




Chapter 1

The Potential Role of Nuclear Energy in Promoting Regional Economic Development in SADC

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1.1 Introduction

The concepts of baseload, peak load, and medium load are fundamental to understanding power generation dynamics. Baseload represents the minimum level of electricity generation that is consistently required over a 24-hour period to satisfy continuous demand. Meanwhile, medium and peak loads pertain to the supplementary power produced in excess of the baseload; however, this additional generation may not always be required at all times (NEMA 2024). A state's capability to produce sustainable baseload energy ensures that the industrialisation process occurs without energy limitations on growth. For centuries, coal-fired energy, a carbon-intensive resource, has championed the Industrial Revolution periods and served as a baseload technology (Unger 2013:5; Jonsson 2012:5). However, an alternative baseload source is required in a world that increasingly seeks environmentally friendly and green energy initiatives. Arguably, there is no such thing as a benign energy project when considering sustainability and the

environment; however, the future of energy generation requires more eco-friendly alternative technology.

Sustainable development is significantly hampered when limited access to energy is experienced as a result of socio-economic development being affected. The leading causes contributing to energy issues in developing and emerging regions include overpopulation, excessive consumption, poor power distribution systems, inadequate infrastructure, and ongoing delays in the commissioning of power plants, all of which are interconnected to the impacts of climate change. Climate change amplifies these issues by putting additional stress on already fragile systems. The unprecedented weather patterns associated with climate change strain energy production, particularly in systems reliant on hydropower, while increasing the energy demand from cooling and irrigation. Numerous efforts to establish sustained electricity generation in Africa have failed, leading to an energy crisis that cripples the continent (Mulugetta, Hagan & Kammen 2019). This is also true of the member states of the Southern African Development Community (SADC). In recent decades, SADC has experienced a significant disturbance in sustainable electricity supply characterised by frequent power outages, load curtailment, and load-shedding. As a result, SADC states have experienced a lower prospect of economic growth, which has implications for the region's industrialisation strategy. SADC's mandate requires a structural transformation that seeks to industrialise, modernise, and improve the region and bring about greater regional integration (Mapuva & Muyengwa-Mapuva 2014:28; Muller 2018:7; Eskom 2020).

South Africa's parastatal power utility, Eskom, supplies electricity to seven states in the SADC region. This makes South Africa the dominant electricity generator in the region—an important role, especially given the state's dominant economic status in the region (Nare 2018). However, Eskom continues to struggle with meeting electricity demand. Over the past decade, it has tried to alleviate the situation by building new coal-fired power stations in order to produce relatively low-cost energy for its customers. However, the demand far exceeds the supply,

and both the new and old coal-fired power stations have been wracked with continual problems. Eskom's continued energy-generation struggle negatively affects the entire Southern African region (Booth & Therkildsen 2012; International Business Publication 2015:79).

This chapter argues that integrating an extended nuclear energy capability into South Africa's energy mix is a no-regret option. Nuclear energy has been an indispensable component of the state's energy framework for several decades. The growing demand for nuclear energy, which is known for its low-carbon emissions and efficiency as a baseload power source, reflects the increasing urgency of addressing climate change. This trend is driven by the global imperative to achieve net zero carbon emissions by 2050, and this further underscores the role of nuclear energy in transitioning to sustainable energy systems (Vásquez-Maignan, Richards & König 2024). As highlighted in the state's 2019 Integrated Resource Plan (IRP2019), decision 8 indicates that the state may proceed with preparations for a new nuclear build programme of the order of 2,500 megawatts (MW). This ensures that nuclear energy remains part of the state's energy mix and part of the future; it is indispensable to the achievement of energy sovereignty in the state (Comins 2024; DoE 2019: 48). The technology is poised to create exponential opportunities for socio-economic development in the country while also alleviating the existing energy crisis, meeting sustainable development goals, and bolstering economic development in the SADC region. This is because the importance of the peaceful use of nuclear technology—particularly civil nuclear technology—as a low-carbon-emitting energy development pathway is gradually growing in importance, despite the heightened concerns around the risks of nuclear energy following the 1986 Chernobyl and 2011 nuclear accidents in Ukraine and Japan, respectively (Olutola 2018b). But the good thing about technology is that it is constantly evolving. Over the decades, conventional nuclear power plants, generating 700+ MW of electricity, have been dominant. However, in recent years, advanced nuclear reactors for electricity generation have emerged that are designed to address some of the challenges of conventional nuclear power plants (Sweatman & Schroer 2024).

The decreased use of nuclear energy in developed states such as the United States of America (USA), Germany, and France, owing to, among other things, the need to replace ageing nuclear plants, has raised concerns about the disruption of energy output. Nevertheless, the desire to include nuclear energy in the energy mix remains strong in some regions, especially in developing states (IAEA 1987; Olutola 2018c). Indeed, as development continues, and with global warming fast becoming a problem, the manner in which baseload energy is generated needs to become cleaner, more effective, less carbon-emitting, and sustainable. Civil nuclear technology should be considered in this regard, as it produces low-carbon-emitting energy, thus making it one of the key solutions for mitigating global warming and ensuring energy security.

1.2 The importance of regionalism and regional economic development

Regional economic development is a key objective of SADC. Söderbaum and Granit (2014) describe regionalism as a set of values, identities, and common objectives that lead to forming regions and regional cooperation within a given geographical area. It fosters the creation and development of government frameworks and regional institutions to shape and regulate collective action. Regionalism takes place in many parts of the world, for instance, in forming multipurpose regional organisations such as the European Union (EU) or African Union (AU). In the case of Southern Africa, regionalism is evident through the formation of specialised organisations, such as the Transboundary Water Management Organisation, or specialised networks, such as the Southern African Power Pool (SAPP) (Söderbaum & Granit 2014).

Regional integration has always focused on access to markets (African Development Bank Fund 2019). Regional cooperation has been important and has attracted attention on several fronts, while the increase in the physical links across the African continent has spread environmental externalities beyond national jurisdictions (African Development Bank Fund 2019). Beyond other existing regionalisation initiatives and the

eight regional economic communities in Africa, most regional initiatives deal with regional public goods. For example, five deal with energy, fifteen with the management of rivers and lakes, three with peace and security, and one with the environment (African Development Bank Fund 2019). Several regional integrations in Africa also stem from its geopolitical economy. Such geopolitical economies indicate that the integration of the economic, political, and military dynamics between states occurs in a manner that takes cognizance not only of international relations but also of the international political economy of the state (Kurecic 2017:318). Economic regionalism occurs when neighbouring states coordinate the opportunities and limitations that arise from interaction between states. It is an international institutional measure for facilitating the free trade of goods and services (Van Houten 2013). Different facets exist in economic regionalism, such as economic unions, customs unions, common markets, and free-trade areas. In the twentieth century, regionalism was characterised by a preference for tariffs, whereas in the twenty-first century regional trade agreements (RTAs) are different, their primary focus being on preferential market access (Amineh & Grin 2003).

The integration of economies in SADC remains an imperative process. Economic policies ought to complement each other to ensure mutual success. Therefore, existing tariff restrictions between each state must be abolished and come to terms with a single cohesive tariff policy for non-member states. The idea is to ensure mutually exclusive benefits by decreasing the cost of living (Madyo 2008:39; Mapuva & Muyengwa-Mapuva 2014). According to liberal economic theory, free trade entails that trade will exponentially increase member states' welfare. The static effects of regional economic integration are often found in the form of production efficiency and consumer welfare. Static welfare effects are evident when tariff barriers of member states of the trade bloc are decreased or abolished (Madyo 2008:40).

SADC mostly engages in cross-border, sector-specific projects such as the SAPP and regional development corridors.

It adopts an explicit market-related integration agenda, with the Regional Indicative Strategic Development Plan (RISDP) 2020–2030 and the SADC Vision 2050 being two strategic plans that provide a guiding framework for implementing regional integration and the developmental agenda (SADC 2020). Even though the RISDP is not legally binding, it enjoys a significant amount of political legitimacy (NEPAD 2015:20). Also, SADC has Vision 2027, aimed at the region's major infrastructure development challenge. Intra-regional trade is limited by inadequate infrastructure, which increases the cost of doing business and makes the region unattractive to investors. The revitalised focus on regional integration ought to emphasise infrastructure development (Dube 2013), which Vision 2027, also known as the Regional Infrastructure Development Master Plan (RIDMP), aims to do. This is a guide to developing and implementing priority infrastructure projects for the region. The RIDMP identifies six priority sectors for development: energy, transport, tourism, information and communication technologies, meteorology, and transboundary water (Dube, 2013). However, the challenge is that, despite SADC having designed various development programmes for integration, the lack of political will for implementing the various treaties and protocols has limited the organisation's success (Oloruntoba 2015).

Africa's integration efforts have failed to yield pleasing results as compared with other regions beyond the continent that have improved their economic welfare through integration mechanisms. The challenge facing Africa's regional economic integration has been its continued reliance on the old model of regionalism—an ideological paradigm of Pan-Africanism with its focus on politics rather than the economy. Moreover, African elites tend to focus on the wrong set of priorities, which do not ensure that state policies include regional development. This is often coupled with too little commitment towards a developed Africa (Qobo 2007). Therefore, for nuclear energy to flourish within SADC, it is imperative to harmonise standards related to nuclear safety, security, and non-proliferation. This would mitigate the risks associated with regulatory discrepancies. Establishing a unified framework through the SADC Energy

Protocol would be advantageous to facilitating the development of national nuclear energy programs under a cohesive regulatory and oversight structure. Furthermore, regional institutions, such as the SAPP, can play a crucial role in coordinating the deployment of nuclear energy across the region, thus ensuring alignment with comprehensive strategies that address regional energy demand and supply dynamics (Velichkov 2021).

1.3 The nexus of energy and development

Industrial development is part of the core developmental integration agendas of SADC. Access to sustainable energy plays an important role in achieving this and is reflected by the prominence of energy issues in recent regional, continental, and global processes. This includes the UN's 2030 Agenda for Sustainable Development, its 17 Sustainable Development Goals (SDGs), the AU's Agenda 2063, and the RISDP. Agendas 2030 and 2063 share several objectives and principles pertaining to sustainable development, poverty, environmental sustainability, and clean, sustainable energy. Both agendas emphasise the need for inclusive growth, human development, and the protection of the planet. In this regard, about 20 of Agenda 2063's goals are strategically aligned with Agenda 2030. For instance, Agenda 2063's Goal 1 (a high standard of living, quality of life, and well-being for all citizens) is linked with Agenda 2030's SDGs 1, 2, 8 and 11 (African Union 2015; The Economic, Social & Cultural Council and African Union 2023). Similarly, the RISDP 2020–2030 is a successor to the previous RISDP, which was a 15-year blueprint that provided a strategic direction for SADC's long-term social and economic goals. The inclusion of peace, security, and governance is a much-needed innovation that recognises the foundational importance of ensuring the necessary preconditions for achieving other priorities. In the long run, the objective of the RISDP 2020–2030 is to increase the region's manufacturing capacity, competitiveness, and trade capacity in order to achieve sustainable economic development. The revised RISDP 2020–2030 aligns with the following UN SDGs: 8—decent work and economic growth; 16—peace, justice, and strong institutions; and 17—partnerships for the goals (SADC 2020;

United Nations 2023). For the respective goals to be achieved in each agenda, national development plans, regional plans such as the RISDP, and continental strategies such as Agenda 2063 must be revised and aligned with the global UN SDGs. Integrating the SDGs into national policies, programmes, and strategies ensures that domestic efforts positively contribute to continental and global agendas (African Union 2023).

The various agendas, as highlighted above, identify the availability of affordable and sustainable energy as key to the realisation of sustainable development (SADC 2018:12). Indeed, access to modern forms of energy is essential for providing sanitation, health care, and clean water. It can also be highly beneficial for development, as it provides reliable, efficient lighting, mechanical power, and telecommunications. Indeed, energy is essential to any kind of development and any thriving society (Walton 2018). And even though, since 2010, there has been an increase in the number of people with access to electricity—approximately 118 million each year—SADCs regional efforts need to accelerate if the region is to meet the UN's SDG 7, which is ensuring access to affordable, reliable, sustainable, and modern energy for all, by 2030 (World Bank 2018). The biggest hurdles to this, according to the World Bank (2018), are challenges related to the extension of grid-based electricity, such as poor transmission and distribution infrastructure, high costs of supply to remote areas, and a lack of affordability. This was one of the reasons for the alignment of the 2010–2020 SADC Regional Energy Access and Strategic Plan (REASAP) with SDG 7 and Sustainable Energy for All (SE4All) initiatives, which correlate access to energy with development (SADC 2020:32).

The SADC Treaty is the primary foundation of the integration agenda for the region. It is based on the premise of creating and enabling an environment of economic cooperation among the SADC member states in various sectors (SADC 2018:18). To keep pace with the rising electricity demand, and coupled with the need to continue supporting and promoting sustainable development and regional integration, certain elements need to be put in place, such as legal, regulatory, and

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institutional frameworks that help to facilitate the growth of the energy sector (SADC 2018). SADC has made some strides in this regard through power pooling, for example. The business of power pooling is clear and powerful. Energy producers are enabled to access larger markets through wheeling, thereby avoiding excessive grid losses by selling to customers close to where the energy is produced. This helps states with energy deficits or limited energy, and also enables access to reliable energy from neighbouring states (Medinilla, Byiers & Karaki 2019).

The practice of power pooling is not straightforward, however. Power pooling requires the gradual development of many interconnected bilateral arrangements and deals between members. A regional regulator should be given authority to facilitate this process and apply its rules, as a power pool is only as strong as its weakest link (Medinilla *et al.* 2019). Yet even though states join power pools, the producers of energy and utilities in those states are the real participants. This is evident with power pools in Africa: the real participants are often public enterprises usually operating as monopoly providers under specific market conditions. They have therefore become political champions, owing to their importance in the market, and form part of a wider system of rent capture and distribution (Barnett, Stockbridge & Kingsmill 2016). In the SADC region, however, significant progress has been made in promoting the development of least-cost power generation to the end-user and power trading, by linking its various generating plants through interconnectors and transmission systems (SADC 2018). Nine power utilities on the Southern African mainland are interconnected, with the exclusion of Angola, Malawi, and Tanzania. Botswana, the Democratic Republic of Congo, the Kingdom of eSwatini, Lesotho, Malawi, Mozambique, South Africa, Zimbabwe, and Zambia form part of the region's integration of power. This interconnectivity has facilitated the establishment of the SAPP as a power trading platform. It enables the SADC member states that experience shortfalls to purchase power from those with surplus power within the regional energy security framework (SADC 2018:14).

1.4 The role of South Africa and nuclear energy as an important player in regional integration in SADC

South Africa has consistently maintained a leadership position in SADC's regional integration and development. According to the International Business Publication (2019), South Africa is a hub for regional integration in Southern Africa. The state's dominance of economic activity in the region has accounted for 60% of SADC's total trade and approximately 70% of the region's gross domestic product (GDP) (Ettang & Leeke 2019). Much of the intra-SADC investment flows through South Africa. Therefore, South Africa's investments play a key role in neighbouring states by accounting for approximately 9–20% of the GDP in Namibia, Mauritius, the Kingdom of Eswatini, Lesotho, and Mozambique (International Business Publication 2019). As far as nuclear technology is concerned, one of the primary goals of South Africa's policy on disarmament, non-proliferation, and arms control includes reinforcing and promoting the state as a responsible producer, possessor, and trader of defence-related products and advanced technologies, such as nuclear technology for civilian purposes. As a member of the International Atomic Energy Agency (IAEA), the Nuclear Supplier's Regime, the Africa Group, and the Non-Aligned Movement, South Africa is in a position to promote the importance of nuclear non-proliferation, as export controls should not become a means of denying developing states access to advanced technologies (Government Communication and Information System 2020).

There may be regional perceptions and concerns that the gains from regional integration would be uneven because of South Africa's dominant status in the integration process. SADC member states, by contrast, view South Africa as a messiah that can potentially drive development and peace-making in the region. The state's soft-power approach has attracted many citizens from the region to its higher education institutions, and the state's exports of goods and services could serve as a model for the subregion (Ettang & Leeke 2019). Indeed, given Eskom's dominance in energy generation in the region, SADC

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ought to consider the importance of South Africa's hegemonic position when it comes to pooling resources through research-led development strategies.

The main objectives of SADC are to achieve economic development, enhance the standard of living and quality of life, peace, and security, and to support the socially disadvantaged through regional integration. This commitment has manifested in several regional integration projects in which South Africa is playing a leading role (Thekiso & Van Wyk 2019; SADC 2022). South Africa also plays a key role as a member of the SAPP by actively seeking to provide a sustainable, economical, and consistent supply of electricity to each of the SAPP members, making reasonable use of the state's natural resources and environmental effects (Thekiso & Van Wyk 2019:59). However, in recent years, due to South Africa's energy problems, its contribution to the SAPP has been limited, and when there is a shortage of supply, Eskom suspends electricity sales to Namibia and Botswana, while supplies to other SADC states that receive electricity from Eskom are cut by 10% (Le Roux 2022). A diversified and sustainable energy mix is desperately needed to bring an end to persistent load-shedding in South Africa, which negatively affects regional integration projects.

Nuclear energy has become one of the focal points when considering a diversified, sustainable energy mix. There are many advantages to nuclear energy, one of which is that nuclear fission does not emit carbon emissions, as opposed to chemical burning, which does and thus amplifies climate change effects. Nuclear energy provides baseload electricity to the electric grid with no carbon emissions output. Similarly, solar and wind energy also produce carbon-free electricity, however these energy sources are intermittent, require favourable conditions for efficient operation, and often need to be accompanied by a battery energy storage system (BESS). Nuclear energy is considered to have the highest capacity factor (a measure of what percentage of the time a power plant produces energy) of all energy sources. Nuclear energy produces carbon-free electricity that is reliable more than 92% of the time—twice as reliable as coal-fired plants at 43.3%, and also more reliable

than natural gas plants at 54.4%, wind energy at 34.6%, and solar energy at 24.6% (Rhodes 2018; Office of Nuclear Energy 2020; Pierce & Le Roux 2022; Thermtest 2024). Additionally, nuclear energy releases less radiation into the environment than any other major source. Notably, while nuclear energy may be expensive to build, the cost of nuclear energy is ultimately a matter for the markets to decide (Rhodes 2018). Civilian nuclear programmes thus present significant potential for addressing Africa's energy challenges. However, the technology also raises several concerns around safety, security, waste management, public perception and acceptance, economic viability, environmental impacts, and regulatory and political challenges (Orikipete, Ewim & Egieya 2023).

Micro and small modular reactors (SMRs) are classified as advanced nuclear reactors that are smaller and have an average capacity of up to 300 MW per unit. Reactor designs are modular and simpler than previous designs, which makes them less capital-intensive, and they are also more fuel efficient, which makes them inherently safer. SMRs are purposely designed to address challenges faced by conventional nuclear power reactors, which have an average power capacity of 1,600 MW, making SMRs game changers and ideal for locations unsuitable for conventional nuclear power reactors (World Nuclear Association 2021). As of 2024, there are three operational SMRs in Russia, China, and India. Three further SMRs are in the construction phase, while approximately 65 SMRs remain in the design stage, with the majority possessing a capacity of between 100 and 300 MW (Liou 2021; World Nuclear Association 2023; Statista 2024).

Several African states, including Namibia, Zambia, and Egypt, have considered nuclear energy as a possible source in the state energy mix. In 2016, Zambia and Namibia each signed a memorandum of understanding with ROSATOM, Russia's state atomic agency corporation, to develop nuclear energy. Globally, the term nuclear renaissance has become a catchphrase. However, there seems to be a limited consensus on the benefits of nuclear energy (Mushota 2016; Madondo 2018; Khripunov 2007; Van Wyk 2013). In August 2024, during the US-Africa

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nuclear energy summit, Ghana signed an agreement with a US developer for a nuclear reactor based on NuScale Power SMR technology. The agreement will see the deployment of NuScale's VOYGR-12 SMR (Reuters 2024).

The attitudes held by African decision-makers, experts, and the public regarding nuclear energy range from the negative and cautious to the positive and enthusiastic. Supporters of nuclear energy see the energy source as a silver bullet that could enable the continent to demonstrate both its technical progress and competence. This vested interest in nuclear energy is motivated by the common concern that Africa is more vulnerable than other regions to climate change (Khripunov 2007). Indeed, Pedraza (2011) and Olutola (2018a) agree on the use of nuclear energy to produce electricity in Africa. African states should pursue the option of nuclear energy in the state's energy mix; it is their prerogative. This is largely attributed to the continent's dire energy crisis. Nuclear energy can become a consideration as it assists states in meeting their targets under the 2015 Paris Agreement to reduce carbon emissions by 35% compared to the business-as-usual levels by 2030 (United Nations 2015; Carbon Brief Staff 2015). It has been established that industrialised regions and states that have achieved relatively decarbonised economies have done so by including nuclear energy as part of the region or the state's low-carbon energy mix (Blue and Green Tomorrow 2016).

SADC (2018) notes the importance of nuclear energy as a key subsector in keeping up with electricity demand. This sub-sector is currently dominated by South Africa, home of the first and, to date, only nuclear power plant (NPP) in Africa. The Koeberg NPP was built in the 1970s on the west coast of South Africa to mitigate the cost of coal transportation from the coal-rich fields in the eastern part of South Africa. The two reactors at Koeberg were synchronised with the national grid in 1984 and 1985 (Eskom, n.d.), and the units together produce approximately 5% of the state's electricity capacity. Koeberg was scheduled to reach its end-of-design life by 2024; however, it is currently undergoing refurbishment to extend its operation by 20 years, which is critical for energy security in the period

beyond 2024. It is considered to have low operational costs and is one of the best-performing NPPs in the world (DoE 2019; Cowan 2022). It has demonstrated the benefits of nuclear energy and has given South Africa a reason to continue extending the programme (Department of Mineral Resources and Energy 2019a; Matya 2022; Moonsamy 2022).

The success of Koeberg has demonstrated how the nuclear industry has a significant role to play in job creation and economic growth by providing short- and long-term employment and economic development. To put it into perspective, a 2017 economic impact assessment report of Koeberg prepared by KPMG found that its combined impact through investment and operations between 2013 and 2016 contributed R30.2 billion to the GDP of the Western Cape Province (approximately 1.4% of the provincial GDP) and R23.1 billion to the South African economy. In the same period, an average of 1,786 direct jobs were sustained while creating approximately 35,000 indirect and induced jobs per year, resulting in a total estimated revenue of R16.4 billion to the national government. Through direct and indirect tax collections, Koeberg and its supply chain stakeholders also contributed R8 billion to the Western Cape's provincial revenue between the 2011/12 and 2015/16 fiscal periods. Moreover, Koeberg contributed R9 billion to the national fiscus in the same period, while R15 billion was contributed to household income in the same fiscal period. Between 2016 and 2020, Koeberg was expected to create and sustain an average of 2,300 direct and 42,000 indirect jobs annually in the Western Cape. Furthermore, Koeberg's employees' income levels are above the industry average in South Africa due to the specialised nature of their work. In the rest of South Africa, during the same period, Koeberg contributed approximately 63,000 jobs. Thus, given that sustainable electricity is a key input for many products and processes in the state's economy, Koeberg is a direct contributor to economic growth, both in the Western Cape province and South Africa at large (KPMG 2017; World Nuclear News 2017; Department of Public Enterprises 2017).

Regarding development, ESI Africa (2016) has noted that building new NPPs has successfully reignited or expanded industrialisation in many states, namely China, South Korea, and the United Kingdom (UK) in the 1960s and 1970s. Interestingly, since 2000, China has increased its number of operating reactors by more than ten times, making the state the fastest-expanding nuclear power generator globally. As of April 2024, the state generates approximately 53.2 GW from 55 reactors (Gil 2017; U.S. Energy Information Administration 2024). A localisation strategy and the selection of the most suitable localisation scenarios have become essential to achieving the expansion of nuclear energy. It serves as a pre-qualification for local companies as per international standards (ESI Africa 2016). South Korea is a good example: it approached technological self-sufficiency in constructing NPPs, and the affected sectors increased their primary metal products, general machinery, and equipment and business services. The idea was to get local manufacturers to extend their normal product production and incorporate nuclear designs and standards (IAEA 2009). The positive spin-off effects from the localisation of plant construction have been evident in primary metal product sector activities. The economic value added during the operations of the NPP displays roughly the same kind of evolution as in the construction phase (IAEA 2009).

1.5 Proposals for moving forward

The adequate availability of uranium resources highly influences the growth potential of nuclear energy in developing regions. Globally, a few states with significant reserves, mining, and export capabilities dominate the uranium supply cycle. The top five uranium producers by mining include Kazakhstan (43%), Canada (14%), Namibia (11%), Australia (9%), and Uzbekistan (6%). South Africa's total uranium production from mines accounted for only 0.4% of the global total production in 2022 (World Nuclear Association 2024a). Currently, the uranium enrichment market is dominated by three key producers: Orano, Rosatom, and Urenco. These companies operate extensive commercial enrichment facilities in several countries, including

France, Germany, the Netherlands, the UK, the US, and Russia (World Nuclear Association 2024b). As technology evolves, the focus has shifted to designs less reliant on traditional uranium-based fuels to improve efficiency, reduce waste, enhance safety, and diversify the fuel supply (World Nuclear Association 2024c). The expansion of nuclear energy in SADC in the coming years largely depends on utilising the region's abundant uranium deposits, particularly in Namibia and South Africa. This endeavour could be supported by China, given its established partnership with Namibia, which has resulted in China's largest investment in Africa: the world-class Husab mine. There are also similarities between China's High-Temperature Gas-Cooled Reactor-Pebble-bed Module (HTR-PM) and South Africa's Pebble Bed Modular Reactor (PBMR) (World Nuclear News 2023b; Namibian Uranium Association 2024).

The revenue from uranium exports from South Africa is noteworthy. South Africa is home to large uranium reserves and maintains an extensive uranium mining industry that makes the state one of the key exporters in the world. By 2019, uranium exports alone have acquired revenue of over R1.5 billion, according to the Department of Mineral Resources and Energy (2019a). The abundance of uranium, therefore, drives the push towards nuclear energy. According to the IAEA (2006) and Dasnois (2012), Africa accounts for 18% of the world's known and recoverable uranium resources, but more uranium might be discovered in Africa through research and further exploration. It is up to the government, private industry, and civil society to work together in developing a robust policymaking framework for all options to be assessed and developed accordingly, taking into consideration the respective cost implications and the benefit to the state and region by supplying reliable sustainable baseload energy (Echávarri 2006; Gumede 2018; National Development Plan 2019). Furthermore, transitioning from coal to nuclear energy can be considered radical decarbonisation since NPPs only release carbon emissions from the ancillary use of fossil fuels during mining, construction, processing of fuel, maintenance, and decommissioning of the NPP (Rhodes 2018).

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Some SADC member states plan to increase their uranium mining and consider the peaceful uses of nuclear technology, which is projected to drive regional growth. Several SADC member states are considering adding NPPs to their states' energy generation mix to help meet the rising electricity demand. A partial synchronisation of existing and emerging regulatory frameworks is required to achieve this, including better networking of the SADC nuclear regulators, development of human resources, and introduction of information technologies. Nuclear energy needs to be highly regulated to ensure the safe and secure handling of the nuclear materials, reactors, and waste disposal of all existing and new nuclear energy projects in the SADC region (SADC 2016; 2018; 2020; World Nuclear Association 2022).

South Africa's 2019 Integrated Resource Plan advocates for the immediate commencement of a nuclear build programme of up to 2,500 MW as a no-regret option in the long term (DoE 2019: 48). In 2019, in his budget vote speech, Gwede Mantashe, South Africa's Minister of Mineral Resources and Energy (DMRE), reiterated the need for the state to begin implementation plans for additional nuclear capacity beyond 2045, as it transitions towards a diversified cleaner energy mix in line with Chapter 5 of the National Development Plan (NDP) (DMRE 2019a). In the 2023 DMRE budget vote speech, Mantashe stated that in the 4th quarter of the 2023/24 financial year, a request for proposals to procure 2,500 MW of nuclear energy build would be issued (DMRE 2023). Mantashe consistently emphasizes that South Africa should have more nuclear energy capacity and be considered part of the green transition (Creamer 2023). However, in August 2024, Electricity and Energy Minister, Dr Kgosientsho Ramakgopa, withdrew a Ministerial Determination for the procurement of 2,500 MW of new nuclear capacity due to a lack of public consultation. The withdrawal came ahead of a scheduled court case initiated by anti-nuclear lobbyists, namely the Southern African Faith Communities' Environment Institute (SAFCEI) and Earthlife Africa Johannesburg, which contested the legality of the gazetted Section 34 determination signed by Ramakgopa (Creamer 2024; World Nuclear News 2024).

Through the SAPP, the SADC region stands to benefit greatly from South Africa's new nuclear build plans. Notably, the SAPP's mandate has always been clear in its attempt to link up the southern and northern energy sources and electricity grids to overcome member states' differences and allow support between states during peak periods and emergencies. The SAPP has observed an increase in the potential benefit that could be brought to the SADC region via nuclear energy. Expanding national electricity power markets beyond state borders could decrease the impact of variable supply and demand while stimulating the economy and investment capacity. Additionally, the SAPP has made significant progress in helping trades grow through the development of the Regional Electricity Market (REM) (Maupin 2016).

The embracing of new technologies, such as Digital Twinning (DT), by South Africa and, to some extent, the SADC region, could provide a perfect catalyst for replicating nuclear facilities. DT is a virtual replication of a nuclear energy facility or process by combining design information, process data, and simulation capacities that optimise operation throughout its entire life cycle (Tecnatom 2021). Companies can use DT when exploring novel technologies and ways of lowering costs or refining designs before breaking ground (Volodin & Tolokonkii 2019; Argonne National Laboratory 2020). DT would not limit SMRs to being built in states such as Namibia, the DRC, and Malawi, which already have existing operational uranium mines and have been uranium producers in recent years (Velichkov 2021).

DT could be particularly attractive, for example, if South Africa's previous design for an SMR, the PBMR, could be revived. The PBMR was envisioned to produce electricity based on a 400 MW design as compared with the pricy pressurised water reactor (PWR) plants like the Koeberg NPP. Initially, the PBMR aimed to deliver energy locally and for export to industry and households. It was expected that the PBMR programme would export 20 reactors per year and 10 reactors would be built for domestic use (Rennkamp & Bhuyan 2016:3; Fig 2010:1). The advantage of the PBMR was its size, as it allows the construction period

to be staggered, thus allowing the initial reactor to be running and generating revenue before the others are completed. This assists in the funding of construction for other reactors. The capital cost required would be reduced by a significant margin as smaller core components would enable modular and standardised construction techniques (Staffel 2005). Unfortunately, the PBMR project was scrapped in 2008 because of the global financial crisis and a lack of potential investors and customers (DME 2008), and was replaced seven years later by plans to build more expensive pressurised water reactors (PWRs) NPPs (Rennkamp & Bhuyan 2017; Cameron 2020). As technology continues to advance, the South African Nuclear Energy Cooperation (NECSA) hopes that advanced designs could potentially lead to a first-of-a-kind high-temperature modular reactor (HTMR)-100 SMR built in five years using graphite-coated spherical uranium oxycarbide tristructural isotropic (TRISO) fuel, which the state has already produced. This design is well-suited to the African market, as it requires low cooling water and maintains the capability of powering remote mines and communities without the need for long-distance power distribution network lines (World Nuclear News 2023a). Dr Kelvin Kemm, Chairman and Chief Executive Officer of Stratek Global, believes this future is now. Stratek Global seeks to develop and implement multiple HTMR-100 in the state. The helium gas-cooled HTMR can be installed in groups of 6 to 10 units to generate power for conventional steam turbines, each with less than 300 MW capacity. This installation is sufficient to meet the energy demands of a major industrial mining complex or to supply electricity to a city comparable in size to Pretoria (World Nuclear News 2023b; Agence France-Press 2024).

Another proposal is the technology transfer and localisation model. The SADC region's vast supply of natural resources, access to uranium, and established construction, manufacturing, and steel industries in some of the member states create an opportunity for South Africa to further develop a nuclear industry that holds great benefits for SADC states and the regional economy (Van Wyk 2012). Nuclear energy projects have the potential to greatly contribute to the economy of the region in which the project is built. Indeed, the IAEA's

regional economic development analysis is based on the input-output analysis that evaluates the direct, indirect, and induced NPP programmes from the increased output and expenditures of labour income. Moreover, the expenditures for goods and services are included in the construction and operation of the plant. For instance, the Ulchin NPP located in the Ulchin region in South Korea is one of the well-documented NPPs regarding its regional economic contribution. The region has experienced a large economic growth spurt due to the construction of the Ulchin NPP. The project led to creating jobs in the construction and operation phases. The development of local infrastructure to support the project, such as the building of schools, training and scholarship programmes, and expansion of medical facilities, amongst other things, contributed immensely to the economic growth of the region (Van Wyk 2012).

Expansion of nuclear energy in SADC also requires consideration of the acquisition of fuel for the NPPs. Acquiring uranium is not the biggest obstacle; SADC has rich deposits. Furthermore, in 2007, the South African government declared uranium a strategic mineral for securing future domestic supply. This was conducted in preparation for the development of the local nuclear industry ahead of the state's uranium mining and beneficiation strategy and the 2008 nuclear energy policy (Van Wyk 2021:33). This policy provides a clear vision for the government to develop an extensive nuclear energy programme that involves the mining of uranium ore and the use of uranium for peaceful purposes. The long-term goal of the policy is to allow the state to be self-sufficient in all aspects of the nuclear fuel cycle (NFC). Additionally, to implement a sustainable nuclear programme and take charge of all potential economic benefits, the government should seek to return to implementation of, or obtain interests in, the complete NFC, which includes uranium mining and milling, uranium conversion, uranium enrichment, fuel fabrication, spent (irradiated) nuclear fuel and radioactive waste management, and reprocessing of spent (irradiated) fuel and recycling of fissile materials as strategic priorities for energy security (Department of Minerals and Energy 2008; Van Wyk 2021:34). It is indeed not far-fetched for the government to take charge of the entire

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NFC, as the state did it once before with the building of the Y- and Z-enrichment plants in 1975 and 1984, respectively, at Valindaba near Pretoria. The Z-plant was a semi-commercial Helikon aerodynamic process enrichment plant that produced low-enriched uranium (LEU) for nuclear energy programmes. It was closed in 1995. The Y-plant was a pilot-scale, aerodynamic process enrichment plant that produced high-enriched uranium (HEU) for nuclear weapons. It was shut down in 1990, after the apartheid government decided to destroy its small, top-secret nuclear arsenal (Barletta & Ellington 1999; Cochran 1994:36; NECSA 2023). In 2013, an IAEA report on South Africa's integrated infrastructure review noted that the state maintains a strong background in the NFC, both in front- and back-end activities, with a vast accumulation of knowledge and technical expertise from the past (IAEA 2013:57).

Currently, however, South Africa faces a huge dilemma because on 4 December 2022, the United States–Republic of South Africa (US–RSA) Section 123 Agreement for Peaceful Cooperation expired. The agreement included a United States Nuclear Regulatory Commission (NRC) licence, XCOM1252, which authorised the export of fuel assembly components to Sweden for the fabrication of fuel assemblies and subsequent shipment of the completed assemblies to South Africa for use in Koeberg Unit 1 (Federal Register 2023). Subsequently, in January 2023, the NRC ordered the Westinghouse Electric Company LLC to suspend the licence. Negotiations around a new agreement are ongoing, with both parties citing the need to expedite the process whilst engaging in measures that ensure continuity of cooperation (Department of Mineral Resource and Energy 2023). At present, the absence of the 123 Agreement for cooperation between the USA and South Africa regarding the peaceful uses of nuclear energy has resulted in South Africa being removed from the advance consent list of states eligible to receive retransfers from Euratom. This includes low-enriched uranium, non-nuclear material, equipment, and source material that has been transferred, as well as low-enriched uranium produced using the transferred nuclear materials or equipment for nuclear fuel cycle activities, except for the production of high-enriched uranium (Federal Register 2024).

Meanwhile, NECSA and Russia's TVEL¹ signed a memorandum of understanding to collaborate in manufacturing nuclear fuel and its components. The strengthening of bilateral cooperation between the two states in this regard will be imperative for South Africa, should it seek to open the possibility of recreating its production capacity for the manufacture and supply of nuclear fuel, especially given the rise in the number of African states interested in nuclear energy. Historically, South Africa has sought self-sufficiency in its NFC. In 2011, initial feasibility studies were completed on re-establishing an NFC programme, with NECSA proposing to establish fuel fabrication capacity for PWR to ensure that the state has fuel supply security (World Nuclear Association 2023). Currently, South Africa has no immediate plans to manufacture its own nuclear fuel, but it wants the possibility of doing so to remain open, as enshrined in international nuclear agreements like the Nuclear Non-Proliferation Treaty (NPT) and the rules of the IAEA (Fabricius 2023). Therefore, any agreement that prohibits the state from this possibility is deemed unfavourable.

Some other challenges remain for the expansion of NPPs in SADC. For example, the physical infrastructure gap for nuclear energy relates to a lack of planned electricity generation projects and the technology's uncertain future (SADC 2018). There is a need, therefore, for nuclear-awareness-building to ensure that proponents and detractors of nuclear technology development agree on the technology's safety in the region. A presentation should accompany this on the safe disposal mechanisms for nuclear waste. The handling of nuclear waste is highly regulated, and no one is permitted to cause pollution (World Nuclear Association 2020). There must also be adequate and consistent assurance that nuclear disaster management plans are in place. While South Africa has measures in place for both waste and disaster management, none of these measures currently exists in the rest of the SADC region (SADC 2018). A demonstration is required to show that nuclear energy can be a safe electricity generation option. Given its long-standing

1 TVEL is a subsidiary of Russia's state atomic energy corporation (ROSATOM) responsible for uranium conversion, enrichment, and nuclear fuel fabrication (Kachkova 2023).

nuclear expertise, South Africa can best fulfil this role. This would help to win civil society's confidence and would help the regional government to endorse the deployment of nuclear energy in the region (SADC 2016).

Notably, exploration and mine development are still required in some prospective SADC states that have the potential to be suppliers of uranium, namely Botswana, Tanzania, Zambia, and Zimbabwe (Velichkov 2021). This would be in line with some IAEA nuclear-related agreements, such as the African Regional Cooperative Agreement for Research Development and Training Related to Nuclear Science and Technology (AFRA), signed in 1990; the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Material, signed in 1997; and the Revised Supplementary Agreement concerning the Provision of Technical Assistance by the IAEA, signed in 2006 (Van Wyk 2013). In the long run, there ought to be discussions by African states and regional blocs about establishing a SADC office on nuclear energy and regulation and commencing the building of NPPs (Dasnois 2012; Velichkov 2021).

1.6 Conclusion

The root of SADC's developmental challenges stems largely from inadequate access to electricity. Without immediate attention, the crisis puts the region's sustained economic and infrastructural development at risk. The energy challenge facing the region has implications for its industrialisation strategy. Structural transformation in the region is one of the key focus areas of SADC's strategy that seeks to industrialise, modernise, improve, and bring about closer regional integration. Compared to the rest of the continent with access to energy, SADC trails behind. Regional integration is a viable option when considering sustained development and free trade between states. Regionalism highlights the importance of regional collaborative efforts and fosters greater commitment by all member states. In essence, a state's economic development is stimulated by regional economic development. Greater efforts can be achieved through region-building and power pooling.

There has been a strong belief that, should African leaders create an environment that enables conducive growth and ultimately integrates the region, this would enable African states to reap the benefit of economies of scale to produce trade and thus maximise state welfare. Through regional integration, cross-border energy cooperation could be established to trade electricity to multiple states in need. There is much potential in the region's geopolitics when it comes to nuclear energy generation, which in turn could bolster economic regionalism. This makes it imperative for SADC member states to have economic policies that complement each other to ensure that collaboration yields fruitful results. A greater synergy is required between the region's developmental policies and member state policies, coupled with the implementation of key performance indicators, to monitor the region's success in policy implementation and to highlight ineffective policies that are not conducive to the developmental agenda. The latter is arguably the continent's challenge when it comes to ensuring integration and sustained development.

It has been well documented that the peaceful uses of nuclear technology positively contribute to the SDGs. Its applications are not limited to energy generation; they also contribute to other aspects of the SDGs. Future developmental prospects require energy generation to be low-carbon emitting. Nuclear energy has proven to be a viable alternative to coal in addressing not only the regional energy crisis but global energy insecurities as well. The inextricable link between access to energy and development is evident when considering the state's or region's access to energy and developmental progress. However, when it comes to ensuring sufficient power capacity some of the biggest hurdles that developmental regions face when increasing power are grid unavailability, the extension of grid-based electricity, and poor distribution and transmission lines to end-users.

There are a lot of misconceptions about nuclear energy in civil society, often due to a lack of information about the technology. This has become the playground for anti-nuclear lobbyists, who cite the dangers of radiation, costly build-up,

and potential environmental harm. This makes information-sharing with civil society and communities important, as it creates awareness and ultimately ensures that proponents and detractors of the development of nuclear technology agree on the safety and economic benefit of the technology. Nuclear energy, being a low-carbon emitting baseload energy generation source, would be a no-brainer as a viable alternative, as states and regions seek to decarbonise. Between the SADC member states, there lie sufficient uranium resources to power their NPPs, which could positively influence the region's growth. The introduction of SMRs could be a game-changer for states looking for an alternative to traditional NPPs, as these states often cite limitations of the electric grid, of funding, and of skilled human resources as issues. SMRs require lower up-front funding, fewer skilled human resources, and have greater compatibility with existing electric grids.

As a dominant state in the region, South Africa has a significant role to play in strengthening regional ties through nuclear energy provision given its long-standing history with nuclear energy. The Koeberg NPP is regarded as one of Eskom's best-performing power plants in its generation fleet in terms of continued operation. Therefore, embracing DT would benefit the state and the entire region by replicating functional NPP facilities, especially in prospective states with functional uranium exploration and mine development. This would align with the SAPP mandate to link up the southern and northern energy sources and electric grids, to surpass member-state differences, and to enable support during peak periods and emergencies. This is subject to grid extension to accommodate additional energy capacity, but through DT, technology transfer could take place to support other states in the region interested in building nuclear energy to offset the energy demand and ensure energy security.

It can therefore be concluded that nuclear energy is a commodity that brings about regional socio-economic development whilst decarbonising the state and alleviating the energy crisis. Attitudes towards nuclear energy should not be subjective but should be based on research and science.

Nuclear technology is not a one-trick pony; it has several positive economic spin-offs that can contribute to the state's economic development and improve the standard of living. It is imperative that SADC member states strive towards harmonising regional energy policies that promote the building of necessary infrastructure to fulfil the SAPP mandate of supplying energy throughout the region.

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