the future.

It should be noted that the scope of the current study was not a census of the engineering population in each country, but gives a high-level view. To determine exact numbers required per sector and industry needs per discipline, a detailed census per sector needs to be carried out. In time, each country should embark on its own detailed research to determine specific discipline requirements.

THE PROLIFERATION OF ENGINEERING PROGRAMMES

In recent years, countries have increased the number of public tertiary education providers, mainly to address regional needs, and have recognised private tertiary education providers. As a result, the number of courses offered has increased dramatically. Private education has become a commercial business, with student fees as the main source of income. For institutions to be viable, there needs to be a balance between students and academics. Where student numbers are low, this limits the number of academics employed, to the detriment of the education.

Each engineering discipline is composed of several subdisciplines. For instance, in civil engineering, structural, geotechnical, roads and transport, and water and sanitation are some of the many subdisciplines that must be covered, while in mining engineering, the range of minerals, underground, opencast, alluvial and other mining methodologies must be covered. Specialists in each subdiscipline or subject are required.

A study of staffing required in a civil engineering department, carried out some years ago, showed that a minimum of 18 academics were required to cover all the specialist subjects, and departments were not viable without at least 50 first year students per year. In many new universities, class sizes are very small, limiting the number of academics and the range of specialists available. As a result, the quality of graduates leaves a lot to be desired.

In other institutions determined to make a profit, only a handful of academics are employed to support thousands of students, who have been promised top-quality engineering education. In one institution there were only two full-time engineering academics to support 1 500 engineering students.

There is an urgent need to rationalise the number of tertiary education institutions offering engineering qualifications per country to ensure that the standard is upheld. Rigorous accreditation is required to approve programmes before universities, polytechnics and colleges should be allowed to take on large numbers of students. The support required per country is covered in detail in each country report.

THE NEED FOR CONSISTENT ACCREDITATION

The content and complexity of offerings vary enormously. Only South African higher education engineering qualifications are recognised under the Accords as outlined in Chapter 3. Educational specialists and industry players with a keen interest in the standard of education have been trained through ECSA’s agreement with the IEA on how to assess and accredit engineering qualifications to ensure equivalence.

Although assessors have found programmes to be equivalent at several institutions in the region, they have also found many degree courses to be equivalent simply to technologist qualifications, technologist courses to be equivalent to technician qualifications, and the theory associated with many technician courses to be equivalent to trade theory.

The number of tertiary institutions offering engineering qualifications is shown in Table 18, along with the differences in accreditation approaches.

The Accords cover the graduate attributes required for each category of engineering. Graduates need to have understood the theoretical underpinning of their chosen discipline or subdiscipline, and to become problem-solvers able to manage the type of work expected of their level of education. Accreditation bodies are expected to monitor and ensure that the appropriate standard is achieved. The attributes that are assessed are broadly:

1. **Knowledge:** Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialisation according to the

Table 18: Different accreditation approaches

(Number of institutions per country offering engineering qualifications)*

COUNTRY	No.*	ACCREDITING BODY	ROLE OF PROFESSIONAL BODY	RECOGNITION BY PROFESSIONAL BODY
Angola	16	National Institute for the Evaluation, Accreditation and Recognition of Higher Education Studies (INAAREES) t	Not involved with the Department	Only recognises five-year degrees offered by public universities
Botswana	9	Botswana Qualifications Authority (BQA)	Works with BQA to review qualifications	Only recognises some of the qualifications as shown in the country report
DRC	123	Ministry of Higher and University Education Looks at resources and credits	Not involved	ACIC recognises qualifications from the Universities of Kinshasa, Lubumbashi, Goma and Mbuji Mayi
Eswatini	2	-	Newly formed professional body plans to accredit qualifications	The professional body recognises all categories of engineering professionals with accredited qualifications
Lesotho	2	Lesotho Council for Higher Education (CHE)	Works with CHE and educationalists from South Africa	NUL is working with the University of Pretoria and ECSA towards achieving Washington Accord provisional status
Madagascar	25	Ministry of Higher Education and Scientific Research (MESUPRES)	Works with MESUPRES to review qualifications.	Only recognises five-year qualifications from public universities
Malawi	5	National Council for Higher Education (NCHE)	The Engineering Act requires the Board of Engineers to accredit qualifications	The professional body recognises all categories of engineering professionals with accredited qualifications
Mauritius	9	Tertiary Education Commission (TEC)	Works with TEC to review and approve qualifications. Only registers engineers with recognised local qualifications or accredited by the Engineering Council	An independent Engineering Accreditation Body (EAB) is being set up which is working towards provisional recognition under the Washington Accord, to be able to accredit local qualification
Mozambique	22	National Council for the Evaluation of the Quality of Higher Education (CNAQ)	Works with the CNAQ to review and approve qualifications	The professional body only recognises engineers from established universities
Namibia	2	Namibia Qualifications Authority (NQA)	Works with the NQA to review and approve qualifications	The professional body recognises all categories of engineering professionals with accredited qualifications
Seychelles	1	Seychelles Qualifications Authority (SQA)	No professional body – being established	-
South Africa	14	Council for Higher Education (CHE)	Assigned responsibility for assessing qualifications	The professional body recognises all categories of engineering professionals with accredited qualifications, and is a signatory to the Washington, Sydney and Dublin Accords
Tanzania	17	Tanzania Commission for Universities (TCU) and the National Council for Technical Education (NACTE)	Serves on TCU and NACTE committees to review and approve qualifications.	The professional body recognises all categories of engineering professionals from established institutions
Zambia	10	Higher Education Authority (HEA) and the Technical Education, Vocational and Entrepreneurship Training Authority (TVETA)	Works with the HEA to review and approve qualifications. Several new universities offer qualifications but are not yet accredited	The professional body recognises all categories of engineering professionals with accredited qualifications, including artisans
Zimbabwe	12	Zimbabwe Council for Higher Education (ZimCHE)	Works with ZimCHE to review and approve qualifications	The professional body recognises engineers and technologists with accredited qualifications

level of complexity required of an engineer, technologist or technician.

2. **Problem analysis:** Identify, formulate, research literature and analyse engineering problems, reaching substantiated conclusions in line with the level of complexity required for the qualification.
3. **Design/development of solutions:** Design solutions of complexity, according to qualification-level requirements, for engineering problems, systems, components or processes that meet specified needs, with appropriate consideration for public health and safety, cultural, societal and environmental considerations.
4. **Investigation:** Conduct investigations of engineering problems of relevant complexity using appropriate research techniques to draw valid conclusions.
5. **Modern tool usage:** Select and apply appropriate techniques, resources and modern engineering and IT tools to engineering problems.
6. **The engineer and society:** Assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to engineering problems.
7. **Environment and sustainability:** Understand and evaluate the sustainability and impact of engineering work in the solution of engineering problems in societal and environmental contexts.
8. **Ethics:** Understand and apply ethical principles and commit to professional conduct and responsibilities, and norms of engineering practice.
9. **Individual and teamwork:** Function effectively as an individual, and as a member or leader in diverse teams.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large
11. **Project Management and Finance**: Demonstrate knowledge and understanding of engineering management principles and economic decision-making, and apply these to own work, as a team member or a team leader.
12. **Lifelong learning:** Recognise the need for, and have the ability to engage in, independent and life-long learning in the broadest context of technological change.

The level of complexity set for each NQF level qualification will vary.

In many countries, the engineering body does not carry out accreditation. This is done by the qualification authority or the Department of Education or equivalent. This often means only ensuring that a range of subjects and adequate credits are included in the curriculum. The content, complexity and principles taught, student-to-staff ratios and quality or availability of laboratories or equipment are not interrogated in depth.

A SADC approach

The Accord standards should be adopted by all countries, and engineering bodies should be assigned the accreditation role. A compromise in standard may be necessary at the outset, but a minimum set of criteria should be agreed on initially, and a 10- or 15-year plan should be developed to ensure that over time all attributes can be achieved, and that qualifications produce the desired result.

CENTRES OF SPECIALISATION

Many countries have introduced new qualifications to address current needs, as discussed in Chapter 2. For instance, Angola has developed qualifications focusing on oil and gas. Others have started offering marine, textile and rail qualifications among others. The number of students who need to complete such qualifications is not high, but such specialisations are required. Collaboration between countries to decide on specialisations is needed and the requirements of all countries should be incorporated so that such qualifications are relevant for the region. Funding for the development of Centres of Specialisation, which can serve all countries, should be raised.

POST-GRADUATE TRAINING

Similarly, post-graduate specialisations should be debated and developed to cover regional needs. For instance, coastal, railway and harbour engineering have been highlighted as areas in which employees require more advanced knowledge.

REGIONAL KNOWLEDGE-SHARING

Other pioneering solutions have been developed which do not require full qualifications but rather short courses and hands-on training, such as the approach to wastewater recycling in Windhoek Municipality. Consideration needs to be given to exchanges between equivalent tiers of government to share knowledge and experience. There are bodies such as the Association of National Road Agencies (ASANRA) and the S.A. Independent Power Producers Association which share knowledge in the fields of roads and energy, but there does not appear to be a SADC grouping of municipal engineers.

STUDENT MOBILITY

Although most countries now have many institutions offering engineering qualifications, there is still significant student mobility for various reasons. Table 19 lists the some of the countries in which students choose to study.

Quality of education

Students travelling to other countries cite the quality of education as an important consideration. In 2015, there were a total of 52 878 SADC students enrolled in South African universities studying towards a range of qualifications, and 719 graduated with engineering qualifications. Students from many countries advise that they will have better job prospects when returning home with a South African qualification than a local qualification.

Qualifications and choice of discipline

In the smaller countries, universities do not offer the full range of engineering disciplines, or all levels of qualifications, hence the need to study outside the country. In these cases, governments at times offer bursaries to ensure that they have an adequate flow of engineering graduates returning to the country.

Foreign support

As part of bilateral agreements, foreign countries have offered free education for students from SADC countries, provided that the government pays the travel and accommodation costs. Although the offer of free education sounds attractive, the associated costs can be high. Furthermore, where tuition is offered in another language, students first need to spend a further year learning the language, adding to the costs and duration of study. In some cases, although the receiving country claims to be offering engineering degree studies, qualifications are not at the level expected and returning students find that their qualifications are not recognised by the local registering body. A coordinated effort is required between the departments responsible for arranging study grants and the departments that are the custodians of the registering bodies.

Table 19: Student mobility - country choices

COUNTRY	COUNTRIES FROM WHICH STUDENTS COME TO STUDY	COUNTRIES TO WHICH STUDENTS GO TO STUDY
Angola	Mozambique	Brazil, Canada, China, Cuba, France, Mozambique, Namibia, Portugal, Russia, South Africa, UK, USA, Zimbabwe
Botswana	Lesotho, Namibia, Zambia, Zimbabwe	Australia, Canada, China, Namibia, South Africa, UK, USA, Zimbabwe
DRC	Cameroon, Congo, Rwanda	Belgium, France, South Africa, USA
Eswatini	Zimbabwe	Russia, South Africa, Taiwan, USA, UK
Lesotho	Zimbabwe	Botswana, China, India, South Africa, UK, USA
Madagascar	Comoros and French-speaking countries, Namibia	China, France, Mauritius, Namibia, USA
Malawi	Mozambique, Zimbabwe	Australia, Kenya, South Africa, Tanzania, UK, USA
Mauritius	Burundi, India, Kenya Madagascar, Seychelles, Sri Lanka, Uganda	Australia, France, India, Malaysia, South Africa, UK
Mozambique	Angola	Algeria, Angola, Brazil, China, Cuba, India, Japan, Malaysia, Malawi, Portugal, Russia, South Africa, Tanzania, UK, USA
Namibia	Angola, Botswana, Kenya, Madagascar, South Africa, Tanzania, Uganda, Zambia, Zimbabwe	Austria, Cuba, Cyprus, Germany, Russia, South Africa, Tanzania, UK, USA, Zimbabwe
Seychelles	India	Australia, China, Egypt France, India, Malaysia, Mauritius, South Africa, UK
South Africa	All SADC countries, plus another 100 – refer to the HEMIS system for information	Australia, France, Namibia, Portugal, UK, USA
Tanzania	Mozambique, Namibia, Zimbabwe	Australia, China, India, Namibia, South Africa UK, USA
Zambia	Zimbabwe	Australia, Namibia, South Africa, UK, USA
Zimbabwe	Angola, Namibia	Australia, Canada, China, Cuba, India, Namibia, New Zealand, Russia, South Africa, UK, USA

RECOMMENDATIONS

A comprehensive academic experience is the foundation for developing engineering professionals. Much support is needed to enhance the quality of education. Specific recommendations are made in each country report. However, in general, the following need to be considered.

Schooling

- **Teachers:** the number of teachers needs to be increased.
  - **Teacher training** needs to be expanded to reduce the ratios of learners to teachers, and programmes to enhance the teaching of mathematics and science are required.
  - **Online learning platforms:** Schools need to be equipped with online learning facilities to increase the number of learners with access to quality teaching, and teachers need to learn how to facilitate large classes using new technology.
  - **Funders and major employers** in both the private and public sectors should be approached to provide computers, tablets and computer laboratories, or offer study rooms or areas where learners can access the internet and study on their own using corporate devices or their own devices.
- **High-calibre learners** need to be identified and given support to develop their full potential.
- **Subjects** need to be reviewed to ensure that they are relevant. Indigenous knowledge should be taught where relevant and subjects appropriate to localities, such as agriculture, need to be included as options when selecting vocational subjects.
- **Infrastructure needs to be upgraded, expanded and maintained**, including schools, classrooms, laboratories, libraries and associated resources. Practical and proven cost-effective school and classroom designs need to be shared in the region.
- **Resources,** including books, computers, laboratory and other equipment are required.
- **Career guidance** should be rolled out using a range of approaches, including videos, presentations, brochures and informative websites covering not only engineering disciplines, but also how to apply to tertiary institutions and access bursaries. Young role models in industry should be harnessed to visit schools where there are learners with potential. This should include reaching female learners, and those in rural and low-income areas.
- **Bursaries** are required where tertiary education is not free to attract learners with good mathematics and science results to study engineering.
- **Studies outside the country:** Where engineering qualifications are not available locally, or capacity is limited, bursaries or support for students to study outside the country is necessary. It is, however, important that:
  - The international institutions selected offer qualifications that will be recognised by the local registering body when students return.
  - The numbers being supported are based on demand from industry and public sector structures.
  - Graduates are obliged to return to work in the country for a contract period, and funding is repaid should recipients not complete their contracts.

Tertiary education: Addressing throughput

A range of interventions is required to improve throughput.

- **Industry liaison:** Liaise with industry on a regular basis to ensure that curricula, methods, software and equipment are relevant, up to date and consider local conditions.
- **Curricula:** Provide funding to research, modernise and develop curricula and associated material where required.
- **Research:** Develop research and innovation capacity.
- **Teaching methods:** Apply the latest methods and technology for teaching, and train academics in 21st century approaches to teaching.
- **Facilities:** Raise funding to develop or upgrade lecture theatres, offices, libraries and laboratory facilities where required.
- **Resources:** Raise funding for computers, engineering software, access to online reference material, and laboratory and other equipment, and ensure adequate support to offer technology-relevant training.
- **Maintenance:** Budget for effective and continuous maintenance of equipment and facilities.
- **Optimal ratios of staff to students:** Determine optimal staff:student ratios to establish the number of additional academic posts required.
- **Attract and retain academics:** Improve conditions of service, support and packages to attract, retain and appoint additional academics.

- Approach industry to subvent salaries or contribute to investment funds, professorial chairs and research students.

- **Academic development:** Provide funding for lecturer post-graduate development and facilitate opportunities for academics to gain experience in industry.
- **Administrative staff:** Ensure that adequate support and administrative staff are in place.
- **Retired professionals:** Approve the use of retired professionals to supplement the teaching load and act as mentors.
- **Part-time lecturers from industry:** Extend the use of industry experts to offer part-time or *ad hoc* lecturing.
- **Student support:** Expand tutoring support, summer and winter school interventions and the development of a buddy system to support students with the transition to the academic environment and, in many cases, city life for the first time.
- **Workplace experience:** Encourage industry to accommodate students requiring industrial attachments.

Tertiary Education: Alignment and rationalisation

To allow for mobility in the region, alignment of the accreditation of qualifications and quality assurance processes is essential. Rationalising the number of institutions offering engineering qualifications to ensure quality output will also be required.

- **A SADC Tertiary Education Engineering Education Committee (TEEEC)**, possibly a subcommittee under the TCCA, should be formed to consider qualification requirements and accreditation. This should be composed of academics and representatives from industry and accreditation bodies. Detailed research into industry needs to be carried out per discipline, and fed into this committee to ensure that relevant solutions are developed.
- **Accreditation and quality assurance:** A consistent approach to accreditation is required. Ideally, professional bodies should be assigned the responsibility of accrediting or assessing engineering qualifications on behalf of the national quality assurance body to ensure that an appropriate range of subjects at the required level of complexity is offered.
- **Alignment of qualifications:** A common understanding of the role expected of technicians, technologists and engineers must be agreed and outcomes for each level of qualifications must be aligned, ideally using the graduate attributes of the Dublin, Sydney and Washington Accords as developed by the IEA.
- **Achieving the IEA standard:** The IEA attributes and accreditation model should be adopted as the benchmark. It will take several years for all countries to reach the same standard, but all institutions should be assessed and rated, and milestones should be set over 5, 10 or 15 years, or whatever is considered necessary to get all institutions up to the same standard. Some institutions may choose not to follow this approach. This would, however, disadvantage their graduates as they may not be registerable by the registering body in that country.
- **Rationalisation of enrolments and the number of institutions:** Norms and standards in terms of staff:student ratios, class sizes and minimum resourcing needs must be agreed. Where these cannot be met, approval for offering engineering qualifications should be withdrawn. Rationalisation of the number of students being enrolled and the number of institutions that can be sustained per country is also necessary.
- **Centres of Specialisation:** Collaboration must be facilitated when qualifications are being developed in specialist areas required only by a subset of countries to obviate the need for developing such qualifications in each country, especially where the numbers are small.
- **Post-graduate qualifications:** Coordination and collaboration are required for selecting appropriate topics and developing post-graduate qualifications.
- **Foreign studies:** The suggested TEEEC should play a role in advising governments on the suitability of qualifications being offered by donor countries.

Chapter 8

Graduate training

Worldwide employers have complained for many years about the difficulty in finding engineering skills. Without interrogating their statements, policy-makers have encouraged the opening of many more universities and the offering of many more engineering qualifications, only to find that the shortage of engineering skills persists.

It is evident from these statements that the difference between a scarce skill and a skills gap was not understood or perhaps inadequately articulated. A 'scarce skill' is one that is simply not available, whereas a 'skills gap' exists where there are qualified people, but they do not have appropriate experience. Employers are complaining about the lack of **experienced** staff. Experience is only developed in the workplace. The opening lines of the publication *Numbers and Needs* highlighted this problem back in 2005.

'Too few, too many.
No experience – can't get a job.
No job – can't get experience.'

The 'too few' referred to 'too few experienced' engineering staff, and the 'too many' referred to far 'too many inexperienced' graduates. The remaining two lines are obvious and must be addressed to overcome skills gaps.

Professor Peter Cappelli from the University of Pennsylvania considers that the skills gap is a myth. The real issue is that employers need to provide more on-the-job training.

THE UNEMPLOYED GRADUATE CHALLENGE

There is much to be considered in terms of the history of training, perceptions and bottlenecks.

THE DEMISE OF PAST PROGRAMMES

Graduates must be absorbed and trained in a structured manner before they can become useful to their employers. Such training was in place in public sector structures across the world until the late 1980s when outsourcing and unbundling were adopted.

Public sector structures which handled the entire process of conceptualisation, planning, design, implementation and operation and maintenance were ideal training grounds, and in many countries were the main structures in which training took place. When many of these functions were outsourced, graduate programmes were discontinued. Countries where this approach was

widely followed have lost 20 to 30 years of growing their own experienced professionals, which is evident from the ongoing complaints of shortages.

The change in employment policies over the years has also impacted on appointing and developing graduates in the public sector. A lifetime career in the public sector was the norm, with graduates being trained and developed through the ranks, and promoted based on performance or as they achieved registration and other further education or training milestones. This is no longer the case, as it is necessary to apply formally for each post that falls vacant. Often the internal candidate is overlooked, thwarting development. Of concern in terms of the graduates' plight is that many public sector structures no longer have junior engineering posts.

Senker captures the challenge of training engineers when he suggests that governments and companies have not realised the importance of the workplace. He asserts that *'the quality and quantity of the learning opportunities afforded by experience at work are the primary factor affecting the quantity and quality of engineers' learning'*.

The large numbers of unemployed graduates must be absorbed and developed, and workplace training for future graduates must be catered for. At present it seems that, in general, only large consulting engineering companies which recognise the value of having more registered professionals, and some utilities and mining companies, have continued to offer comprehensive graduate training programmes.

EMPLOYMENT CHALLENGES

There are many reasons why graduates are unable to find work, the most important of which are:

- **Oversupply:** The supply greatly exceeds the demand for graduates in many countries.
- **Limited projects:** Organisations cannot afford to take on graduates unless they have enough work, which has become a problem in tough economic times.
- **Quality:** The quality of graduates leaves a lot to be desired and organisations select only the best to employ and train.
- **Not career ready:** Companies consider that graduates should be career ready like the medical profession or teachers, and wish to employ only experienced professionals, but do not consider the years of internship covered in the qualifications of the other professions. (It should be noted, however, that the cost of

internships for the medical and education professions are borne by the state in teaching hospitals, etc.)

- **Competitive bidding:** Companies cannot afford to train graduates. The latter has come about because governments have delegated training to the private sector, at the same time expecting the sector to compete for work at rock-bottom prices.
- **International service providers:** Most large projects have been awarded to international consultants and contactors. The latter rarely appoint local staff, let alone train graduates.
- **No junior posts:** In many countries there are no junior posts in the public sector, or legislation prescribes that only registered professionals may be appointed. This precludes recent graduates from joining the public sector.
- **Moratorium on employment:** In several countries there is a moratorium on employing new staff in the public sector.
- **Inappropriate qualifications:** Graduates returning from studying overseas may find that their qualifications are not recognised in their home country.

GRADUATE EXPERIENCES

The fortunes of graduates vary across the SADC region, depending on the percentage of graduates, the quality of higher education and the development taking place in the country.

Unemployed graduates are an exasperated group of young people, a large percentage of whom have had very frustrating experiences trying to enter the workplace, and often don't get meaningful work once appointed.

In many countries appropriate posts are not advertised. Out of desperation, graduates send their CVs to hundreds of employers, and often do not get a single response. They therefore take employment outside of engineering and the longer they are out of engineering, the more difficult it is to find an engineering post. Others start their own businesses outside of engineering, never to return.

As a matter of interest, some Member States reported that unemployed graduates make good mathematics teachers. The TeachFirst initiative in the UK has recognised the value of using those with undergraduate qualifications to enter the teaching profession and offer intense short-term training to help graduates transition into teaching – perhaps something similar should be offered in the region.

Graduate engineers also apply for technician posts in the hope of eventually being able to move into an appropriate post when it becomes vacant, thus precluding technicians from filling the limited number of posts available.

Employers take advantage of the oversupply, pay very low wages and at times use graduates to carry out menial tasks not related to engineering.

Due to limited opportunities locally, the brightest graduates apply to do post-graduate studies in other countries and once they have proved their worth in host countries, do not return home.

Many try their luck at applying for posts outside the country, but generally only those who come from respected and long-established institutions are successful.

SUPERVISION CAPACITY

The reality is that the major part of an engineer's training is in the workplace, working on real projects under the guidance of experienced supervisors who act as coaches, ensuring skills transfer. In a structured environment, a mentor would also be assigned to the training phase to monitor progress and ensure that in the long term the graduate has gained a range of experience of increasing complexity, and has been given the opportunity to take increasing responsibility and make decisions under guidance.

Supervisors and mentors, however, also have their own roles to play in terms of leading projects, monitoring progress and liaising with stakeholders, among others, and only have limited time to spend with each staff member who reports to them. The growth in the number of graduates reflects the increasing number of those under 35 in most SADC countries. Table 20 shows the ratio of 25- to 34-year-olds to the supervisor/mentor age group of 35 to 64. In some countries, the number of 25- to 34-year-olds is more than 70% of the number of 35- to 64-year-olds. In Africa the average is 63% as against the world average of 42%. This presents a huge challenge in terms of training capacity. In Europe the ratio of younger to older is as low as 30%, in North America it is 35% and it is only slightly higher, at 40%, in South America and Asia.

There are simply not enough of the experienced age group with adequate time to devote to the development of young people, if traditional workplace skills transfer methods are the only methods used. Techniques such as Action Learning, pioneered by Revans after World War II when the ratio of senior to young staff was also very low,

Table 20: Percentage per age group

REGION	COUNTRY	PERCENTAGE PER AGE GROUP				RATIO OF 25–34 TO 35–64
		0–24	25–34	35–64	>=65	
SADC	Angola	63.55%	14.04%	19.54%	2.88%	72%
	Botswana	45.90%	16.67%	32.08%	5.34%	52%
	DRC	62.96%	13.97%	19.83%	3.24%	70%
	Eswatini	54.60%	17.09%	24.81%	3.50%	69%
	Lesotho	53.74%	17.11%	24.88%	4.27%	69%
	Madagascar	57.86%	15.10%	23.39%	3.65%	65%
	Malawi	60.66%	15.38%	20.92%	3.04%	74%
	Mauritius	30.30%	14.22%	40.69%	14.79%	35%
	Mozambique	61.78%	14.58%	20.34%	3.30%	72%
	Namibia	53.38%	16.09%	26.19%	4.34%	61%
	Seychelles	34.50%	13.43%	39.32%	12.75%	34%
	South Africa	44.16%	16.48%	32.75%	6.61%	50%
	Tanzania	61.68%	14.36%	20.58%	3.38%	70%
	Zambia	62.21%	14.82%	20.24%	2.72%	73%
	Zimbabwe	57.03%	16.34%	23.47%	3.17%	70%
World and Continental Averages	World	39.87%	14.59%	34.71%	10.83%	42%
	Africa	57.37%	14.91%	23.66%	4.06%	63%
	Asia	37.29%	14.89%	37.04%	10.78%	40%
	Europe	26.35%	12.23%	40.31%	21.11%	30%
	Northern America	30.91%	13.19%	37.43%	18.47%	35%
	South America	36.67%	15.12%	36.78%	11.43%	41%

Legend	% OK	% a little high	% excessive

should be considered. The Revans approach advocates group learning on actual projects where the subjects *'learn with and from each other by mutual support, advice and criticism during their attacks on real problems'*. This approach has been used successfully in MBA programmes for many years.

Given the big infrastructure projects planned in many SADC countries, there is no reason why graduates cannot be appointed in groups and given a range of tasks to solve together. In this way they will learn from each other as well as from the line manager assigned to supervise and manage their development. However, it is not every experienced engineering professional who considers that it is his or her duty to train graduates. Two approaches need to be considered in this regard:

- Making graduate training a key performance area for seniors
- Appointing external, possibly retired, staff to oversee groups being assigned to projects, under the direction of the line manager.

GRADUATE DEVELOPMENT

Clearly, many factors must be in place for effective development to take place. These include:

- **Commitment:** The employer, graduates-in-training, supervisors, mentors, and managers involved must be committed for graduate programmes to be successful.
- **Orientation:** An orientation session should be convened to explain the requirements of the registering body, the roles players, activities and programme and what is expected of graduates.
- **Plan:** A plan should be drawn up to ensure that graduates are exposed to a variety of engineering activities and that the outcomes expected by industry and the registering body will be achieved.
- **Projects:** There should be suitable projects on which to gain experience, which will allow graduates to take increasing responsibility and learn how to solve increasingly complex problems. Where the range of such projects is limited, rotation to other departments, or secondment to other organisations should be considered.
- **Supervision and coaching:** There must be experienced line managers, with sufficient time to supervise and coach graduates.
- **Resources:** Appropriate tools and equipment, including computers, software and protective gear, among others, must be available.
- **Support systems:** There must be access to reference material and a community of practice

to whom graduates may refer for additional input and support.

- **Reporting and reviewing:** Graduates should report on the work they have carried out and progress should be reviewed on a regular basis.
- **Mentoring:** A mentor must be assigned to monitor progress, challenge graduates and select additional or alternative engineering activities where necessary. The mentor may also be the supervisor, but must recognise his or her role to monitor the graduate's long-term progress, as well as the day-to-day tasks carried out under his or her supervision.

Recognising the need to re-implement formal programmes, countries have started to develop structured or national approaches which should be used to create guidelines for a regional model. The most substantial programmes are outlined below.

TANZANIA

The Structured Engineers Apprenticeship Programme (SEAP), as outlined in the Tanzania report, spells out the need for funded, structured training programmes to develop tomorrow's professionals. The programme was launched by the Minister of Works, Hon John P. Magufuliin, in January 2003 and is supervised by the Engineers Registration Board (ERB). It aims to enable Tanzanian graduate engineers to qualify for registration as professional engineers in the shortest possible time. The ERB monitors progress, engages with mentors and reviews quarterly reports.

After extensive consultation, a detailed programme implementation document was developed which covers among others:

- Competence standards to be achieved
- The requirements for employers
- Roles and responsibilities for all parties
- Suggested training activities per discipline
- Supervision and monitoring
- The use of a logbook and monitoring requirements
- Assessment methods
- Various contract documents and agreements between the ERB, employer and graduate.

Of importance is the list of activities suggested per discipline. Although comprehensive, the list is not prescriptive, and recognises that experiences will vary per sector and type of industry, even for the same discipline. Achievement of the outcomes is the ultimate aim. It is thus suggested that appropriate activities should be selected per employer to make up the training plan.

This principle is important when developing any training programme, as it will not be possible in any one environment for graduates to gain experience in the range of activities associated with their discipline within the first few years of their careers. Given that the guidelines were developed some 15 years ago, additional disciplines need to be added to the guideline, and the outcomes should be aligned to those of the IEA, although many are essentially the same.

In the early 2000s the programme focused on placing graduates in government, but as funding has been reduced, the private sector has taken over funding and offering placements. Since 2003, a total of 5 300 graduates have been taken on, of whom just over 2 000 graduates had been supported by the private sector since 2015. The public sector training posts are now reserved for female students, who are taken on with the assistance of foreign funding. Although graduate training has increased, it is estimated that only half of the graduates are trained through SEAP.

SOUTH AFRICA

In South Africa, the *Training Standard* was gazetted by the Construction Industry Development Board (cidb) in 2013. If appended to a tender, it compels service providers to make provision in their tenders to train apprentices, students and graduates. Requirements include the provision of a training plan, logbook or reporting template, an experienced supervisor who will assign tasks and coach graduates, and a mentor who will monitor progress and intervene when experience being offered is inadequate.

A structured approach to training has been re-implemented by several parastatals, large infrastructure departments and metropolitan municipalities. These organisations take on graduates and generally follow relatively rigid programmes, which in some cases are not demanding enough as complex work is outsourced to consultants and contractors.

A graduate being developed towards professional registration is known as a candidate. Candidate training has been recognised as a learning pathway where *'candidacy means a period of workplace-based learning undertaken by a graduate as part of the requirement for registration as a professional in the required professional designation as stipulated by a professional body'*. Employers may access funds from the Sector Education Training Authorities (SETAs) for candidate training beyond public sector projects.

There is a need for the cidb Training Standard to be made mandatory on all public sector projects.

MAURITIUS

In 2014, to try to address the unemployed graduate challenge, the Ministry of Labour, Industrial Relations and Employment has created the Youth Employment Programme (YEP). It is possible for graduates to apply for support, or for companies to approach the YEP for suitable graduates to take on for a period of two years. During this period, the employer is expected to train graduates towards the competence expected of their profession. The programme pays the stipend for graduates if employed in the public sector, and 50% of the stipend if in the private sector. The YEP also contributes towards the costs of supplementary training during the period, as long as it is recognised by the Mauritius Qualifications Authority (MQA).

The challenge is to ensure that graduates follow a structured programme of meaningful work to achieve the outcomes expected by the Council of Registered Professional Engineers (CRPE). It is important that mentors are in place to monitor the process. The Institution of Engineers Mauritius (IEM) is busy designing graduate training programmes for the industry to use, to ensure that graduates are given appropriate experience.

ZAMBIA

In Zambia, although it does not address graduate training, the Copperbelt Energy Corporation has stepped in to assist with making students more career-ready. Recognising that academia cannot compress engineering fundamentals, changing technological and industry needs into undergraduate programmes, they have constructed a complete power system (composed of two substations and a transmission line complete with a control system) at the University of Zambia's School of Engineering. They have also supported the development of a curriculum in solar energy technology at the Copperbelt University as part of their recently constructed 1 MW solar photovoltaic power plant.

They also support students in the annual Shell Eco-Marathon in which they are challenged to design, build and drive the most energy-efficient car, and they offer internships to make students more employable upon graduation. Many more companies should be encouraged to follow suit.

OTHER SECTORS AND THE UTLITIES

In many countries one or more utilities are still offering structured training in some form or another, while in Angola companies are called upon to submit and have their training plans approved to access training funds made available from the sale of oil.

Of concern is the fact that limited training is seen in the private sector in areas such as manufacturing, ICT, consulting and mining in some countries.

In the words of Professor Cappelli *'… employers… must be deeply involved in the process of skills development—just as they were in the past. But how can we get decentralized employers to help provide work-based learning experiences in some structured way for people who are not already their employees? That seems to be the challenge, and it's a big one.'*

RECOMMENDATIONS

Investment in tertiary education will not achieve the engineering capacity desired without following through and ensuring that funds are invested in graduate training. Methodologies for funded, structured training must be developed and agreed upon, emerging from this study. The large numbers of unemployed graduates must be absorbed and developed to become the experts of the future.

Graduate training

- **A regional committee** should be formed under the SADC Technical Committee on Higher Education, Training, Research and Development composed of employers and professional bodies, who have been successful with graduate training. The committee should develop graduate training guidelines for the region to ensure that graduates achieve the level of competence required by industry and for professional registration.
- **Guidelines** should include an overview of the variety of engineering activities that could contribute to graduate development, along with all the elements listed under the section titled *Graduate Development,* such as:
  - Committed employers, graduates, supervisors, mentors and managers, and suitable projects on which to gain experience
  - Approaches to developing and updating training plans
  - Supervision, coaching and mentor roles, requirements and techniques
  - Resources and support systems required

- Reporting and reviewing mechanisms, etc.

- **Management and structure:** Programmes should be managed by engineering professionals and should include the opportunity for rotation or secondment where appropriate experience is not available in existing positions. Graduates must also be afforded the opportunity to take on increasing responsibility and increasingly complex work.

The committee will need to consider and propose various options, allowing for flexibility and adaptation by employers, as experience per discipline and sector varies and no two workplaces are alike.

Training opportunities

Approaches to ensure that every '*engineering workplace becomes a training space*'[2] need to be considered.

- **Private sector incentives:** Offer tax rebates or incentives for private sector companies to develop graduates.
- **Public sector support:** Ensure that public sector structures take on and train graduates, and that they are absorbed and developed through the ranks.
- **Institutional support:** Institutionalise graduate training in all organisations by setting KPIs for experienced staff to act as supervisors and mentors.
- **Project support:** Make graduate training a requirement of all public sector projects and ensure that the progress of graduates is monitored, and penalties are imposed for non-compliance.

Promotion and support

Once adequately designed and documented, professional bodies should become the vehicles for promoting such programmes, advising on them and assisting with access to mentors, as well as training employers, mentors and candidates alike on what is expected of them in the first few years of a graduate's career.

[2] This is a phrase coined by Minister Blade Nzimande when he was the Minister of the Department of Higher Education and Training in South Africa.

Chapter 9

Professional registration

The science of modern-day infrastructure, such as surfaced roads, railway networks, waterborne sewage removal, piped potable water and, later, electrification, as outlined earlier in the report, only emerged in the late 18th century and needed to be shared by the pioneering masters with their peers to ensure that the technology was widely adopted and implemented.

In 1818, an exuberant group of young pioneers recognised the need for a structured method of sharing information and formed the London-based Institution of Civil Engineers for the purpose of *'promoting the acquisition of that species of knowledge which constitutes the profession of a civil engineer'*. Over time, institutions or 'learned societies', as they were known, sprang up worldwide with the goal of sharing knowledge; they are still leaders in sharing information and technological advances today. One of the first institutions to be formed in the SADC region was the South African Institution of Civil Engineering which was formed in 1903. Many others followed as purely 'Voluntary Associations', a term which is in common usage. There are several VAs in each SADC country, addressing discipline and/or sector interests, although some are not very active, or have been dormant for some time. Details of all the VAs are covered in the country reports.

PROFESSIONALISATION

In the 1920s a change in approach to corporate membership of institutions began to emerge in the UK and the USA. Simply practising in the field did not ensure the competence and associated high standards that were considered important. Many institutions introduced professional exams and licensing. The London-based Institutions of Structural Engineers and Civil Engineers introduced their exams in 1920 and 1932 respectively, and in the USA, the Californian Structural Engineers became one of the first to introduce professional registration and 'licensing' exams in the 1930s. Structural engineering received early attention due to the obvious threat to public safety in the event of unsatisfactory designs, and in California, in particular, due to the behaviour of structures during earthquakes.

More recently, licensing has become the domain of statutory bodies. In the UK, the Engineering Council was formed in 1982 as an outcome of the Finniston Report which investigated the responsibility and status of engineers in the UK. The Engineering Council took to moderating exams set by the Institutions and issuing the Chartered status required for independent practice. These bodies are referred to as Registering Bodies (RBs).

Mauritius was the first country in the region to form a statutory body. Amendments to the Private Bill governing the Institution of Engineers Mauritius (which was formed in 1934) were submitted to parliament for consideration. The Select Committee recommended that a statutory body be set up for this purpose, hence the emergence of the Council of Registered Professional Engineers (CPRE) in 1965. Tanzania and South Africa followed suit in 1968, with the formation of the Engineers Registration Board (ERB), Tanzania, and the South African Council of Professional Engineers (SACPE) respectively. SACPE has since become the Engineering Council of South Africa (ECSA). Both are statutory bodies responsible for registering engineering professionals.

By the early 2000s, there were 10 registering bodies in the SADC region. In 2009, 2013 and 2018, registration Acts were promulgated in Botswana, Eswatini and the DRC respectively (see Table 21 to 23). As the Act associated with l'Ordre National des Ingénieurs Civils (ONICIV) was only promulgated in the DRC on 13 December 2018, details were not available to include in this report.

Most statutory bodies fall under the Ministry or Department of Public Works or Construction in each country. These ministries or departments may also have set up statutory bodies to regulate contractors, and in some instances consulting engineering practices. In South Africa and Tanzania, overarching bodies have been RBs. In South Africa, the Council for the Built Environment (CBE) was set up under the CBE Act. It oversees the RBs for engineering, architecture, landscape architecture, quantity surveying, construction project management and construction management, and property valuations. In Tanzania, the National Construction Council (NCC) was set up under the NCC Act. It oversees the RBs for engineering, contracting, architecture and quantity surveying.

CATEGORIES OF REGISTRATION

Details of the categories of registration per country are shown in Table 21. Eswatini, having a small population, has elected to set up one RB for all built environment professionals. Lesotho is in the process of finalising a registration bill in which they have adopted a similar approach. The Seychelles is also developing a registration bill.

Table 21: Registration categories and criteria per country, 2018

COUNTRY	Graduate engineers	Graduate technologists*	Graduate technicians	Professional engineers	Professional technologists*	Professional technicians	Temporary professional engineer	Minimum period to professional registration	Other categories
Ordem dos Engenheiros de **Angola** (OEA)	-	-	-	√	√ TE	-	-	After graduation	√
Engineers Registration Board, **Botswana** (ERB)	√	√	√	√	√	√	<1 year	4 years	Registered Engineer, Technologist, Technician
l'Ordre National des Ingénieurs Civils, **DRC** (ONICIV)	√	-	-	√	-	-	Unknown		-
Architects, Engineers, Surveyors & Allied Professionals Registration Council of **Eswatini** (AESAP)	√	√	√	√	√	√	√	3 years	Certificated Engineer Professional Architect, Surveyor and Allied Professional
Ordre des ingénieurs de **Madagascar** (OIM)	√	-	-	√	-	-	-	1 year	-
Board of Engineers, **Malawi** (BoE)	√	√	√	√	√ TE	√	-	1–3 years	Selected Registered Engineer
Council of Registered Professional Engineers of **Mauritius** (CRPE)	√	-	-	√	-	-	√	2 years	-
Ordem dos Engenheiros de **Moçambique** (OrdEM)	√	-	-	√	-	-	-	2 years	-
Engineering Council of **Namibia** (ECN)	√	√ IE	√	√	√ IE	√	√	3 years	-
Engineering Council of **South Africa** (ECSA)	√	√	√	√	√	√	-	3 years	Certificated Engineer, Specified Category
Engineers Registration Board, **Tanzania** (ERB)	√	√ IE	√	√	√ IE	√	√	3 years	Registered Consulting Engineer
Engineers Registration Board of **Zambia** (EngRB)	√	√	√	√	√	√	√	2 or 4 years	Registered Craftsperson
Engineering Council of **Zimbabwe** (ECZ)	√	-	√	√	-	√	√	3 years 2 years for technicians	-

* Professional technologists are known as Technical Engineers or Technician Engineers (TE) or Incorporated Engineers (IE) in some countries

From Table 21 it can be seen that countries have adopted different approaches. Initially, most Acts only catered for the registration of engineers. Amendments, as listed in Table 23, have generally included additional categories, recognising that the engineering team comprises several levels of engineering practitioners, each responsible for different elements of engineering projects. However, not all countries offer tertiary education qualifications covering the content considered appropriate for engineers, technologists (also known as incorporated engineers or technical engineers) and technicians.

It should be noted that the development of competent engineering practitioners is a two-step process, whereby professional registration is the summative assessment of the competence developed in the education and workplace phases (known as Stage 1 and Stage 2 in the IEA documentation). This applies to the registration of engineers, technologists and technicians, but may be different in some of the other categories.

Other categories of registration

As can be seen from Table 21, there are several other categories that have been accommodated by various bodies.

- **Craftspeople:** The inclusion of craftspeople by the Zambian EngRB is a departure which needs to be debated. The structure of craft training is substantially different from that of engineering practitioners in that the bulk of training is hands-on through an apprenticeship in a workplace. Before being certified as a craftsperson, or tradesperson, learners must undergo a summative assessment which largely assesses their ability to build or repair the equipment, machinery or infrastructure relating to the field. This means that crafts- or tradespeople have already effectively been registered. If registering bodies are going to adopt these categories, it will be necessary to decide what role they should be playing in terms of ensuring standards.
  If the call for registration has arisen as the quality of artisan training has declined, then the causes must be addressed. If the requirement for registration persists, registering bodies will need to have access to workshops, tools, material and master artisans to carry out appropriate assessments.
- **Certificated engineers** as registered by ECSA are practitioners who have a Government Certificate of Competence under the Mining or the Factories Acts and are responsible for health and safety management on large mechanical or electrical installations. Before registration they must have taken responsibility for such installations for at least two years.
- **Specified categories** relate to master artisans or specialist operators responsible for items of equipment that could be hazardous to public health and safety if they are not adequately calibrated or maintained, such as Lift Inspectors, Lifting Machinery Inspectors and Medical Equipment Maintainers.
- **Selected registered engineers** as recognised by Mauritius refers to experienced registered engineers who have been nominated to supervise and develop graduates towards professional registration.
- **Registered engineers, technologists and technicians** in Botswana refers to an additional level of registration whereby applicants who are found to have inadequate experience for registration as professionals, but who have had three or more years of experience, are given interim registration. They are required to return for re-assessment once they have had sufficient experience to satisfy the outcomes prescribed. However, many simply use the ERB registration certificate reflecting the category 'Registered' to show that they are registered, and clients without intimate knowledge of the ERB system believe that this certification signifies a competent professional. The ERB are considering withdrawing this category of registration.

Registration of graduates

There are varying approaches to the registration of graduates. In some countries, graduate registration is not a prerequisite for professional registration but is voluntary. The term 'candidate', or 'graduate-in-training', or the specific category-in-training, such as 'engineer-in-training' or 'technician-in training', is used.

In other countries such as Zambia and Tanzania, registration of graduates is compulsory. They are given a grace period after being employed by which time they must have registered. In Namibia, they must first register with the ECN before they can apply for a job, which can delay their opportunities for employment.

ASSESSMENT AND REGISTRATION

Professional registration is a measure of competence and the ability of graduates to work independently. The International Engineering Alliance (IEA) has developed attributes for what is expected of registered professionals per category, to allow the mobility of professionals. In the SADC region, there is disparity in approaches to professional registration, which requires consideration.

ASSESSMENT

Although assessment takes place, in some countries the measure for registration is simply the time spent in a workplace after graduation, while in other countries there is a rigorous approach to assess the complexity and quality of work carried out. Detailed reports must be submitted, and applicants are interviewed or must write an exam. The structure of detailed reports and the assessment of what is required of a professional, however, also vary.

The IEA attributes require that a person ready for registration should be able independently to:

1. Comprehend and apply knowledge of complexity relevant to category of registration, which underpins good practice
2. Comprehend and apply knowledge specific to the jurisdiction of the area of practice
3. Define, investigate and analyse engineering problems
4. Design or develop solutions to engineering problems

5. Evaluate the outcomes and impacts of engineering activities
6. Recognise the reasonably foreseeable social, cultural and environmental effects of activities, consider the need for sustainability, and recognise that the protection of society is the highest priority
7. Meet all legal and regulatory requirements and protect public health and safety in the course of engineering activities
8. Conduct activities ethically
9. Manage part or all of one or more engineering activities
10. Communicate clearly with others in the course of engineering activities
11. Undertake CPD activities sufficient to maintain and extend competence
12. Exercise sound judgement in the course of engineering activities and choose appropriate solutions
13. Be responsible for making decisions on engineering activities.

There is always the danger that applicants did not complete their own application forms or were given substantial assistance to complete their forms. Interviewing applicants or setting professional exams offers the opportunity to determine where applicants have performed to the level as outlined in their submissions and whether they can think on their feet. The disadvantage of interviews is the time required for professionals to devote to interviews, but it does allow the applicant's ability in his or her practice area to be thoroughly scrutinised and the opportunity to test high level-thinking, problem-solving and creativity, as outlined under Bloom's Taxonomy in Chapter 3, *Developing professionals.* The disadvantage of professional examinations is the difficulty in being able to cover the practice areas of all applicants, hence the pass rate for professional exams tends to be lower than that for the interview process.

As part of the registration process, all professionals are expected to abide by the Code of Conduct of the respective body. Most Codes of Conduct are similar and expect professionals to act with integrity and not perform work other than that for which their education, training and experience has rendered them competent. The applicant's understanding of ethical issues must be interrogated when attending the professional interview.

As part of the preparation for professional registration, many countries have included the requirement for Initial Professional Development (IPD). This requires that graduates grow their knowledge and skills through self-study, and by attending courses, workshops and conferences as required. This is not limited to technical development, but covers any skills required to grow as a professional, which could include the use of software, public speaking, etc. IPD has been introduced not only for development during the graduate training phase, but also to develop the culture of life-long learning.

Consideration should be given to alignment of the registration process in the region, including

Table 22: Numbers of candidates and professionals registered

COUNTRY	CATEGORY								METRICS		
	GRADUATE/CANDIDATE-IN-TRAINING				PROFESSIONAL				COMPARISONS		%
	Engineer	Technologist	Technician	Certificated	Engineer	Technologist	Technician	Certificated	Total professional	Engineering workforce	% professionally registered
Angola	506	-	-	-	3 337	-	-	-	3 337	9 000	37.1%
Botswana *	1 542	297	1 201	-	1 272	123	357	6	1758	6 000	29.3%
Eswatini	12	3	17	2	36	6	6	-	48	1 600	3.0%
Madagascar	-	-	-	-	765	-	-	-	765	11 000	7.0%
Malawi	-	-	-	-	706	423 TE	163	-	1 292	3 200	40.4%
Mauritius	-	-	-	-	851	-	-	-	851	5 000	17.0%
Mozambique	1 225	-	-	-	1 868	-	-	-	1 868	11 000	17.0%
Namibia	452	321 IE	197	-	506	201 IE	102	-	809	2 800	28.9%
South Africa	7 749	4 385	6 674	281	15 862	5 513	3 921	966	26 262	110 000	23.9%
Tanzania	9 428	661	-	-	5 699	409	-	-	6 108	30 000	20.4%
Zambia	-	-	-	-	2 066	566	483	-	3 115	12 000	26.0%
Zimbabwe	-	-	-	-	1 754		473	-	2 227	7 600	29.3%

*Candidates includes those in the Registered, but not Professional categories interviews and assessments based on the IEA attributes.

Comprehensive workplace training and adequate exposure to a sufficient range of experiences is thus required to prepare graduates for such assessments. The scope of workplace training and registration requirements were outlined in Chapter 8, along with the associated challenges of gaining adequate workplace experiences.

REGISTRATION

Different types of registration are in place. In Angola and Madagascar, graduates are not professionally registered in the manner carried out by other registering bodies, but rather those graduating from accredited institutions are granted a 'licence' to enter the engineering workplace. If the region works towards a uniform accreditation process for all engineering qualifications as discussed in the previous section, this approach should be replaced with the more rigorous approach of assessing workplace competence.

Both countries, plus the DRC, the Seychelles and Lesotho, are looking at implementing professional registration systems and need support in this regard.

FUNCTIONALITY PER BODY

There are several other differences in the various Acts, as shown in Table 23, as discussed below.

RECOGNITION OF PRIOR LEARNING (RPL)

Very few Acts make provision for the recognition of prior learning (RPL). RPL recognises that practitioners could have achieved the knowledge and practical competence by experience rather than through a combination of qualifications and experience. This normally applies to older practitioners, or those who have studied and gained experience in countries where the structure of engineering education and training is different from the structures in the region. Detailed analysis of work done, and the knowledge gained, is assessed to determine equivalence to registration requirements. Documenting experience to demonstrate competence via RPL is very demanding and assessments are extremely rigorous. However, the process is worth considering to ensure that those who have developed the competence can be recognised and can contribute to the engineering workforce.

RECOGNITION OF FOREIGN QUALIFICATIONS

In the absence of the Accords applying worldwide, it is difficult to determine whether applicants with foreign qualifications have received an education on par with the local qualifications required for professional registration. Several countries have developed a register of those qualifications which they recognise, but do not have streamlined mechanisms for assessing qualifications from other higher education institutions. In the absence of receiving a transcript of the courses covered, the projects and problem-solving undertaken, and the lecturing capacity and laboratory facilities in place, it is difficult to assess equivalence. Some countries do not accommodate these assessments.

Other countries require all the documentation listed to be validated by the SADC country's embassy in the country of study before they will assess them. Where there is no embassy in the country of study and documents must be sent to the embassy in another country for validation, the process can takes months or years, or not happen at all. It is essential that mechanisms are established for the recognition of qualifications gained in other countries.

Registering bodies also need to work with ministries on the choice of countries and institutions to which students are sent to study overseas. Although receiving countries offer free tuition, the countries sending the students must pay travel and accommodation costs. It has been found in several instances that returning students have discovered to their dismay that the qualifications they have gained do not match the requirements of their country's registering body.

When considering the world ranking of countries in terms of GDP per capita, or the ranking of higher education institutions, it has been found the students are at times sent to countries which are weaker financially, and to institutions of lower ranking than in their home country. These returning graduates struggle to compete with those who studied locally.

CONTINUING PROFESSIONAL DEVELOPMENT (CPD)

To keep up to date with the latest technologies, methodologies and legislation, it is essential that professionals learn from experts at the cutting edge, have access to the latest documentation, and attend courses and workshops to expand and share their knowledge. CPD is the life-long process by which professionals can enhance their knowledge and skills to complement both their current role and their future career progression. As career progression is so important and to encourage the application of best practice, CPD should be a requirement for all

Table 23: Details of registration Acts

COUNTRY	ACT NUMBER	ASSESSMENT METHODS				OTHER						
		Detailed experience submission	Interview	Exam	Provision for RPL	Requirement for CPD	Recognition of VAs	Compulsory registration	Registration in public sector compulsory	Council selected or endorsed by Minister or Council (MS/ME/C)	Minister may register individuals	Annual practising certificate
Angola: OEA	Decree No. 39-E/92, 1992	Qual.	-	-	-	-	-	-	-	C	-	-
Botswana: ERB	Eng Reg Act CAP 61:0, 2009 & Act 23/2013	√	-	-	-	√	√	√	√	ME BIE	-	√
Eswatini: AESAP	Act 15/2013	√	√	√	√	√	√	-	-	ME	√	√
Madagascar: OIM	Law 95-024, 1995	√	-	-	√	√	?	-	-	C	-	-
Malawi: BoE	Act 17/1972 Amended Act 5/1988	√	√	√	-	-	-	√	√	MS	-	-
Mauritius: CRPE	RPEC Act 49/1966 Amended 1967	√	√	-	-	-	-	-	√	ME VAs	-	√
Mozambique: OrdEM	Law No. 16/2002	√	√	-	-	-	-	√	√	C	-	-
Namibia: ECN	Act 18/1986 Amended Act 25/1991, GN 22/2004	√	option	-	-	-	-	-	-	MS	-	-
South Africa: ECSA	SACPE, Act 81/1968 ECSA, Act 46/2000	√	√	option	√	√	√	-	In nat. & prov. depts	ME	-	-
Tanzania: ERB	Act 48/1968 Amended Act 15/1997, 24/2007	√	√	√	-	√	√	√	√	MS	√	√
Zambia: EngRB	Act 17/2010	√	-	-	-	√	-	√	√	C	-	√
Zimbabwe: ECZ	Act 161/2010	√	-	-	-	-	√	-	Exempt	MS	-	√

ME = Minister Endorses MS = Minister Selects C = Council Selects VAs = with the help of VAs (or BIE)

professionals to retain their registration status. CPD is, however, not a requirement of many of the current Acts.

RECOGNITION OF VOLUNTARY ASSOCIATIONS (VAs)

Some Acts recognise the value of voluntary associations (VAs) and require the registering body to assess the services offered by VAs to ensure that they are up to standard. Registering bodies set criteria for the size and services that voluntary bodies are expected to offer to be recognised as VAs.

In some countries membership of the engineering VA is compulsory and in others recognition of competence is required by the VA before practitioners can be registered by the registering body.

COMPULSORY REGISTRATION

There is disparity in the requirements for compulsory registration and membership of VAs. In Zambia and Tanzania, registration is compulsory, hence large numbers are registered, as shown in Table 22. These institutions keep a close watch on the industry in terms of quality of work and registration of practitioners in all companies and on sites. In other countries, even though registration is compulsory, it is not enforced.

In South Africa, the Act requires practitioners to be registered who are carrying out *'engineering work'*. The definition of engineering work has never been agreed upon, and in 2015, the Competitions Commission ruled that compulsory registration was anti-competitive and was not acceptable. This flies in the face of world best practice and the Constitution, which states that the public has a right to be protected in terms of health and safety.

In Mauritius, only a subset of those carrying out engineering work are required to be registered professionals. The Act states that '*Nothing … shall prevent or deem to prevent … any person from operating, executing, or supervising any works as owner, contractor, superintendent, foreman, inspector or master*', and goes on to exempt '*the work of an employee … of a person registered …, where such work does not include final designs or decisions …*'.

Membership of VAs, as the name suggests, is voluntary in most countries, except Zambia and Zimbabwe. In Zambia membership of the EIZ is compulsory and in Zimbabwe registration with the ECZ is only possible after an applicant has been assessed to be competent and made a Corporate member of the ZIE.

REGISTRATION OF PUBLIC SECTOR EMPLOYEES

Although they are not always defined in the Acts, regulations associated with registration and posts have been developed in most countries. In some countries, such as Malawi, Tanzania and Zambia, public sector engineering officials are expected to be professionally registered, while in Zimbabwe, the law specifically exempts public sector officials from being registered. In South Africa, registration is required for personnel filling technical rather than management posts in provincial and national government. Registration is not specified as a requirement by local government or the utilities.

In those countries where registration in government is compulsory, a problem has arisen in that new graduates cannot be appointed into the structures and trained to grow in the ranks. Where efforts are made to take graduates on for training, they are offered short-term contracts. Thereafter they find themselves unemployed and the departments are without the resources that they have trained. Organograms need to be revisited and must span from junior to senior posts. Registration should only become a requirement above a certain grade.

APPOINTMENT OF COUNCILS

With regard to the agreements developed by the IEA, engineering registration boards should be independent of government to ensure impartiality in setting standards, and in decisions relating to accreditation, registration and malpractice. Many Acts have been carefully crafted to ensure that, although the Acts are statutory, members of the councils are selected from the pool of professionals in each country, and are nominated by VAs and the councils, and not government. Although ministers may appoint the councils, they do not involve themselves in the process, but merely rubber stamp the selections made by professionals (denoted as ME in the table for 'Minister Endorsed'). In this way, the IEA has accepted that statutory bodies may serve as accrediting bodies on their behalf.

Some Acts, however, give the minister the power to select and appoint councils (shown as MS in the table for 'Minister Selected'). Such registering bodies would not be able to serve as signatories to the accords or the mobility agreements. It also means that there may be long delays between the end of one council's term, and appointment of the next council, as identifying and appointing council members is not always a priority within the ministry under which the council falls. Consideration needs to be given to peer selection and the wording, *'appointed by the Minister on recommendation of'* should be included in all Acts.

POLITICAL INTERFERENCE

Of concern is the fact that a few Acts empower the minister to overrule the accreditation and registration decisions made by the appropriate committees. Cases have been reported of ministers insisting that an applicant be granted professional registration, even when the committee has determined that the applicant has not achieved the outcomes and level of competence required. This flies in the face of the registration philosophy, which is to protect the public from inadequate designs and solutions, which are usually the hallmark of those with insufficient experience to solve complex engineering problems. A review of these clauses is urgently needed.

ANNUAL RE-REGISTRATION

In some countries, re-registration is stringently administered annually and professionals are given an annual licence to practise. If fees are not paid by the cut-off date, the names of those registered do not appear on the annual register. In others, even if registration fees are not paid, names continue to be published but a series of warnings are issued before the professional is finally struck off the list.

ACCREDITATION OF QUALIFICATIONS

Acts vary in their requirements for registering bodies to perform as the accrediting bodies for tertiary education engineering qualifications, as outlined in Chapter 7.

MALPRACTICE

All Acts assign the responsibility of addressing malpractice to registering bodies. However, in some countries they may only intervene when practitioners who are reported for poor performance are registered professionals. This means that those practicing without registration must be charged through the courts, which is a lengthy process. Until compulsory registration is in place, this will continue to be a problem.

In some countries registering bodies wait for complaints to be formally lodged before investigating malpractice and in others registering bodies have teams of inspectors actively looking for transgressions.

UPDATING OF ACTS

The previous comparisons are based on requirements and activities defined in the various engineering Acts. However, much more detail is contained in by-laws and regulations, which would also be valuable to share with Member States. These will eventually be compiled and shared on the African Engineering Portal www.aepportal.co.za.

Several registering bodies in the region are considering updates to their Act and bylaws to accommodate many of the omissions and shortcomings discussed.

RECOMMENDATIONS

There is a substantial amount of work to do to achieve alignment of professional registration in the region. Until there is uniformity in qualifications and registration requirements, the mobility of engineering resources will be restricted, limiting the potential for local practitioners to contribute towards infrastructure development and industrialisation.

A regional committee/working group

A subcommittee under the TCCA, composed of registering bodies, those aspiring to introduce registration, a representative from the Southern African Federation of Engineering Organisations (SAFEO) and, when required, advisers from the IEA, should be set up to interrogate all Acts and best practice in registration, and to ensure that all adopt one set of outcomes per category and similar assessment processes to achieve a standard on which the region can rely.

Harmonisation of approaches

Issues that will need to be considered are:

- Categories of registration and attributes to be measured
- Methods of assessment
- Approaches to be adopted for RPL
- Approaches to assessing foreign qualifications
- Graduate training requirements
- IPD and CPD requirements
- Recognition, membership and roles of VAs
- Types of work for which professional registration is compulsory
- Methods of appointing registration councils, assessors and reviewers to ensure impartiality
- Licensing versus registration
- Handling of malpractice
- The development of a SADC Register modelled along the lines of the International Register.

Promoting professional registration

Registering bodies and VAs should work together to promote professional development and registration to ensure a standard of engineering that can be relied upon. In the words of Eng. Martin Manuhwa, when he was president of SAFEO in 2017, *'… there is a need to … mainstream the development of engineering programmes to promote infrastructure development in Africa'* and for all African countries *'… to be signatories of the International Accords, Competency Recognition and Mobility Agreements …'*.

Chapter 10

Tomorrow's leaders

Developing tomorrow's engineering specialists, experts and leaders requires more than university education and graduate training. They must be visionary strategists, able to conceptualise and implement unique solutions to address client and global needs, and must inspire others to be part of the vision and solution. This requires the development of not only graduates but young professionals and those in their mid-careers to grow into leadership roles.

The diagram in Figure 24, which is the thinking adopted by Engineers New Zealand, shows possible career paths for an engineering practitioner.

CAREER PROGRESSION

The education, early workplace training and registration process have been covered. However, professional registration is only the beginning of an engineering career. After the registration milestone, engineering professionals will continue to build expertise from project to project. Although they are able to operate independently after registration, most professionals will work on complex projects that require considerable teamwork. Team members will debate possible solutions, challenge each other's views, learn from each other, and develop throughout their careers, ultimately becoming the experts who are now in great demand.

As their careers progress, they may elect to become technical specialists, or follow the management route, or a combination of both. As they advance, they will increasingly be given the responsibility of supervising others and checking their work, and later motivating and leading teams, departments or organisations. The progression of roles and responsibilities for a practitioner who remains in the corporate environment is described in more detail in Table 24.

It should be noted that there are many stages in the graduate development process. The speed with which the graduate develops is dictated to some extent by the projects and supervision in place, but largely by the graduate's own initiative and willingness to investigate and research solutions independently and to take on increasing responsibility.

Progression would be slightly different with regard to long-term planning, operations, maintenance, etc., if Table 24 was applied in a public sector structure.

In all cases, to succeed, ongoing development is essential. Development opportunities, however,

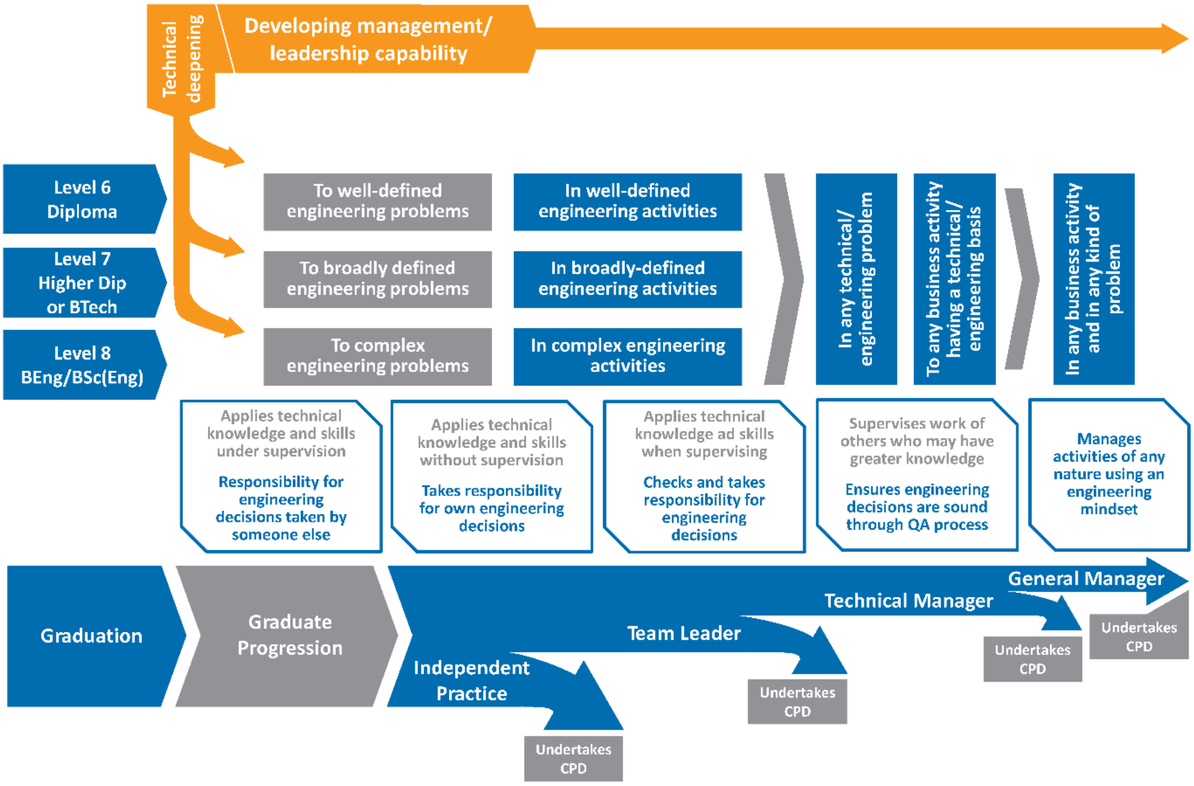

Figure 24: The engineering career model

(Courtesy: Engineers New Zealand)

Table 24: Career progression

Increasing Complexity and Responsibility

STAGES	ACTIVITY
Graduate	▪ Responsible for initial checking of own work while working under close supervision
	▪ Responsible for managing own work and prioritising tasks, following established processes and procedures when working on defined tasks under supervision
	▪ Same as above under limited supervision
	▪ Responsible for parts of projects under limited supervision ▪ Manages and checks own work and that of others, prioritises tasks, organises activities, prepares documentation, and attends internal meetings
Independent Practice	▪ Responsible for small projects under minimum supervision ▪ Manages and checks own work and that of others, coaching them when required, prioritises tasks, organises activities, prepares documentation, attends internal meetings and external project meetings
	▪ Responsible for projects of some complexity, mainly without supervision ▪ Schedules resources as required, prioritises tasks, organises activities, prepares documentation, attends internal meetings and external project meetings ▪ Checks own work and that of others, motivating and coaching them when required
Team Leader	▪ Solely responsible for major, complex activities or projects from inception ▪ Plans, schedules resources as required, prioritises tasks, organises activities, prepares documentation, attends project meetings ▪ Manages staff as above and assumes mentoring role ▪ Becomes involved in corporate budgeting, setting long-term goals, negotiating, etc.
Technical Manager	▪ Senior manager responsible for one or more teams and multiple projects ▪ Manages the planning, design and implementation of major projects, schedules resources within budgets and timelines, organises activities, attends project and other local meetings ▪ Becomes more involved in corporate activities as above, plus recruitment ▪ Takes on corporate roles of motivating for budgets and support for major projects, negotiating with funders, service providers and suppliers, and handling stakeholder and inter-governmental relations
	▪ Part of senior management involved in corporate strategy and setting and managing key performance areas ▪ Managing the planning, design and implementation of major projects within tight constraints and dealing with stakeholders as above ▪ Responsible for organising activities, attending major national and international events
General Manager	▪ Becomes Technical Director responsible for leading an office and making technical and some strategic decisions OR
	▪ Becomes General Manager responsible for making strategic corporate decisions

seemed to be limited in many SADC countries, particularly in ministries.

DEVELOPMENT ACTIVITIES

There are three areas of development that must not be overlooked, namely continuing professional development (CPD), technical and management development.

CPD

CPD applies to all engineering professionals, regardless of the career path they choose as outlined in the previous chapter. Not only does attending CPD events offer formal learning, but networking with others in the industry often offers more insight than the content of the course or workshop itself. Attendance at such events should be supported and budgeted for in all organisations.

CPD activities should not be limited to technical topics. Financial management, advanced use of software and negotiating skills are all important for enhanced performance.

TECHNICAL DEVELOPMENT

Technical leaders need to be innovators and experts in their field. The SADCQF for Level 8 describes engineers as being able to think critically, conceptualise and develop original solutions. The final two Levels, 9 and 10 on the qualifications framework, require even more of professionals.

- **Level 9:** Demonstrates mastery of theoretically sophisticated subject matter, showing critical awareness of current problems and new insights at the forefront of the discipline area. Shows independence, initiative and originality in complex and unpredictable situations.
- **Level 10:** Makes a substantial and original contribution to knowledge in the field of study through research and scholarship.

Level 9 is clearly the kind of mastery required of a technical leader and relates to the level achieved after completing a Masters' degree. Post-graduate studies, and particularly the research required in a Master's, forces students to work independently and become the critical thinkers. Professionals should be supported to complete Master's degrees, whether part-time or full-time. Where appropriate qualifications are not available locally, study outside the country should be encouraged, linked with contracts for incumbents to return and work for the funding organisation.

In two separate major research exercises carried out in the engineering profession in 2004 and again in 2014, it was found that some 40% of all successful senior engineering personnel in South Africa had a post-graduate qualification of some sort.

Employers should not limit themselves to supporting Master's studies, but should strive to develop expertise and support PhD studies in niche areas, as this will assist corporates to differentiate themselves in the market, and governments to ensure that they are delivering optimum engineering solutions nationally.

Of concern is the limited number of post-graduate courses and engineering research being carried out in the region. From 1994 to 2008 it is reported that South Africa contributed 79% of all SADC scientific publications.

ENGINEERING MANAGEMENT

It has been suggested that to develop managers, three types of knowledge and experience are required. They are:

- **Declarative knowledge:** Knowing 'what', which requires a primary degree in a particular discipline, e.g. engineers completing an engineering degree.
- **Strategic knowledge:** Knowing 'why, where, who and how' in the primary field. This requires experience of at least five to seven years, to develop contextual expertise.
- **Procedural knowledge:** Knowing 'how' in the management field after completing management studies to develop an understanding of management principles on which to build procedural expertise.

Professionals moving into this stream should be encouraged to complete some form of management studies.

LEADERSHIP

Once such individuals have gained experience and have developed expertise in a specific area, society relies on them to lead, drive change and embrace innovation. Recognising this need, the University of the Witwatersrand's Business School has introduced a Master's degree and a post-graduate diploma in the field of Energy Leadership. One of the key aims is to *'… develop a new generation of decisive, effective and solutions-oriented leaders that the sector so badly needs … we now need to develop the leadership skills to manage change and transformation'*.

The Business School is also inviting doctoral candidates to pursue a PhD to develop new research in African energy leadership. Engineers should not just be technocrats, but should be developing throughout their careers to deliver solutions appropriate to the time and need.

THE DEVELOPMENT HIERARCHY

All too often it is expected that a senior person should train a recent graduate in a short period before retiring, or as part of a short-term training contract. Development is a life-long process and one experience builds on the other.

Declarative and strategic knowledge are critical before moving into either the management role or a technical specialist role. Without a thorough understanding of the environment, more advanced coaching and support will be without context and will not be of much value. The stages of development as described in Table 24 require different levels of coaching and skills transfer. Expecting an international expert to teach a recent graduate the intricacies of his or her specialist area would be premature. The specialist should be coaching the technical manager or technical leader, or both. They in turn should be coaching younger professionals, who, in turn, should be coaching graduates and even supporting students on industrial attachments.

Where there is a skills vacuum, and structures must be set up from scratch, the duration of contracts for senior personnel brought in to set up structures, systems and procedures cannot be short term. Staff of different levels of seniority are required, and a culture of skills transfer must be developed. Only when the senior personnel have developed the level of specialist skills required will it be practical to withdraw support.

Of concern in the region appears to be the inability to develop bankable projects. This requires good project preparation where credible risks and potential returns are determined and presented. Master plans need to be in place but, as outlined in Table 24 the ability to plan takes years of experience and cannot be left to junior staff. This must also be part of the skills transfer process when capacitating new structures.

TIMEFRAMES

There is much debate about the pace at which people develop, and there is an ongoing demand to fast-track very junior personnel into senior positions.

Malcolm Gladwell (Canadian journalist and public speaker) is famous for suggesting that the most successful people of the world, including sportsmen and -women, business people and scientists, have not achieved success through natural aptitude alone, but through hours of hard work, such that a minimum of 10 000 hours of application are required to become an expert. The progression of experience and developing expertise shown in Table 24 is a long process, given the complexity and breadth of engineering work.

The temptation to fast-track skills development has resulted in steps being skipped, leaving many young or inexperienced managers floundering. Although fast-tracking may fill senior posts, it will achieve little in terms of building capacity, and in the long run will disadvantage those who have been fast-tracked, because eventually their level of development will be inadequate for further promotion.

Those who are promoted to a level beyond their ability will either make the wrong decisions or will not be confident to make any decisions and will hold up development. They will also not be able to pass on adequate expertise to those who follow.

To illustrate, the fast or express train runs from one major centre to another, without stopping to pick up passengers or goods along the way. Young people today are expected to make it from graduation to senior positions at break-neck speed and are not given adequate opportunity to gain experience along the way. The slow or milk train, on the other hand, stops at every siding and waits for long periods for the fast trains to pass. Care must be taken to ensure that young practitioners are not side-lined on menial tasks or assigned several repeat experiences.

Mainline trains, however, take a little longer than express trains because they stop at the major centres to pick up passengers and valuable commodities. Engineering graduates need to be ‘mainlined’ or ‘right tracked’ and supported from graduation to being tomorrow’s leaders.

RECOMMENDATIONS

Essentially, all employers, whether in the public or private sector, need to recognise that all staff require development throughout their careers.

- **CPD:** Staff should be encouraged and supported to participate in CPD activities, including courses, workshops, conferences, online learning, self-study, etc.
- **Post-graduate studies:** Provide bursaries for post-graduate studies and link graduates to practising specialists to assist with practical application and the development of expertise.
- **Developing managers and leaders:** Employers should continue investing in graduates after professional registration to grow management and leadership capabilities.
- **Understudies:** Mid-career specialists and managers must be assigned to foreign experts to be coached and ultimately to be able to fulfil the role currently provided by expatriates.

Local specialists and strategic leadership are essential to develop appropriate local solutions to complex engineering problems.

Chapter 11

The public sector

Although the region is investing in educating young people with a view to expanding the engineering skills base, it is not developing mid-career practitioners or valuing, using or retaining those with experience. Furthermore, contract conditions often preclude local skills development.

ENGINEERING PROFESSIONALS

In the public sector it was found that the number of engineering staff has reduced over the years, in many instances as a result of short-term saving measures or transformation targets. Years of experience have been lost due to these policies. A lack of skilled personnel results in many unwelcome consequences:

- Long-term planning does not take place.
- Projects are not prioritised and planned for, or uncoordinated development takes place.
- Capital, operating and maintenance budgets are not prepared, or inadequate estimates are made by non-technical managers.
- Decisions are not made, or the wrong decisions are made in terms of projects, appointing service providers and purchasing materials, machinery and equipment.
- Service providers are not adequately managed, and poor quality and overclaims become the norm.
- Operations are not managed, which can result in wide-ranging disruptions, delays or unsatisfactory conditions, as in the case of refuse not being collected.
- Maintenance does not take place, resulting in the reduction of the useful life of assets worth millions, and in some cases billions, of dollars
- Junior staff are not supervised and developed.

Professionals have much to offer their organisations. As they develop, they are able to take on strategic and leadership roles as shown in Figure 24. However, to attract and retain professionals, the environment must be supportive. This requires an adequate engineering team, systems, processes and acceptable working conditions to be in place. Many challenges were identified in the public sector.

INVESTING IN ENGINEERING STAFF

Throughout the region, there was the mistaken belief that engineers are expensive, and due to budget constraints, the number of engineers in government or local government should be reduced. This is the logic of those who do not understand engineering. The public sector outsources much of its work to private sector service providers. Without experienced engineering personnel defining the scopes of work and ensuring that what is being offered matches the requirements, millions of dollars can be wasted on the development of inadequate solutions, which do not satisfy the needs in the long term.

Furthermore, without experienced engineering personnel overseeing the development of projects or the installation and commissioning of equipment, the final solutions could be far from satisfactory, which may be costly to rectify once projects have been signed off. As discussed above, if maintenance is not managed, the costs upgrades when the infrastructure has failed could be prohibitive.

Given that engineering salaries are a small percentage of the total costs of engineering assets, the 'cost saving' associated with reducing the number of engineering staff members per department amounts to nothing more than being 'penny wise, pound foolish' as it results in premature infrastructure failure and substantial increases in long-term repair and upgrade costs.

Organograms and competence profiles

When systems are not functioning, there is always a temptation to restructure. In many public sector structures, it is simply necessary to appoint teams of competent personnel trained appropriately for each post. Thus the solution is to rebuild and not to restructure.

Organograms with all levels of staff need to be developed to allow young people to grow through the ranks and to rebuild institutional knowledge. In countries where professional registration is a requirement for appointment, graduates are excluded because they are not professionally registered. Registration should only be a requirement above a certain level or grade.

It was found that many technical posts in the public sector were vacant or were filled by non-technical personnel. All too often cadre deployment or nepotism was the determinant in who should be employed, rather than selecting an appropriately qualified and experienced person.

Competency profiles must be developed and staff must be appointed who have the requisite qualifications and experience, particularly at senior levels. Senior staff must also be given authority to make decisions. This will ensure that there is strategic capacity to plan and implement appropriate solutions.

Table 25: Challenges facing engineering practitioners in the public sector

COUNTRY	EMPLOYMENT OF ENGINEERING PRACTITIONERS IN THE PUBLIC SECTOR
Angola	There are still engineering skills in the public sector, but salaries are said to be lower than in the private sector and attract staff away from ministries and utilities.
Botswana	Salaries are lower in the public sector and funds are not available for CPD. Career progression is a problem in some structures, as staff are not being trained to take over from experienced staff due to retire in the next few years.
DRC	With limited budgets in infrastructure departments, there are few opportunities for development or maintenance. Although posts are not all filled, in some instances, staff complain of not having any meaningful work to do.
Eswatini	Salaries are low, making it difficult to attract high-calibre staff. Junior staff may commence their careers in the public sector, but leave when they have gained experience.
Lesotho	Salaries are reported to be low and positions are not filled when people leave. The value of technical staff has not been appreciated and their recommendations on suitable appointments are often overlooked.
Madagascar	There has been a moratorium on employing staff in the public sector for many years, hence the numbers have reduced over time. Succession plans do not make provision to replace those who are retiring. There are few, if any, specialists in the various structures.
Malawi	The vacancy rate in the public sector is extremely high, reaching 40% in some departments. The very low salaries offered in the sector make it difficult to attract staff.
Mauritius	Local government and ministries generally have limited engineering staff, while posts in the utilities are largely filled. Government salaries are said to be much lower than in the utilities, making it difficult to attract and retain staff in government.
Mozambique	No information
Namibia	Experienced professional engineers have been replaced by junior technicians, leaving no capacity for coaching and mentoring. With limited experience, they are unable to motivate for suitable budgets, which limits development opportunities and maintenance.
Seychelles	There has been a moratorium on employing staff in the public sector, hence the numbers have reduced over time. Succession plans do not make provision to replace those who are retiring.
South Africa	The number of engineering practitioners has dropped in many government departments, due to budget constraints, and posts are frozen as staff leave. Experienced professional engineers have been replaced with junior engineering technicians. The lack of authority afforded to engineering professionals in terms of leadership and decision-making does not attract experienced engineers into the sector.
Tanzania	There has been a moratorium on employing staff in the public sector, hence the numbers have reduced over time. Succession plans do not make provision to replace those who are retiring.
Zambia	Only a few departments reported vacancies, and practitioners generally valued posts in the public sector as they offered job security and in many cases the opportunity for further study.
Zimbabwe	Salaries are extremely low and as engineering staff have left, they have not been replaced. Generally, only older staff still remain. Succession plans do not make provision to replace those who are retiring.

Tanzania has embraced this philosophy from cabinet level down and has appointed engineers as ministers and principal secretaries in engineering ministries and departments, such as roads and transport, water, public works, etc.

Engineers were also found as principal secretaries or directors general in engineering ministries in other countries, but these were the exception rather than the norm. Without leaders who understand engineering imperatives, the range of challenges, as listed above, will persist.

Salaries

Salaries were found to be a challenge in many countries, with chief directors and even more senior levels earning only US$600 per month. Few senior engineers remain, which is concerning given the value of the infrastructure under the control of each department. Substantial salary increases or scarce skills allowances need be considered to attract and retain engineering professionals. Scarce skills allowances are, however, not favoured, as pension cover, disability allowances and other benefits were not increased in line with the increase in earnings. Total package increases should be considered.

Professional registration and CPD

Many employees from both the public and private sectors complained of the lack of recognition of the importance of professional registration and belonging to professional engineering institutions, or the lack of support or opportunities for CPD. Some reported having to take leave to attend courses.

PROFESSIONAL JUDGEMENT AND AUTHORITY

Engineering professionals are trained to investigate and solve problems and use their engineering judgement to make decisions. Sadly, in many

situations in the public sector, the authority to make decisions has been taken away from engineering professionals, to the detriment of service delivery.

Technical decision-making

It is recognised that engineers have a key role to play in conceptualising, planning, prioritising, designing and delivering solutions. However, in the public sector, their recommendations are often ignored or their decisions are overruled.

All too often, grand schemes are agreed upon which are inappropriate. For instance, in a small rural community the idea of a US$20 000 wastewater treatment plant was 'sold' to the municipality, when a waste stabilisation pond could have been constructed at a fraction of the price, which needs little or no maintenance.

Decisions relating to engineering solutions should rest with senior engineering professionals.

Financial decision-making

All too often technical departments are assigned a budget based on the prior year's budget without any consultation. Determining the size of budget required for infrastructure should be the function of technical personnel, considering development as well as operations and maintenance requirements.

There is a need to increase tariffs for services in many countries and to enforce payment by those who can afford to pay, but this is not a popular choice. The AfDB says that tax revenue collection in Africa is below the threshold of 25% of GDP considered necessary to scale-up infrastructure spending.

Until adequate funds are available for infrastructure, the current cycle of no growth available to fund development will continue. Demand management methods to reduce consumption and losses must be considered, including the use of prepayment meters, repairing of pipes and cables, etc.

Supply chain

Appointing competent service providers and purchasing appropriate materials is critical for the success of projects, operations and maintenance. All too often these decisions are made by supply chain practitioners, politicians or other non-technical people, but engineering professionals are still responsible for the end result.

Human Resources (HR)

The Human Resources (HR) function has been removed from many technical departments. As a result, new employees are at times not selected by those who will be employing or managing them. This disconnect between the employer and those handling the process results in inappropriately qualified or inexperienced staff being appointed in many cases. It is essential that the screening, selection and appointment process reverts to technical departments and HR only offers the support of advertising, setting up interviews and finalising the contracts. Any interview panel should include professionally registered supervisor(s) and peer(s), where relevant, relating to the position.

Authority

Support departments, although intended to support line departments, have usurped the authority and undermined the processes which are the domain of technical departments. Professionals in any discipline are specifically trained to investigate and solve problems, and to use their professional judgement to deliver solutions. Working in the public sector is particularly frustrating for professionals whose highly developed ability to make professional judgement calls are overridden by support personnel following guidelines that are often not relevant to the issue at hand.

Professionals are accountable for the services they deliver but are often not responsible for the decisions made on their behalf based on inappropriate structures, systems or guidelines. To create an enabling environment for technical professionals, it will be necessary to wrest authority away from support functions and return it to the leaders of line functions.

REGISTRATION OF PROFESSIONALS

Without a measure to ensure the competence of engineering professionals, there is no way of ensuring that those appointed in posts to plan, design or oversee construction or implementation are capable of the task at hand. Senior engineering personnel in government should be professionally registered and should be responsible for developing young professionals in their structures.

DEVELOPING LOCAL CAPACITY

The intention of this research project was to determine the number of engineering professionals in each country, the future demand and supply, and to suggest interventions required to address gaps and grow local capacity and job creation opportunities.

However, as countries are increasingly employing international consultants for the design phase, international contractors for construction, or encourage international manufacturers to set up local plants or supply, operate and maintain equipment, as part of investment agreements, the opportunities to develop local skills and create local employment appear to be decreasing. This undermines the very spirit on which Agenda 2063 and industrialisation is based. Furthermore, where local appointments are made, they are often not based on technical merit or include skills development requirements.

Policies and approaches concerning the following need to be revisited:

- Classification and use of service providers and their conditions of contract
- Adopting local standards and approving solutions locally
- Ensuring localisation as part of investment.

CLASSIFICATION OF SERVICE PROVIDERS

Without a measure for ensuring that service providers have adequate expertise, capital and equipment, contracts have little chance of succeeding if simply awarded to the lowest bidder. As discussed under *Construction* in Chapter 6, the level of sophistication of service providers required per contract will vary according to the complexity and size of the project. Service providers should at least be categorised according to the following:

- The availability of engineering and built environment professionals
- The type and size of machinery and equipment owned
- Working capital available
- Access to finance
- Track record.

Based on these and other appropriate parameters, a limit should be placed on the size and type of project each contractor may be appointed to carry out.

Construction councils in several countries do assess some, if not all, of these parameters. In some countries, foreign companies are precluded from tendering on small projects to protect the many small local contractors and ensure local job creation.

Recognising the need for regional integration and a multi-lateral trading system, the SADC Trade Negotiating Forum (TNF) was set up to negotiate the progressive removal of barriers to trade in construction services and the energy sector within the SADC region. The Forum is composed of officials from ministries associated with construction and energy, and many representatives from construction councils. Member States are expected to make offers in areas of trade that they are prepared to relax. The Forum has been exploring the possibility of relaxing the various conditions set for foreign contractors and consultants to accommodate the mobility of SADC companies. In the absence of agreed standards, this is proving difficult to achieve.

Given the need to create job opportunities and grow local skills, liberalisation in the lower levels could impact negatively on each country's growth, job creation and skills development drives.

The following should be considered:

- Develop standardised categorisation criteria for the region, negotiating with contracting companies to ensure that the criteria are practical, rather than imposing unrealistic restrictions. The US$ value thresholds may be different per country based on costs in each country.
- Determine the category below which contracts should be reserved for local contractors.
- Determine the categories for which SADC contractors may be appointed.
- Determine the category above which international contractors may be appointed – this would be higher than for SADC contractors.
- Adopt standardised conditions of contract where practical.
- Set requirements for using and developing local skills
- Ensure that there are requirements for using local materials, machinery and equipment where available.

The concept and aim of industrialisation is to accelerate growth, create employment and improve living conditions, but all too often when contracts are awarded to foreign companies, foreign skills, material, machinery and equipment are used, limiting local opportunities. The use or importation of foreign equipment is possibly only necessary in the case of specialised mining and manufacturing equipment.

Construction has long been recognised for its job creation potential, and presents significant opportunities to develop engineering graduates, apprentices, small contractors, subcontractors and suppliers.

Furthermore, large and mega projects are the most important way of developing high-level skills and

expertise. The approaches outlined in the Angolanisation and Zambianisation policies, which require understudies to be assigned to foreign experts, must be adopted and enforced. However, as discussed in Chapter 10, staff with experience should be assigned to experts to take the next step in their technical development.

In countries where local development is included in the conditions of contract, these conditions are frequently not enforced. Regional resolve to grow local skills and opportunities is critical.

ADOPTING LOCAL STANDARDS AND APPROVING SOLUTIONS LOCALLY

When international service providers are used, design solutions cannot be checked at times due to language barriers or different approaches and terminology. Furthermore, the lack of knowledge of local conditions often results in inappropriate designs.

Although the world is now considered to be a global village, local conditions, needs, customs, styles and habits need to be considered when developing solutions. Variables such as the weather, the orientation of buildings relative to the position of the sun in the southern hemisphere, geotechnical conditions, religious beliefs, local lifestyle, customs and indigenous systems need to be considered. Many of these factors are not considered or are ignored, at great cost to each country, when designs are concluded without consultation and approval by local engineering and built environment professionals.

The failure of the high-rise housing development in Luanda, which did not consider local needs or style of living, is well documented. Selecting inappropriate material has resulted in the failure of many roads. The inappropriate orientation of buildings has caused much discomfort due to excessive exposure to the summer sun. The use of international, rather than local, codes has resulted in the failure of stormwater systems, as the size of 20- and 50-year floods was underestimated. These and many more examples have been challenged by local engineers, but have been ignored, or overridden by the powers that be.

A policy should be put in place, and adopted throughout the region, requiring that all designs carried out internationally be checked and approved by local engineers together with the client body. This would ensure that all design calculations, drawings, operating manuals and associated documentation are made available in the local language, which is not happening at present. Local teams would then be able to operate and maintain the infrastructure rather than relying on only those who can read the documentation.

Developing local codes and standards

Some countries do not have a full suite of locally researched and developed engineering design codes and standards. As described above, using inappropriate values for various controlling parameters can result in unsuitable solutions being developed. Support is needed to research local parameters and develop new codes, or to adapt codes from other countries to match local conditions.

Unbundling of projects

Many major projects are awarded on turnkey contracts. This means that the company that is awarded the contract is responsible for both design and construction or implementation. There is thus little or no oversight at the delivery stage. Traditionally, when separate design and construction contracts were awarded, the consulting engineer who designed the project would oversee construction and ensure that the work was carried out in accordance with the design and local specifications. Consideration needs to be given to unbundling of projects or at least providing local professionals, with authority, appointed by the client, to oversee the design and delivery process.

LOCALISATION

The preceding discussions have largely covered skills development associated with public sector infrastructure. Where countries are looking to investors to develop the local manufacturing sector, it is also important that funds coming into the country are spent on developing local skills and capacity. All too often investors supply their own skills, machinery and equipment to develop a local resource. While this may be necessary at the outset, the manufacture of local components and the employment of locals and skills transfer should be factored into all agreements.

In many cases, subsidiaries of international companies only employ elementary skills locally but provide high-level skills from their headquarters. While it is understood that control is required, there is no reason why local professionals cannot be developed to become part of the international executive team. Skills development at all levels should form part of offset agreements.

Many countries look at investments on a case-by-case basis to identify localisation opportunities. Regional knowledge-sharing in this regard and implementing more robust policies should be considered through the Industrial Development Forum. These should include penalties where investors have committed to use local materials, develop component manufacturing plants, support and train emerging manufacturers, but have ignored their obligations once set up in the country.

This project would not have adequately served the region if policies do not emerge to protect and develop opportunities for local engineering skills and job creation. Institutional commitment will, however, be necessary to ensure that such localisation policies are enforced.

INVESTMENT

Adequate investment in the planning, development, operations and maintenance of infrastructure, products, systems and/or processes is essential for success. Key elements to consider are:

- Investing in infrastructure
- Investing in maintenance
- Investing in systems
- Investing in research and new technologies
- Sourcing funding that is best value for money
- Investing in agricultural solutions
- Developing rural solutions
- Investing in reliable data.

INVESTING IN INFRASTRUCTURE

The most elaborate industrialisation plans will not make a substantial impact on growth without developing economic infrastructure. In most countries the inability to transport agricultural products or mining output to markets was noted as a major limitation. Furthermore, the lack of energy and clean water is an impediment to existing organisations, let alone the need to develop new market niches. Before the number of graduates is increased, commitment to development and investing in infrastructure is key. Once projects are underway, they offer an ideal training ground for new graduates.

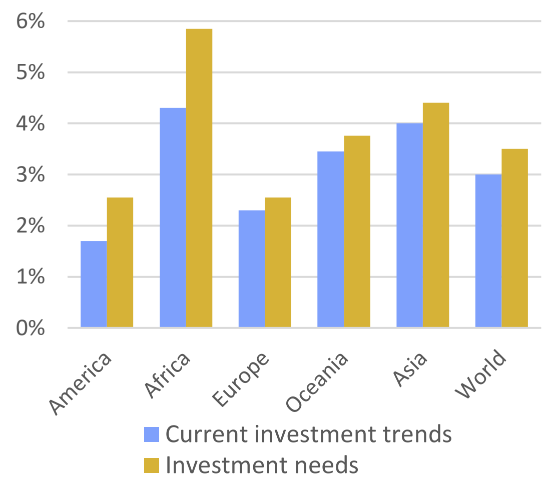

Figure 25: Infrastructure financing gaps as a share of GDP in selected regions, 2016–2040
(Africa Economic Outlook 2018, AfDB)

The *Africa Economic Outlook 2018* reports that the world needs to invest an average of US$3.3 trillion per year to support currently expected rates of growth. However, there is a large gap, when considered as a share of the GDP, the largest being in Africa, as shown in Figure 25.

INVESTING IN MAINTENANCE

Once there has been investment in infrastructure, there is a need for ongoing maintenance. The range of maintenance activities includes preventative maintenance, planned maintenance and routine maintenance, all of which can dramatically extend the life of infrastructure. If these are not in place and aggressively managed, infrastructure can fail years before the end of the design life at substantial cost to the country.

When considering roads for instance, if they are only maintained for the first time after 10 years rather than after 6 to 7 years, the cost will be six times greater, and if left for 15 years, the damage and upgrade needs would cost about 18 times more than if maintenance had been carried out every 5 to 7 years. Countries cannot afford maintenance once roads or any other infrastructure requires rehabilitation. if attention is paid from the outset, the cost of maintenance is relatively low.

In the words of Saied Solomons, President of the Southern African Road Federation, '*preserving Africa's road assets at times gets overshadowed by what's new but is the backbone to infrastructure provision. For politicians, preservation is not as attractive as a new piece of infrastructure, but it is ignored at its peril*'.

INVESTING IN SYSTEMS

Many previously functional systems have not been kept up to date, making management of infrastructure difficult. Systems need to be reinstated and updated to improve the efficiency of technical departments, particularly in the absence of a sufficient number of skilled staff.

Standard operating procedures have disappeared over time, and there are limited guidelines for new appointees to follow. Preparing budgets, dealing with

public complaints, and planning and reacting to operations and maintenance needs are the first systems to suffer.

INVESTING IN RESEARCH AND NEW TECHNOLOGIES

Clearly from the discussions thus far, the SADC region is unique and is rich in resources – from minerals and gems to fertile agricultural lands and a long coastline, among other things. Opportunities abound to harness these resources and create new industries along with millions of new jobs, but such solutions will not emerge without research, development and understanding market needs and trends.

The region is also faced with many challenges – global warming, climate change and some countries are water stressed. Solutions to address these challenges are also needed. The region cannot wait for solutions to appear, they must be researched and developed locally to ensure that they address the local needs.

Furthermore, much equipment is out of date and inefficient in terms of energy and fuel consumption and the like, and should be replaced to reduce operating costs. In delaying the investment into new technologies and solutions, countries are wasting millions of dollars on operating costs.

SOURCING FUNDING THAT IS BEST VALUE FOR MONEY

In times past, funding was made available with various terms and conditions to ensure that sustainable solutions were developed, and funds were put aside for maintenance. More recently, more expensive funding has been accessed with no strings attached other than repaying the funds over many years in either cash or goods. These funds have, however, often been supplied along with foreign labour, materials and equipment, offering little or no economic benefit to the receiving country, or include conditions of transfer of the ownership of the asset or associated commodities to the funder if countries delay repayments or default. This has negatively impacted many countries.

Taking this easier but unsustainable option has invariably been the decision of high-ranking officials or politicians who have benefited personally from the funds. Corruption has taken its toll on the region.

Regional policies need to be developed with regard to the type of funding that should be harnessed, and the terms and conditions that should be set for both funders and recipients.

INVESTING IN AGRICULTURAL SOLUTIONS

Of concern has been the limited progress evident in increasing agricultural output and strengthening subsistence farmers. As agriculture is the primary employer in many countries and subsistence farmers produce a substantial portion of the food, urgent attention needs to be given to helping farmers to improve their productivity, develop and market cash crops, and get their goods to the intended destination efficiently. Modernisation, mechanisation (even handheld), irrigation, improved inputs and agro-processing opportunities need to be considered and complete value chains need to be developed. The potential is there to increase productivity, increase exports, reduce imports and create wealth.

The SADC Food, Agriculture and Natural Resources Directorate (FANR) should engage with the Pan African Society of Agricultural Engineers, a network of agricultural engineering professionals in academia, research, industry and policy, for their ideas on possible engineering solutions in agriculture, food security and related industries. The Mauritian model of making equipment available to smallholders should also be considered.

The essential message of the *2017 State of Food and Agriculture* report by the FAO is that the key to achieving the 2030 Agenda for Sustainable Development is in transforming rural communities and promoting agriculture. The FAO recognises the large growing rural population and the need to make small units productive. Strong local organisations need to be formed representing the rights of farmers able to enter the agro-processing value chains, gain access to markets and negotiate with traders, food processors and retailers.

It was found that in many countries investment in and support for agricultural engineers, technicians, agronomists and extension services had reduced, leaving farmers to follow traditional, inefficient methods. The ratio of farmers to agricultural engineers and agronomists made it impossible to drive large-scale changes. This urgently needs to change.

Another problem that was identified is the approach to training agricultural practitioners. Limited hands-on training takes place during their academic studies, and since they have only theory and limited experience or practical advice to share, smallholders place no confidence in the solutions that they

Figure 26: Maasai warriors jump at sunrise near their village
(Photographer: John Kerrod Wells)

suggest. Disillusioned with their first attempts to contribute, many leave the sector. It would seem that substantial internships on farms should become part of these qualifications, similar to the structure of medical qualifications, or rigorous structured graduate training must be put in place.

Agricultural engineering and extension services hold the key to developing opportunities for rural communities to earn a decent living and become the source of each nation's food.

DEVELOPING RURAL SOLUTIONS

Much has been written about the need for decent work opportunities. Indeed, SDG 8 calls for '*Decent work and economic growth*'. The question must, however, be asked: what is decent work?

Does the proud Maasai Warrior herding and protecting his livestock, raising his mischievous little sons on the land and sharing indigenous knowledge with them, not enjoy a decent day's work?

Many rural communities would consider that their daily working experiences are satisfying and more than decent. What is not decent is their living conditions – they are often appalling. The lack of electricity, long walks to collect water (and the increased risk of being attacked or raped), the hard work of collecting firewood for cooking and heating and, in many places, the lack of protection from the elements make for tough living conditions. Furthermore, there is often limited access to education and health care facilities.

Moving to the cities and following a lifestyle associated with the high GDP per capita suggested by Agenda 2063 is an alternative that is far from being able to offer decent work or living conditions for all in the foreseeable future. The nightmare of slum dwelling is well documented and evident throughout the region. With the large, increasing under-15 populations and growing automation in the formal sector, there is limited prospect for large numbers to be absorbed into formal employment in the cities.

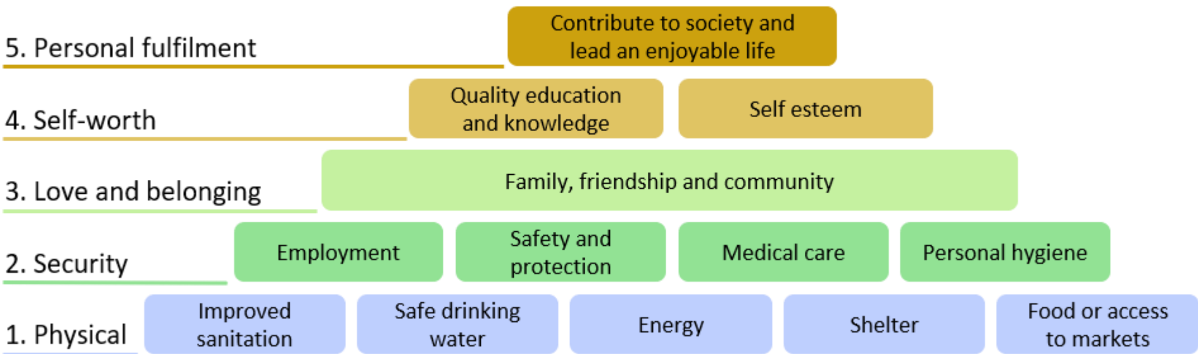

Figure 27: Infrastructure requirements for rural communities considering Maslow's Hierarchy of Needs

As discussed in Chapter 1, historically, transport and associated infrastructure development was linked to the exploitation of resources, whether in mining areas, commercial centres or linking to ports. Limited infrastructure has been extended to rural communities.

Considering Maslow's Hierarchy of Needs applied to rural communities, factors such as employment, family, friends, community, indigenous knowledge and fulfilment in contributing to society are in place. However, water services, energy, markets, community centres, health and education facilities need to be made available to support and grow communities, and to encourage de-urbanisation. Rather than cost nations, such developments will increase food production, reduce imports, increase income, and address the missing elements in Maslow's Hierarchy of Needs. They will also reduce the costs of having to support large numbers of poor people.

INVESTING IN RELIABLE DATA

Labour force surveys and availability of data

This project has been extremely difficult due to the lack of data. As discussed in Chapter 5, only the Seychelles and South Africa could provide data down to occupation level and even these figures could not be used without some adjustment based on understanding qualification levels and sectors. Labour force surveys are therefore nothing more than overall employment status quo reports and are of little or no value for skills planning. The region needs to consider different methods of gathering the detail of employment data.

Labour force surveys should be enhanced by increasing the sample size and setting up a more robust method to determine occupations.

Alternatively, as part of annual personnel tax returns, more information about occupations should be gathered from each taxpayer and employers should be asked about skills shortages and needs when completing the annual company returns. This will not cover the informal sector but will offer a clearer picture of the number and type of skills employed in the formal sector and allow better skills planning.

Higher education data

Higher education data also proved extremely difficult to collect, for two reasons: the lack of records and the inconsistency in qualification naming and levels.

Few institutions could extract the data requested from a system but needed to go through their annual records to provide the data. Others were not that fortunate and needed to read through graduation programmes to count how many of each discipline graduated each year.

South Africa and Mozambique had a central database from which the information could be extracted. Angola and Madagascar have started collecting data centrally since about 2013 and were able make annual reports available down to discipline level. Other education departments could offer total numbers graduating per year, but not down to discipline and gender level.

Consideration should be given to developing a central system into which all countries can report. This does not mean that every country needs to use an identical system, but interfaces will need to be developed that will allow the required data from national systems to be uploaded into a regional system.

For mappings to be possible it will be necessary to have all National Qualification Frameworks aligned and the different types of qualification categorised.

Support of professional bodies

As discussed in Chapter 9, registration bodies are key structures to drive the development of engineering competence. Consideration should be given to designing comprehensive data structures which can be a resource not only for managing these institutions, but also for feeding into national skills planning initiatives. Many datasets received contained only the contact details of members, but they should be expanded to include disciplines, specialisation, region, age, gender and nationality, among the many parameters that need to be managed. Reliable data could also be of benefit to immigration authorities for approving work permits for those with scarce skills.

RECOMMENDATIONS

A strong public sector is critical to ensure that infrastructure is planned and developed, and that conducive policies are in place to support the development of the agricultural, construction, manufacturing and mining sectors. Substantial changes in approach to training and harnessing professionals, appointing service providers and investing in development are required.

Engineering professionals

Public sector structures need to consider:

- **Technical staff:** Revisit organograms and rebuild structures to allow for career progression.
  - Reprioritise budgets to fill vacant posts, ensure that salaries are competitive and develop succession plans from junior levels to make the public sector an employer of choice.
- **Authority:** Give authority to engineering personnel for:
  - Long-term planning, prioritisation of projects and decision-making in consultation with stakeholders
  - Appointment of technical staff
  - Budgeting for the development, operations and maintenance of infrastructure
  - Supply chain decisions with respect to both service providers selected and products purchased
- **Training and development:** Commit to staff training and development at all levels.
  - Ensure that every technical structure sets up an internal graduate training and development programme, with the required support to ensure its sustainability
  - Support CPD and the development of young professionals, technical specialists, managers and leaders
- **Resources:** Ensure that departments have adequate systems, software and equipment.
- **Systems and procedures:** Redevelop systems and implement standard operating procedures.

Registration of service providers

Form a subcommittee under the TNF to review and harmonise all construction council Acts and contracts and encourage others who do not have a system in place to follow suit. Items to be considered include:

- **Grade:** Grade of contractor based on working capital, machinery and equipment, premises and skills sets (such as engineers, architects, tradespersons, etc.).
- **Categories:** Categories of contractors relating to the type of work they may take on.
- **Conditions:** Period of registration, licensing and insurance requirements.
- **Local support:** The levels below which foreign participation should be excluded and, for larger contracts, the requirements for foreign contractors to use local labour, subcontractors, materials and machinery, and to form joint ventures with local companies.
- **Training and development:** Training criteria relating to skills, small contractors, subcontractors and, where appropriate, communities.
- **Suitability of solutions:** A mechanism for assessing and approving proposed solutions, ensuring that they address local needs and customs and that designs comply with national codes and standards.
- **Handover:** The documentation required at the time of handover.
- **Quality assurance:** Mechanisms for monitoring progress and imposing penalties for poor performance.

Localisation

The Industrial Development Forum to share experiences on setting up offset agreements relating to local development with foreign investors. Agreements should include not only the use of local labour, plant, equipment and developing local manufacturers but should include the training of engineering professionals.

Investment

Reprioritising budgets, accessing funds with the most favourable terms and collecting outstanding funds in each country will be essential to ensure that infrastructure development takes place in a sustainable manner. Consideration must be given to the following:

- **Economic infrastructure:** Investing in the development of economic infrastructure such as electricity, roads, rail, ports and airports, and addressing the supply of water services.
- **Maintenance:** Investing in maintenance to preserve the integrity of new infrastructure and to prevent further deterioration of existing infrastructure.
- **Tariffs and payment:** Reviewing and increasing tariffs where appropriate, enhancing domestic revenue collection and demand management to fund development.
- **Cost-effective solutions:** Developing cost-effective and bankable projects and identifying and agreeing on funding options that offer the most favourable terms, at the same time avoiding risks that could be detrimental to the country in case of delayed payment or default.
- **Research and new technologies:** Investing in research and new technologies to address local needs.
- **Agricultural and rural development:** Investing in agricultural development, particularly support of smallholders, and developing rural communities and economies.
- **Data availability:** Investing in more robust labour force data acquisition and management models, in the collection and management of tertiary education data, and in engineering registration data.

Chapter 12

Numbers and Needs

Many research projects, papers and forecasts have suggested the need for many more engineers in Africa, with one paper suggesting that Africa needs 4.5 million engineers. This is premised on the number of engineers per hundred thousand population in OECD countries. But does this need exist?

THE ROLES THAT ENGINEERING PRACTITIONERS PLAY

To answer the question, one must consider the roles that engineers play. They design, develop, operate and maintain infrastructure; conceptualise, build and operate manufacturing and processing plants and mines; and contribute to agricultural production through the use of technology. This means that infrastructure must be in place and funds must be available for ongoing development, operations and maintenance, and that manufacturing must be of the complexity that requires engineering skills. The level of service with regard to infrastructure is also a deciding factor on the type of engineering skills required. Considering each in turn will offer a better picture of the numbers required.

INFRASTRUCTURE

It is important to consider the level of service and extent of infrastructure per country.

Levels of service

The remoteness of many communities means that the delivery of piped water, waterborne sanitation and electricity from the grid is unaffordable and impractical in terms of capital costs and ongoing operations and maintenance. As a result, localised solutions have been developed, including yard tanks, ventilated pit latrines and localised solar energy solutions. These types of solution do not require large teams of engineers to carry out the design and construction of complex networks, treatment works or power stations, nor large teams to operate or carry out ongoing maintenance.

Table 26 shows the minimum levels of service suggested for different environments in South Africa in 2004. The number of engineering practitioners required increases from left to right. Should plans be put in place to increase the levels of service for substantial portions of the population, then an increased number of engineering practitioners would be required.

Extent of investment in infrastructure

The AIDI, discussed in Chapter 6, is a good indicator of the extent of the infrastructure in each country and gives a sense of the level of expenditure that has taken place in the past. As discussed, without investment and a flow of funds, development cannot take place, limiting the need for engineering practitioners and the opportunities for developing graduates. Figure 28 shows that there is a strong correlation between the GDP per capita and the AIDI.

South Africa is the only country that does not closely follow the trendline. The quality of the infrastructure can be attributed to massive spending on infrastructure in the newly independent apartheid South Africa from the early 1970s to the early 1980s. The construction spending at the time remained at an all-time high for several years, the level of which was only reached again during heightened construction spending in 2008 to 2009 in preparation for the Soccer World Cup (SWC).

During the earlier period, national roads, rail, ports, airports, major dams and power stations, along with associated distribution networks and the Mossgas and oil-from-coal projects were developed.

Table 26: Levels of service

SERVICE TYPE	MINIMUM SERVICE	LEVEL 1 BASIC	LEVEL 2 INTERMEDIATE	LEVEL 3 FULL
Increasing level of service				
Water	6 kl of drinking water per month, within 200 m of each household	Communal standpipes	Yard taps, yard tanks	In-house water
Sanitation	VIP latrine or better	VIP latrine	Loflos or septic tanks	Full waterborne in-house
Electricity	50 kWh per month per household. One street light for every 4 stands or high-mast lighting	5–8 A or non-grid electricity	20 A	60 A
Roads	Residential roads to provide all-weather access to within 500 m of dwelling	Graded	Gravel	Paved/tarred & kerbs
Stormwater drainage	Must be controlled in rural and urban areas	Open earth-lined channel	Open lined channel	Piped systems
Solid waste disposal	Street refuse container within 200 m per household and weekly collection	Communal (residents)	Communal (contractors)	Kerbside

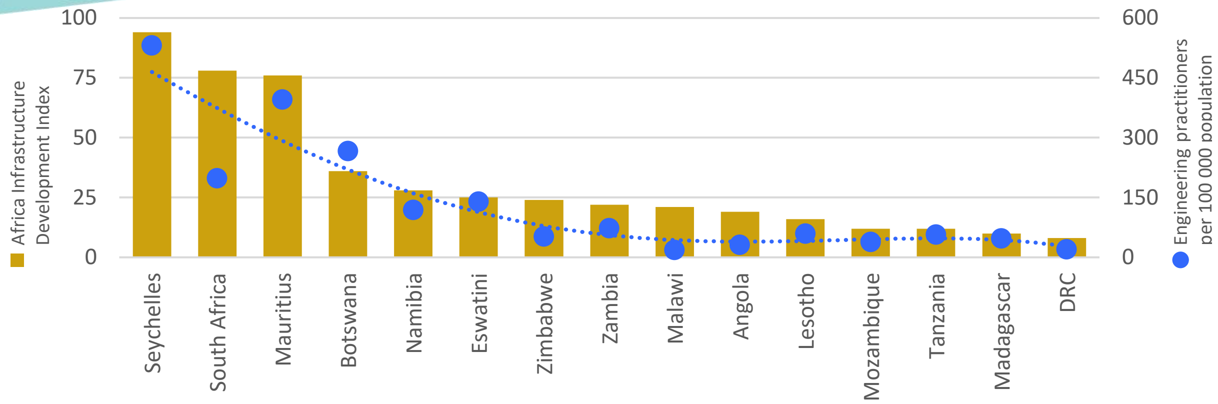

Figure 28: The correlation between AIDI and engineering practitioners per 100 000 population

Many foreign experts were encouraged to immigrate to South Africa to manage developments, but at the same time government offered bursaries to thousands of young people to study engineering and work as juniors on these projects. As graduate-in-training programmes had been introduced in the early 1970s, graduates were given all-round structured training over the 10 years and went on to become well-respected engineers. The number of civil engineers graduating at the time topped 350 a year, a number that had dropped to 130 by the early 2000s as demand dropped.

FILLING VACANCIES

Each country reported significant vacancies in the public sector. In some cases 50% or more of the vacancies were required to be filled in order to handle the current workload. An interesting concept of 'latent skills shortages' also exists. These occur where there are unrecognised skills gaps and the organisation copes without the necessary skills, but is not delivering the service required. Should funding be made available for vacant posts and to fill latent gaps, the numbers in industry would also increase.

ACADEMIA

The staff:student ratios in tertiary education are another factor that influences the number required. At outlined in Chapter 7, ratios of 1:75 and higher were not uncommon in SADC tertiary institutions. Should countries commit to achieving ratios of 1:15, and develop sufficient capacity to achieve the target, this will also increase the number employed.

Considering a country with 7 500 engineering students, the current number of academics at 1:75 of 100 would need to increase to 500.

MANUFACTURING

Manufacturing is important in any country, not only for producing goods required for local consumption, but also to offer employment and tap export markets to increase national income. Manufacturing has been the catalyst for growth and employment in economies that have achieved a high GDP.

The manufacturing sector is relatively small and contributes less than 10% to the GDP in many Member States. The size of the sector varies between countries and is particularly low in those at relatively low stages of development. It also continues to be resource-dependent, with low value addition and low levels of exports of advanced products. The levels of innovation and private sector investment are also low in many countries.

Table 27 shows the UNIDO classification of manufacturing into low-, medium- and high-tech. Generally, agro-processing (which in many countries holds the major share) is low-tech; plastics, basic metals and repairs are medium-tech; while machinery, electronics, etc. are high-tech. Research has shown that there are considerable differences in the employment ratios and requirements between the levels of technology.

As high-tech requires innovation, significant R&D is necessary. Furthermore, high-tech products have many components, hence require many production lines to produce a single end-product. The selling and supporting of high-tech products requires ongoing engagement, creating downstream jobs.

Table 28 shows a range of manufacturing activities and their associated multiplier effects. As manufacturing becomes more sophisticated, the job multiplier rises. Even in general manufacturing, for every manufacturing job created there are approximately 1.6–2.5 indirect jobs created. With the increasing complexity of high-tech manufacturing, the number of high-end engineering skills required increases and the number of indirect jobs created rises to between 4 and 15 for every direct manufacturing job.

Table 27: UNIDO Classification of low- medium- and high-tech manufacturing

DIVISION	CATEGORY ISIC REV. 4	DESCRIPTION
Low technology	10	Food products
	11	Beverages
	12	Tobacco products
	13	Textiles
	14	Wearing apparel
	15	Leather and related products
	16	Wood and products of wood and cork
	17	Paper and paper products
	18	Printing and reproduction of recorded media
	19	Coke and refined petroleum products
	25 excl. 252	Fabricated metal products, except weapons and ammunition
	31	Furniture
Medium technology	22	Rubber and plastics products
	23	Other non-metallic mineral products
	24	Basic metals
	Group 301	Ships and boats
	332 excl. 325	Other manufacturing except medical and dental instruments
	33	Repair and installation of machinery and equipment
Medium-high and high technology	20	Chemicals and chemical products
	21	Pharmaceuticals
	Group 252	Weapons and ammunition
	26	Computer, electronic and optical products
	27	Electrical equipment
	28	Machinery and equipment n.e.c.
	29	Motor vehicles, trailers and semi-trailers
	30 excl. 301	Other transport equipment, except ships and boats
	Group 325	Medical and dental instruments

Analysing the manufacturing industries proved very difficult as value add or output data per UNIDO category was not available from many countries. In most cases the top three or four industries that contributed to the manufacturing GDP were listed and the rest were lumped under 'Other'. The data that was available is shown in Table 29. Unfortunately, the data per country is from different years, as shown in the country reports.

Examination of the range of products manufactured and the associated levels of technology shows that only South Africa followed by Botswana have achieved a reasonable proportion of high-tech manufacturing. The ranges of these activities are outlined in the country reports. The SADC industrialisation strategy suggests that countries should aim to increase the share of medium-and high-technology manufacturing to 30 % by 2030 and to 50 % by 2050.

Table 28: Types of manufacturing and associated jobs multiplier

TYPE OF MANUFACTURING	JOBS MULTIPLIER
General	1.6-2.5
High-tech	3.5
Microprocessor electronics	4.1
Jet engines	7-8
Electronic computers	15

In selecting the areas into which each country intends to develop, curricula should be revisited to ensure that the appropriate technology is covered, and bursaries programmes should be linked to such developments so that students and graduates can be part of developing and setting up the new processes.

An increase in the number of engineering practitioners required should be based on the percentage increase in manufacturing planned, taking into account the level of technology.

The increase in the number of high-end skills for hi-tech engineering is not limited to manufacturing but is recognised in many sectors. The South African electricity utility (Eskom) suggests that in their sector, a ratio of 1 engineer: 1 technician: 1 artisan is required for the building of hi-tech generation plants, whereas 1:2:4 is appropriate for medium-tech builds and 1:4:8 for low-tech developments.

Table 29: Classification of low-, medium- and high-tech manufacturing percentages in SADC countries

<table>
<tr><th rowspan="2">COUNTRY</th><th colspan="5">LOW TECH</th><th colspan="3">MEDIUM TECH</th><th colspan="5">HIGH TECH</th><th colspan="4">TOTAL</th></tr>
<tr><th>Food & beverages</th><th>Tobacco products</th><th>Textiles</th><th>Wearing apparel, leather, footwear</th><th>Wood, paper, printing, furniture</th><th>Petroleum, rubber, plastics</th><th>Non-metallic minerals</th><th>Metals & metal products</th><th>Chemicals & chemical products</th><th>Machinery & equipment</th><th>Electrical equipment</th><th>Medical & precision instruments</th><th>Motor vehicles & other transport equipment</th><th>Other</th><th>Low tech</th><th>Medium tech</th><th>High tech</th></tr>
<tr><td>Angola</td><td>88</td><td></td><td></td><td></td><td></td><td></td><td>7</td><td>2</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td>88</td><td>9</td><td>3</td></tr>
<tr><td>Botswana</td><td colspan="2">26</td><td colspan="2">3</td><td></td><td></td><td></td><td></td><td>5</td><td>15</td><td></td><td></td><td></td><td>51</td><td>29</td><td></td><td>20</td></tr>
<tr><td>DRC</td><td>46</td><td></td><td></td><td></td><td>11</td><td></td><td></td><td></td><td>11</td><td></td><td></td><td></td><td></td><td>32</td><td>57</td><td></td><td>11</td></tr>
<tr><td>Eswatini</td><td>85</td><td></td><td>9</td><td></td><td>2</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td>2</td><td>96</td><td>2</td><td></td></tr>
<tr><td>Lesotho</td><td colspan="2">72</td><td colspan="2">13</td><td></td><td></td><td></td><td></td><td>6</td><td></td><td></td><td></td><td></td><td>9</td><td>85</td><td></td><td>6</td></tr>
<tr><td>Madagascar</td><td>17</td><td>17</td><td>33</td><td></td><td>2</td><td></td><td>26</td><td>2</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td>69</td><td>28</td><td>3</td></tr>
<tr><td>Malawi</td><td>48</td><td>25</td><td colspan="2">2</td><td></td><td>3</td><td>5</td><td>3</td><td>8</td><td></td><td></td><td></td><td></td><td>6</td><td>75</td><td>11</td><td>8</td></tr>
<tr><td>Mauritius</td><td>34</td><td></td><td colspan="2">38</td><td></td><td>4</td><td>4</td><td>3</td><td>4</td><td></td><td>1</td><td></td><td></td><td>12</td><td>72</td><td>11</td><td>5</td></tr>
<tr><td>Mozambique</td><td>37</td><td>8</td><td>2</td><td></td><td></td><td>1</td><td>6</td><td>42</td><td>2</td><td></td><td></td><td></td><td></td><td>2</td><td>47</td><td>49</td><td>2</td></tr>
<tr><td>Namibia</td><td>51</td><td></td><td>4</td><td></td><td>7</td><td></td><td>3</td><td>24</td><td>5</td><td></td><td></td><td></td><td></td><td>6</td><td>62</td><td>27</td><td>5</td></tr>
<tr><td>Seychelles</td><td>71</td><td>3</td><td></td><td></td><td></td><td></td><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td><td>18</td><td>74</td><td>8</td><td></td></tr>
<tr><td>South Africa</td><td colspan="2">26</td><td colspan="2">3</td><td>18</td><td>11</td><td>3</td><td>9</td><td>11</td><td>9</td><td>2</td><td>1</td><td>7</td><td></td><td>47</td><td>23</td><td>30</td></tr>
<tr><td>Tanzania</td><td>61</td><td>9</td><td>4</td><td></td><td></td><td>4</td><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td><td>15</td><td>74</td><td>11</td><td></td></tr>
<tr><td>Zambia</td><td>63</td><td></td><td colspan="2">6</td><td>18</td><td>4</td><td>1</td><td>2</td><td>5</td><td></td><td></td><td></td><td></td><td>1</td><td>87</td><td>7</td><td>5</td></tr>
<tr><td>Zimbabwe</td><td colspan="2">27</td><td>3</td><td>4</td><td>17</td><td></td><td>20</td><td>20</td><td>3</td><td></td><td></td><td></td><td>6</td><td></td><td>51</td><td>40</td><td>9</td></tr>
</table>

AGRICULTURAL ENGINEERING

In many countries the number of agricultural engineers and extension officers is low and has been reducing over the years. Given the need to support millions of rural farmers to achieve sustainability, a rethink of national policy with respect to food security, developing sustainable villages and developing agricultural engineers, scientists and extension officers could well add more numbers of engineers to the workforce. Agricultural engineers lament never having been involved in the formulation of the agricultural policy in their countries and have many ideas to share.

DEVELOPING SPECIALISTS FOR AND THROUGH PROJECTS

Countries cannot expect to develop experts in niche, particularly high-tech, areas overnight. When entering new, particularly high-tech markets or embarking on complex projects, conscious skills development plans must be put in place. Initially, it may be necessary to use international expertise to get projects, systems or processes off the ground, but the conscious transfer of skills as discussed in *Tomorrow's Leaders* must be put in place.

In new areas, attention also needs to be paid to developing or accessing suitable qualifications, offering bursaries and ensuring that a pool of appropriate skills has been developed. In Mozambique for instance, detailed research has been carried out on the level of skills required for the emerging gas market. Bursaries are being offered for students to study in this field and local qualifications are being developed.

Turning to the SKA project being rolled out in several SADC countries, a skills plan that includes the training of a range of engineers and scientists all the way up to PhD level has been put in place to ensure a pool of experts able to work at the cutting edge.

The philosophy of the publication titled *Skills for and through SIPs*, which is the skills plan for the development of Strategic Integrated Projects in South Africa, says it all. Skills need to be developed for particular projects or tasks, but considerable skills can be developed when working on projects. By planning well in advance, it is possible to develop skills for projects and through projects once they commence.

WHAT NUMBERS?

There is no one answer to what numbers? Each country and each industry has different needs which must be analysed on a case-by-case basis. The numbers will vary according to the type of

development, the level of service and the level of technology.

Using the Seychelles ratio of 540 engineering practitioners to 100 000 population as a target to which to strive, it is possible to see how, in time, this number may be achieved in other countries.

Considering Madagascar for instance, with 11 000 engineering practitioners (45 per 100 000 population) and an AIDI of 10.73, it is conceivable that in developing substantially more infrastructure to achieve an index of 100 (i.e. almost 10x the current number) seven to eight times the current number of engineering practitioners associated with infrastructure would be required, increasing the number by 26 000. Much of the existing infrastructure is at the lowest level of service, with many isolated rural settlements. Increasing the level of service to networked solutions would need two or three times more engineering staff, increasing the number in infrastructure from 29 250 to perhaps 70 000. Increasing manufacturing and the percentage of high-tech manufacturing may require a further 7 000. Addressing current vacancies may require a further 2 000 to 4 000. To achieve a 15:1 ratio of students to lecturers would require more academics and several thousand more are required in agricultural engineering to enhance farming methods and productivity. This could take the total number to some 85 000, representing almost 350 engineering practitioners per 100 000 population – a far cry from the existing 45.

As per the discussion in the previous chapter, this cannot happen without investment in infrastructure, followed by ongoing maintenance. If funds are not forthcoming and development does not take place, there will be no need for more engineering personnel and no work on which to train young graduates.

Furthermore, if higher levels of service are not possible in practice due to geographic and logistical constraints, there will be no need for the number to increase from 29 250 to 70 000 for infrastructure as postulated above, and the ratio will be consistently lower than in countries where a large percentage receive the highest levels of service.

Lower ratios of engineering practitioners to population relating to types and levels of service are not limited to developing countries. In the UK, the LFS reports some 770 000 engineers and engineering technicians, i.e. a ratio of about 1 160 practitioners to 100 000 people. The LFS survey in the USA shows some 2.76 million practitioners, which equates to 850 per 100 000 population, a difference of over 300 practitioners per 100 000. Given the vastness of the USA and the many isolated areas, it is possible that a higher portion of the population is served by off-grid solutions such as diesel generators, dry sanitation and rainwater harvesting. The installation of these services is the domain of the artisan and maintenance of some services can be handled by the user, whereas in the UK, most consumers are served from national grids. These and many other factors need to be considered when comparing ratios.

SKILLS PLANNING

Before rules of thumb are used to decide on the number per discipline to be educated and trained, it is essential that robust research and planning is carried out to ensure that the numbers to be trained and the needs of the country do indeed match.

When asking employers about this, however, it is essential to determine the level at which their shortages exist. All too often the cry is heard '*we can't find engineers*', but there are thousands of young engineering graduates who cannot find employment. What employers really mean is that they can't find experienced engineers. Questionnaires need to be carefully framed to determine the experience levels and specialisations required, rather than just asking about the number required per occupation.

The number to be trained must be based on the demand, i.e. the types of services, industries and numbers and disciplines actually needed.

WHAT NEEDS?

It is clear that there are many needs to be addressed, throughout the skills pipeline. To develop the appropriate number of engineers, engineering technologists and engineering technicians in the region there is a **need** to:

- Determine the demand per discipline and sector
- Enhance mathematics and science teaching
- Improve the capacity of tertiary education institutions to increase the throughput of engineering students
- Rationalise engineering studies into strong institutions
- Align qualifications in the region and ensure that they align with international best practice
- Address graduate training
- Align registration processes and ensure that they align with international best practice
- Develop mid-careers professionals to become the leaders of tomorrow

The above are all critical to address the quality of engineering skills in the region and develop expertise. However, if economic growth does not take place, there will be no need for the numbers to increase. The engineering activities on which to develop graduates will also be limited. To support growth, countries **need** to:

- Fill key positions with engineering professionals
- Invest in infrastructure and associated maintenance and engineering skills to plan, develop and manage infrastructure
- Support research and development to emerge with new technologies to contribute towards diversification of the economy and job creation
- Capitalise on the abundant mineral reserves in the region through mining and beneficiation and develop international markets
- Stimulate and support agro-processing, develop value chains and grow the manufacturing sector, particularly heavy and advanced manufacturing
- Balance the need for local job creation with liberalisation and align policies and criteria for the appointment international service providers and the involvement of foreign investors in the engineering sectors
- Enhance agricultural productivity and develop sustainable rural communities.

In the individual country reports, detailed recommendations have been made. Each country's **needs** are different. Once firm development plans are in place, skills plans must be developed with the engineering community to ensure that supply will match the demand.

Many regional trends and **needs** have been identified for which solutions have been suggested in the preceding chapters. Collaboration with the engineering community will be essential to ensure alignment of approaches and support mobility of engineering professionals.

ENGAGEMENT WITH THE PROFESSION

Throughout the research, it was surprising to find how little interaction there was between professional bodies and engineering ministries and utilities. Professional bodies represent the range of professionals – those from academia, consulting, contracting, manufacturing, mining, production and all the disciplines and subdisciplines associated with these sectors. Furthermore, membership includes those in both the public and private sectors.

It is in the business interests of private sector companies to keep up with the latest trends and technologies, and to carry out or commission research. It is important that their hands-on experience and pioneering is shared with government departments to offer direction and, in some cases, train and develop public sector staff.

It is suggested that a *National Engineering Advisory Team (NEAT)* be constituted per country to engage with government as and when considered necessary. It should be composed of a pool of experts nominated by the range of associations, institutions and engineering boards in each country, including academics and practitioners from the private and the public sectors, covering all disciplines. The names of the team members should be shared on all organisations' websites, and knowledge of the existence of the NEAT should be widely publicised. The composition should be a collegial arrangement across all bodies representing engineering, with no one body taking over, or imposing its views.

Government should be in a position to call upon members of the pool for advice, or when issues arise that need reaction, and team members should work together to develop input or a response as required to address engineering matters.

CONCLUSION

The future can be anything we design it to be. Member States are blessed with many natural resources and the climate supports extensive agricultural production. It is time to capitalise on the opportunities for agro-processing, mineral beneficiation and downstream processing to support growth, job creation and address poverty.

With a growing cadre of new leaders and the increasing calls for change and regional development, it is time to craft and implement agreements built on partnerships in the interests of the region. With the right policies, plans, investment and commitment in place, the aspirations of Agenda 2063 and the Industrialisation Strategy can be achieved.

Engineering professionals must be harnessed and are ready to support development – the words of Lesotho born, Seetella Makhetha, when he became president of the South African Institution of Civil Engineering (SAICE) in 2011 ring true when he launched the Credo of the African Engineer.

The Credo of the African Engineer

I am an Engineer and in my profession I take deep pride. To it I owe solemn obligations. Since the origins of humanity on the continent of Africa, human progress has been spurred by the engineering genius.

Engineers have made usable nature's vast resources of material and energy for humanity's benefit. Engineers have vitalised, and turned to practical use, the principles of science and the means of technology. Were it not for this heritage of accumulated experience, my efforts would be feeble.

As an Engineer, I pledge to practice integrity and fair dealing, tolerance and respect, and to uphold devotion to the standards and the dignity of my profession, conscious always that my skill carries with it the obligation to serve humanity by making the most sustainable use of Earth's precious resources.

As an Engineer, I shall participate in none but honest enterprises. When needed, my skill and knowledge shall be given without reservation for the public good. In the performance of duty and in fidelity to my profession, I shall give the utmost.

SOURCES OF INFORMATION

Data and information were gathered during meetings, interviews, telephone and Skype conversations, and via email. SADC reports, master plans and strategies and many standard international sets of data as listed in Chapter 5, *Research Approach,* were also consulted. Comprehensive documents focusing on specific issues as listed below were additional sources of information.

AfDB (African Development Bank). 2018. *African Economic Outlook 2018.* Abidjan, Côte d'Ivoire: AfDB.

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Part 3
Country Reports

PART CONTENTS

Detailed findings and recommendations per country are contained in the following section. Each country report looks at the different engineering sectors, and developments planned or required to give a sense of the need for engineering skills. The numbers per country are established, graduations and possible growth scenarios are considered to determine the adequacy of the supply side to feed demand. The reports are structured as follows:

- The economy
- Engineering activities
- Education, training and professional development
- The workforce
- Engineering Numbers and Needs
- Key recommendations
- Acknowledgements
- Sources of information

The countries are ordered as follows:

ANGOLA
BOTSWANA
DEMOCRATIC REPUBLIC OF THE CONGO
KINGDOM OF ESWATINI
KINGDOM OF LESOTHO
MADAGASCAR
MALAWI
MAURITIUS
MOZAMBIQUE
NAMIBIA
THE SEYCHELLES
SOUTH AFRICA
UNITED REPUBLIC OF TANZANIA
ZAMBIA
ZIMBABWE