DISSERTATION

The techno-economic impact of a high penetration of embedded generators on South African, Brazilian, Australian and Ugandan distribution networks: A comparative review

by

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DECLARATION

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ABSTRACT

Owing to current electricity capacity shortages and rising electricity prices in South Africa, customers are opting for self-generation to mitigate the effects of load shedding and offset their electricity bills. In June 2021, the South African government removed the licensing requirement for private generation to encourage the uptake of self-generation, close capacity shortages and promote investment in private generation. While the increase in private generation is seen by the electricity industry as a positive step towards meeting energy supply demands, there are concerns about the impact that high numbers of embedded generation facilities will have on the distributors, i.e., their networks and revenues. The aim of this study was to conduct a review of the technical, economic and regulatory impact of a high number of embedded generators on distributors and their networks. The impact in South Africa is compared with the impact in Brazil, Australia and Uganda. The research study seeks to identify some of the success strategies implemented by these countries to address challenges associated with private embedded generation, and to provide recommendations for South Africa. South Africa compares well with Brazil and Australia in terms of electricity access and installed generation capacity vs population; however, in terms of embedded generation, particularly from variable renewable energy sources, South Africa's penetration levels are still lower than those of Brazil and Australia, although higher than those of Uganda. The review highlights that the impact of embedded generation is largely driven by technical, economic and regulatory policy changes. The absence of a clear market structure or market direction, enabling legislation and policies, regulatory tools (such as national rules for integration or compensation and unbundled tariffs for some customer categories) make it difficult to minimise the negative effects of a high penetration of embedded generation and to capitalise on potential positive effects. In Brazil and Australia, the success of renewable energy embedded generation is largely a result of clear policy and regulations, which lead and drive positive changes in their electricity industries. Recommendations are made for legislation, policy and regulation changes to support embedded generation, the creation of a clear market structure, and the publication of national guidelines for embedded generation management. In addition, tariffing mechanisms should be reviewed to ensure a fair distribution of costs.

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ABBREVIATIONS

AEMC	Australian Electricity Market Commission
AEMO	Australian Electricity Market Operator
AER	Australian Energy Regulator
ANEEL	Brazilian Electricity Regulatory Agency (Agência Nacional de Energia Elétrica)
BRICS	An intergovernmental organization comprising Brazil, Russia, India, China, South Africa, Egypt, Ethiopia, Iran, Saudi Arabia and the United Arab Emirates
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed Energy Resources
DG	Distributed Generation
DMRE	Department of Mineral Resources and Energy
EG	Embedded Generation
ERA	Electricity Regulatory Authority (Uganda)
ERA	Electricity Regulation Act (South Africa)
ESKOM	South African Electricity Public Utility Company (Electricity Supply Commission)
EPP	Electricity Pricing Policy (South Africa)
GHG	Greenhouse Gas Emissions
IEA	International Energy Agency
IRP	Integrated Resource Plan
NERSA	National Energy Regulator of South Africa
NEM	National Electricity Market
NER	National Electricity Rules (Australia)
NSP	Network Service Provider
NTCSA	National Transmission Company, South Africa
OECD	Organisation for Economic Cooperation and Development
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme

RES	Renewable Energy Sources (some are programmable or dispatchable such as biomass, hydro, biogas & CSP)
RMIPPPP	Risk Mitigation Independent Power Producer Procurement Programme
UEDCL	Uganda Electricity Distribution Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UMEME	Uganda's main electricity distribution company
RES	Renewable energy sources

CHAPTER 1: INTRODUCTION

1.1 Introduction

Owing to current electricity capacity shortages and rising electricity prices in South Africa, many customers are opting for self-generation in the form of embedded generators to mitigate the effects of load shedding and to offset their electricity bills. An embedded generator is defined in Schedule 2 of the Electricity Regulation Act, 2006 (Act no. 4 of 2006) ("the Act") and the South African Distribution Code as a legal entity that operates one or more unit(s) that is connected to the distribution system, or that desires to connect one or more unit(s) to the distribution system [1] [2]. Generation may be from renewable energy sources or from non-renewable energy sources. Types of embedded generation include but are not limited to [3] [4]:

- wind
- solar PV (photovoltaic)
- open and closed cycle gas turbines
- reciprocating engines (diesel, oil)
- small hydro schemes
- cogeneration (combined heat and power (CHP))
- fuel cells.

On 12 August 2021, Schedule 2 of the Act was amended and published in Government Gazette No. 44989 to cover the lifting of the licensing threshold for generators from 1 MW to 100 MW. With the amendment, generators with a rated output power of up to 100 MW would be allowed to generate this power without a licence and would only need to register with the National Energy Regulator of South Africa (NERSA) [1]. This threshold increase was meant to help address the electricity supply shortages that the country currently faces, and to unlock private sector investments in embedded generation. On 17 January 2023, the schedule was amended again in Government Gazette No. 47887 to remove the limit altogether; private generators of any size or capacity are now allowed to generate power without a licence but must register with NERSA and comply with the Codes.

Since 2008, the public utility, Eskom, as the main supplier of electricity, has been struggling to meet the country's growing electricity demand and has been rationing supply by implementing load shedding to avoid a complete system blackout. The removal of licensing requirements for private generators is envisaged as a way of boosting private electricity generation and reducing the demand placed on the utility's aging generation fleet. Private generators of any capacity may generate for own use and may sell to one or more customers through wheeling or bilateral agreements without a licence [1]. NERSA's licensing process was highlighted as a major barrier to private generation, preventing the addition of power on the grid. Licensing was designed for utility-scale projects that participated in national procurement programmes such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) aimed at supplying the general public.

While the reform presents benefits to the electricity industry and to consumers, an increased number of embedded generators on the network presents challenges to the system operator responsible for the safe and efficient operation of the national grid and to the network service providers responsible for regional networks. It is anticipated that a large portion of these generators will be generating from renewable energy source technologies such as photovoltaic (PV) and wind energy. The variable nature of these renewable energy sources poses a threat to grid stability and reliability, while an increased penetration of these renewable energy plants might also cause congestion on already constrained networks.

Du Plessis [5] highlighted that power systems (or networks, in this case) around the world differ, in that one utility might easily cope with a 10% proportion of variable renewables, while to another, 10% variable renewables might be impossible to handle. Similarly, one distribution network might easily cope with and benefit from a high penetration of embedded generators, while another might fail as a result. The South African power system is predominantly vertically integrated, with the bulk of the baseload electricity generated from a coal fleet situated in the northern and north eastern parts of the country, and a nuclear station in the Western Cape [6] [7]. For urban networks, electricity is transported from these stations in bulk through long transmission lines to distribution stations situated near load centres, whereas for rural networks, most of the stations are in remote areas, connected to customers with long radial medium voltage lines. For the most part, the Eskom distribution network operates in rural areas and smaller towns, while distribution in the city is carried out by local municipalities [6]. The existing networks are designed for a unidirectional flow of power, with power flowing from a central source to the loads. With the introduction of embedded generation, there is now bidirectional flow of power, therefore, distribution networks can no longer be passive [8] [9] [10]. Depending on the type of generator, its size and location on the network, and the characteristics of the distribution network to which it is connected, embedded generation (EG) may have positive or negative effects on the network.

Many European countries have a high penetration of EG from renewable sources but also have interconnections with other countries for baseload generation, along with access to gas. This gives them flexibility with regard to generation, they are able to supplement for the intermittency and variability of the renewable energy sources. South Africa, on the other hand, is a net exporter of electricity and does not have many electricity interconnections with other countries on which it may depend for baseload capacity. The country also imports most of its gas from Mozambique, although there are plans to explore domestic sources of gas, given the considerable amount of shale in the country that could be exploited [11].

With the introduction of EG on the network and the variable nature of renewable sources, the burden of providing backup power will remain with Eskom, whose full fleet will still be called on during unfavourable weather conditions or peak times. It is therefore necessary for the utility to take this into account when setting tariffs for customers with embedded generation, so that the connection is sustainable for the utility and presents a good business case for the customer. The utility must consider the cost of supplying customers with embedded generation, and therefore cost-of-supply studies are important. Various dynamics brought about by the connection of embedded generation should not negatively affect customers who do not have embedded generation. In other words, the additional costs that arise because of embedded generation should not be socialised. When setting tariffs, Eskom will need to balance cost recovery for services and utility sustainability with fair grid access and affordability [8].

Thus, allowances for private generation are by no means a straightforward issue. Given the country's socio-economic inequality challenges, there is a real concern that if the country's wealthy consumers opt for self-generation, electricity prices will be pushed even higher, since currently, wealthy consumers subsidise poorer consumers [12]. With an increasing level of private electricity generation, the utilities may be forced to raise their prices to ensure cost recovery for services, and electricity may become unaffordable for the poor. There is therefore a critical social element that makes the topic of this research study even more relevant in a developing country such as South Africa.

The main objective of this research study is to review the technical, economic, and regulatory impacts of high levels of embedded generation on South African distribution networks, partly by comparing South Africa's challenges and methodologies with those of Brazil, Australia, and Uganda. The aim of the research is to identify solutions that have been implemented in these countries to address the challenges associated with an increase in the number of embedded generators. Technical, economic, and regulatory changes that have contributed to the success of embedded generation in these countries will be identified, and based on these, recommendations will be made for South Africa. The overall goal is to ensure that the uptake of embedded generation in South Africa can increase without a commensurate disruption of supply to all, and that it helps to close or narrow South Africa's current energy capacity shortages.

The results of this research study may benefit utilities, customers and the regulator by presenting both the challenges and benefits that South Africa can expect from an increase in private electricity generation. The study examines the technical, economic, and regulatory changes that have been introduced in other countries to ensure a smooth transition from centralised electricity generation systems to distributed systems. Electricity stakeholders in South Africa have a great deal to learn from the experiences of other countries. The removal of the licensing requirement for private generation is expected to accelerate the uptake of embedded generation, and South Africa needs to be prepared for the associated challenges. It is hoped that this study will contribute to an awareness of the relevant issues to be considered.

1.2 Study objectives

The aim of the study is to present a review of the impact of increased levels of embedded generators on South Africa's distribution networks, largely by examining the impact and mitigation measures implemented in Brazil, Australia and Uganda. The focus is on technical, economic and regulatory aspects of changes made in these countries. The overall objective is to propose solutions that may be adopted by South Africa.

The study has the following sub-objectives:

- to determine the impact of increased levels of embedded generation on South Africa's distribution networks;
- to conduct a comparative analysis with Brazil, Australia and Uganda; and
- to recommend solutions to the identified challenges.

1.3 Methodology

The approach adopted in this study was to examine the literature on the impact of embedded generation on the developing and developed countries of Brazil, Uganda Australia and South Africa. The implementation plan was as follows:

- Carry out a literature review of the impact of embedded generation on distribution networks.
- Identify similarities and differences in the power market structures among the four countries.
- Identify similarities and differences in the composition of the distribution networks.
- Survey installed embedded generation in each country (including their types, sizes, location, etc.).
- Identify the dominant energy sources for installed embedded generation.
- Identify the specific technical, economic and regulatory challenges introduced by a high penetration of embedded generation.
- Identify regulatory or policy changes introduced to facilitate and manage the uptake of embedded generation.

- Identify solutions to address the identified challenges, including tariff structures and regimes.

1.4 Study outcomes

The intended study outcome is the identification of implementable solutions to the challenges currently being experienced in South Africa as the country moves to an increased rate of private electricity generation.

1.5 Overview and structure of the dissertation

In Chapter One, the context of the study, along with the research objectives, methodology, and expected outcomes, is introduced. The value of the research is also discussed.

In Chapter Two, the existing literature on embedded generation will be reviewed with the aim of highlighting the benefits and challenges that embedded generators present to electricity distribution networks from technical, economic, and regulatory perspectives.

Chapter Three will provide an overview of the electricity industry in each of the four countries under investigation—South Africa, Brazil, Australia, and Uganda. The focus will be on identifying the similarities and differences in the power market structure of each country. The structure of the market is one of the factors on which the success of embedded generation depends.

In Chapter Four, the penetration levels of embedded generation in each country will be presented, along with its impact and a brief overview of the legislative or regulatory changes that each country implemented to facilitate the uptake and effective management of embedded generation.

In Chapter Five, a detailed review of the enabling legislation, policies, and regulations in each of the four countries to facilitate the uptake of embedded generation will be provided. The purpose of the review is to highlight the changes that contributed to the successful uptake of embedded generation, those that did not achieve the stated aims, and the nature of any other changes introduced to address aspects that were initially deemed unsuccessful.

Chapter Six will examine the economic impact of high levels of embedded generation and outline measures to ensure the sustainability of network service providers, attract investment, and incentivise customers. It is also important to look at measures to prevent the negative effects of embedded generators on customers who do not benefit from embedded generation.

Finally, in Chapter Seven, the study will be concluded, and a summary of the recommended actions for adoption by South Africa will be presented.

CHAPTER 2: LITERATURE REVIEW

This chapter presents a review of the literature on the technical, economic and regulatory impacts of an upsurge of embedded generation.

2.1 Challenges presented by embedded generation

There is a growing need for competition in the utility and energy markets. In South Africa, the amended Schedule 2 of the Electricity Regulation Act (ERA) and policy documents such as the Integrated Resource Plan (IRP) support the inclusion of embedded generators in the country's energy mix. This implies that the number of generators connected to the sub-transmission and distribution networks will increase significantly in coming years [8]. Embedded generators introduce a new dynamic in the electricity power system, which requires careful consideration, particularly with respect to voltage control and protection [8].

Solar and wind power are the most prevalent variable renewable energy sources in South Africa. Most generators seeking connection to the national grid (at both utility scale and small scale) are wind farms, solar PV parks or concentrated solar plants. South Africa is a water-scarce country, and therefore does not have many hydropower generators in the mix, other than at existing Eskom hydro pump storage peaking stations. According to the South African Grid Code, Version 10.1, and the Distribution Code, Version 6.2, when a connection application is made by these generators, network service providers are responsible for the provision of open access, according to agreed standard terms, for all parties wishing to connect to or use the transmission or distribution system.

Many challenges arise as result of a high penetration of embedded generation, especially if a high share of the capacity is from renewable energy sources. Challenges may be associated with the nature of the source, the connection technology used, and the voltage level of the connection. An important aspect to note about the nature of the resource is uncertainty vs variability. Specific challenges that may be experienced include the following:

- *Source of energy:* The source may be weather dependent, and therefore variable, as in the case of solar and wind. Production may not be constant throughout the day or the year, due to changing weather conditions.
- *Location specificity:* If the generation facility is located far from the load, there is the issue of network congestion if there is no proper transmission or distribution infrastructure to evacuate this power.
- *Fluctuation uncertainty:* The intermittent nature of sources such as solar and wind affect planning and forecasting. There is no guarantee that the forecasted production will be realised.
- *Low capacity factor:* There may be an inability to produce constant maximum output throughout the day or year. Capacity factor is the ratio of the generation output over a given time to the rated output.

A high penetration of embedded generation will inevitably have technical, economic, financial, environmental, social and regulatory effects on the grid and on the country. All these need to be taken into consideration. In this study, the focus is specifically on the technical, economic and regulatory aspects.

Technical aspects of the impact fall into two groups; system wide impacts and network/local impacts [13]. Each of these is discussed below.

2.2 Technical impacts: System wide

System-wide technical impacts are additional reserve and balancing requirements, difficult up and down ramping hours, the risk of over generation, the regulation of frequency, and reduction in system inertia. Each is discussed below.

2.2.1 Additional reserve and balancing requirements

The variable and intermittent nature of the sources deployed in embedded generation demands that the system operator call on many resources to provide additional reserves and balancing services. For example, solar PV is known for a phenomenon known as the duck curve, whereby the profile of the output power of a typical solar plant results in a demand profile that resembles the shape of a duck. Figure 2.1 below shows the demand profile for the state of California as an example, where most of the electricity demand is supplied from solar generation.

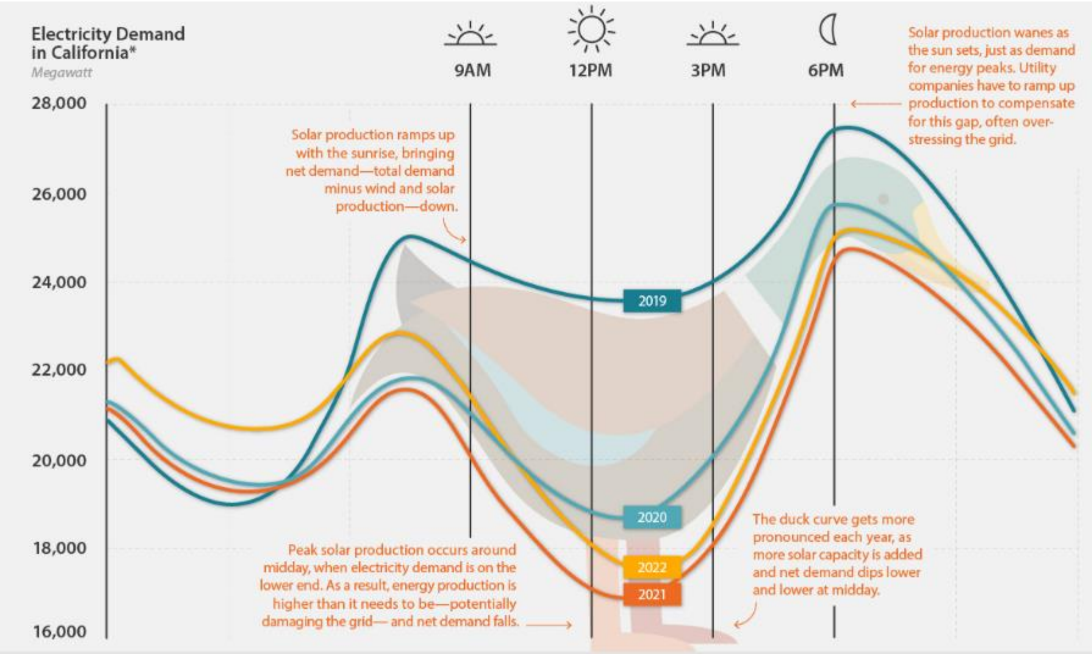


Figure 2.1: Electricity demand profile of the state of California [14]

Solar production is high during the day when the sun's irradiance is high, bringing the net demand down. Production disappears in the evenings around 6 PM when the sun sets, this is a critical time when the system needs a great deal of power, since demand peaks in the evenings and mornings. These are the very times that customers with embedded solar generators piggyback on the grid, in the absence of the solar supply and utility companies must ramp up production to compensate for the lost solar supply. The duck curve gets more defined each year with the addition of more solar power.

From a system operation point of view, more power is needed to balance demand with the required supply. Still using the example of a solar PV plant, if, during the day, conditions become overcast or a cloud covers the area where the solar PV plant is installed, plant output will be minimum. This will require the customer with a solar generation plant to draw most of their load requirements from the grid. This sudden disappearance of generation output from the solar plant requires the system operator to bring in additional reserves. The same applies to wind generation; if suddenly the plant is disconnected from the system or the wind stops blowing, the system operator will need instantaneous reserves to replace the lost generation.

Difficulties may be experienced in balancing the system during critical hours, since during the day there is high generation and low load (especially in the case of solar PV), while in the mornings and evenings there is low generation and high load.

2.2.2 Difficult up/down ramping hours

For the system to accommodate the variable nature of renewable energy sources, it needs to be flexible. The power system in South Africa is predominantly supplied by coal-fired power plants, which are meant to provide baseload generation characterised by a constant power profile, 24/7. The variable nature of renewable energy sources forces these plants to ramp up and down quite steeply at times, which can accelerate the aging and deterioration of these plants. This happens when customers with solar or wind embedded generation come back to the system when the sun sets or when a cloud covers the plant, or, in the case of wind generation, when the wind stops blowing. Flexible generation such as that provided by open cycle gas turbine plants is required to deal with the intermittent nature of renewable energy sources. Interconnectivity with other countries that can assist with the provision of baseload generation is one of the best ways to provide flexibility in a power system.

2.2.3 The risk of over-generation

The risk of over generation happens mainly during the day when solar generation output is at a maximum and demand is low. This forces the system operator to curtail the plants to avoid an over frequency scenario. If solar plants are coupled with battery storage, this challenge can be mitigated, with the excess generation used to charge the batteries during the day, so that in the evening, the stored energy may be used to supply the peak load. Storage facilities also add to the flexibility of the system. In most countries, customers are advised to invest in battery storage to help limit the impact of their facilities on the national system. Wind generation plants introduce a similar challenge, because the technology is not programmable. There are instances where the plant output is higher than that required by the system.

2.2.4 More challenging frequency regulation

The intermittent nature of renewable sources causes the difficulty of over-frequency and under-frequency. Over-frequency is experienced when the facilities are producing at their peak but there is not enough load to absorb the power. Under-frequency is experienced when there is a sudden disconnection of a unit or a sudden reduction in the generation output due to weather conditions. This requires the system operator to deploy more ancillary services to help mitigate the challenge of over- or under-frequency. Having a store of instantly available reserves is one way to mitigate this challenge.

2.2.5 Reduction in system inertia

System inertia refers to the phenomenon that occurs when large rotating generators and some industrial motors remain rotating when supply of power ends abruptly. This inertia provides a form of stored energy. In can be particularly valuable when a large power plant fails, as the inertia can temporarily make up for the power lost from the failed generator. Renewable energy sources affect the dynamic behaviour of the power system, in that the total inertia of the power system reduces with a high share of wind and solar plants. Synchronous generators are dynamic, providing system inertia, whereas renewable energy sources are static in nature and do not provide system inertia, and therefore cannot provide its benefits. However, with recent technological developments, there are some inverter-based technologies that can provide synthetic inertia.

2.3 Technical impacts: Network and local

The addition of embedded generators to the distribution network introduces several technical challenges. The distribution network is designed to distribute power to end users/customers [6] [8] [9] [15], but with distributed generation, the flow of power is no longer unidirectional; power can flow from any direction, that is, from the grid to customer and also from customers to the grid and other customers.

It is generally accepted that technical considerations of connecting embedded generators include the challenge of maintaining steady-state voltage limits, variable fault levels, thermal loading/network congestion, rapid voltage changes, technical losses, transient stability, a reduction in visibility and controllability, the estimation of hosting capacity [6] [7] [8] and the possible technical benefits of proximity and battery storage. Each of these aspects is discussed below.

2.3.1 Steady-state voltage limits/reactive power management

An important supply requirement is that voltage be kept within specific limits. In South Africa, the utilities are obliged to maintain voltage within 5% of the nominal voltage at distribution level [12]. With embedded generators exporting to the network, voltage on the network may rise if power is injected onto the network and there is no demand for it. Voltage may also drop if the embedded generator suddenly gets disconnected from the network or the production is very low due to unfavourable weather conditions, in the case of renewable energy generation. The impact of high levels of embedded generation on the network must be evaluated to ensure that voltage is kept within specific limits under all loading and generation patterns (high generation–high load, high generation–low load, low generation–high load and low generation–low load) [6] [16].

2.3.2 Fault levels

The generator's fault level contribution needs to be considered when it connects to the network. Connecting a generator may increase fault levels at the point of connection and, as a result, lead to fault currents exceeding the design fault level rating of the network [6] [9]. It is therefore necessary to evaluate each generator's contribution to the network fault level, so that both the utility and the generator know what measures to put in place to ensure that their equipment is adequately rated to cater for the increase in fault level. Network topology changes over time as more customers connect their loads and generators, and, as highlighted in [6], fault levels are sensitive to the future location of other generation sources. This makes it necessary to assess the impact of a potential increase in embedded generation to come up with optimal plans and designs that take future fault levels into account.

2.3.3 Thermal loading/network congestion

Network congestion occurs when a transmission or distribution network fails to transfer power based on the load demand. With the addition of embedded generators on the network, network loading should be kept within specified thermal limits for all loading conditions (i.e. high generation–high load, high generation–low load, low generation–high load and low generation–low load). If proper load flow studies are not performed, an increase in embedded generators of the network may lead to a violation of conductor and equipment thermal ratings, and thus, network congestion.

2.3.4 Rapid voltage change (RVC)

Generators are required to withstand certain system events and remain connected to the network. A sudden disconnection of a generator from the network will have an impact on the voltage at the point of connection.

> *Rapid voltage change (RVC) is a phenomenon in which there are changes in voltages noticeable by other customers at the point of connection. These voltage changes can be caused by changes in generation output. Rapid voltage changes can be caused by changes in generation output, tripping of plant and switching of devices* [6] [9].

2.3.5 Technical losses

Technical losses are energy losses in a network that occur as a result of the flow of current in the network. Generators may cause an increase or decrease in technical losses, depending on their location on the network [6]. Generators positioned near the point of consumption will have a positive effect on network losses, whereas generators positioned far from load centres result in higher technical losses because energy must be transferred through the network over longer distances to the point of consumption. Therefore, technical losses are a dynamic aspect of the system and will vary significantly as the network changes, and as load changes and additional generation is connected [6].

2.3.6 Transient stability

It is important that the distribution system remains stable under all network conditions, with the increase in distributed generation, transient stability studies are becoming more important to determine the impact of generation suddenly connecting and disconnecting from the grid. In the past, transient stability studies were not popular for generators connected to distribution MV networks, depending on the size and location of the generating plant(s) [6].

2.3.7 Reduction in visibility and controllability

Most distributed energy resources are embedded within the system, with some systems connected on the low voltage side behind the customer meter, making it difficult for the system operator to see the plant remotely and have control over it. In South Africa, Section 13 and Appendix 10 of the RPP code [3] specify the minimum information that must be shared with the system operator or network service provider, and the types of signals that must be provided. However, signalling for dispatch of resources becomes extremely complicated with behind the customer meter connections due to the lack or reduction in visibility and controllability for these types of connections.

2.3.8 The estimation of hosting capacity

The contribution of some connected generators is easy to estimate, while for others, the task is extremely difficult. A challenge is introduced by the fact that small-scale embedded generators (<100 kW) need not register with the energy regulator and are managed by the distributor to which the generation facility is connected. Distributors are required to submit a register of connected generators every quarter to NERSA, including the size of the plant and the specific location in which it is connected. This information is then made accessible to the system operator upon request for planning purposes. However, distributors do not always provide this information which makes planning and hosting capacity estimation difficult.

2.3.9 The technical benefits of proximity and battery storage

Depending on its location, the embedded generator may assist in reducing technical losses on the network. This is more likely when the generator is placed close to the load it will be supplying.

Embedded generators can also assist in de-loading the network, eliminating or reducing congestion by taking care of some of the demand that would have otherwise been placed on the network. For example, hybrid systems are helpful to the system, because they include battery storage that comes into play during peak hours and when there is little to no generation from the generator due to unfavourable weather conditions.

2.4 Economic impacts

The economic impacts of an upsurge of embedded generators on the distribution network include a possible rise in electricity prices, loss of revenue by the utility, the need for more network upgrades, and the positive impacts of a deferment of infrastructure development and a reduction in technical losses. Each of these is discussed below.

2.4.1 Impact on electricity prices

Economic challenges arising from a high connection of embedded generators generally emanate from the impact that the upsurge has on the utility. An increase in privately owned generators has a cascading effect in terms of the affordability of electricity when wealthy, commercial, mining, industrial or agricultural customers begin generating their own electricity and no longer subsidise the overall cost of electricity for the poor [17]. Customers who are most likely to install embedded generation are those who currently pay the most, i.e., those falling into one of the above customer categories. If many of these customers supply their own power and only use the utility supply to supplement their deficit, distribution utilities will have to review their tariff structures in order to remain sustainable. The authors in [18] have clearly articulated that electricity prices or tariffs are derived from cost-of-supply studies. They examine ways to balance affordability with sustainable supply, stating that electricity must be affordable so that customers can pay for it, and at the same time must enable the utility to recover enough revenue to keep operating. If the higher income customers move off the grid, customers remaining on the grid are unlikely to be able to afford electricity, because the price would no longer be subsidised by these higher income customers.

> *The loss of cross subsidy for both Eskom and municipalities from high-end customers who have started to install solar PV systems has led to what* [10] *identify as a challenge for any just transition, and a tension between establishing a low-carbon energy supply at the same time as ensuring affordable electricity and other basic services for low-income households* [17].

2.4.2 Loss of revenue by the utility

In South Africa, rising consumer tariffs have contributed to incentives for wealthier residential and commercial consumers to establish their own source of solar PV generation, thereby reducing revenues of both Eskom and municipal distributors [17].

A case study was conducted by Fakude and Ogudo [19] on a property that had both a utility installation and embedded generation from solar PVs. Data from the PV system was populated to analyse the offset percentage and the possible revenue loss by the municipality. The study showed that the onsite generation offset over 50% of the projected income by the utility, showing that over time, the utility would run at a loss. The study found that revenue losses by the utility were directly proportional to the level of penetration of the embedded generators.

The current electricity pricing methodology in South Africa is based on revenue determination requirements, so that any loss of revenue by the utility will have a direct impact on electricity tariffs. A reduction in utility revenue may result in higher electricity tariffs for the utility not to run at a loss, which would have a direct impact on all customers connected to the network. The case studies summarised in the AMEU paper [18] show that the rapid uptake of small-scale embedded generation has the potential to significantly impact municipal revenue if correct (cost-reflective) tariff structures are not put in place [18]. The higher the tariffs, the more viable the embedded generators become for customers, and the greater the financial stress experienced by the utility.

2.4.3 Utility network upgrades

Another element that has an indirect impact on the economy is the cost that the distribution utilities may incur from network upgrades triggered by a high number of connected embedded generators. As indicated in Section 2.3.2 of this study, embedded generators are likely to increase the fault levels at the point of connection to the grid. According to Collinson, et al. [9], network upgrades such as switch gear replacements would be required to cater for the increased fault level brought about by the additional generation capacity. In cases where the total cost of the upgrade has to be covered by the applicant, the connection could become uneconomical, particularly at lower voltage levels.

In cases where the cost of the upgrade has to be covered by the distribution utility in order to enable access by an applicant and others, the costs will form part of the costs allowable to licensees, as per the Distribution Network Code, Section 7 [2], which deals with network planning investments. These costs are recovered or allocated for in the approved tariffs. This means that ultimately, customers or taxpayers will be paying for these upgrades. This results in socialised costs, in that even customers who do not have embedded generators and do not benefit from them end up paying for the upgrade. Another aspect to be considered is the requirement for the network to be enhanced to be able to deal with power that now flows not only from the utility network to customers but, as a consequence of distributed generation, from the generators to the utility and other customers. This necessitates investment in smart metering or bidirectional metering [20] for efficient network operation.

2.4.4 Deferment of infrastructure upgrades and reduction in technical losses

An increased level of embedded generation on the distribution network may help defer infrastructure development [9]. In the case of renewable energy sources that are intermittent in nature, deferment of upgrades will be possible if storage is included as part of their design, to accommodate demand during unfavourable weather conditions. There will also be a reduction in technical losses due to the reduction in bulk power that needs to be transferred on the feeder. For example, under normal circumstances, without the addition of embedded generators, a particular feeder may transfer 50 MVA to cater for an entire load; if a customer installs an embedded generator to offset their load and injects their surplus into the network, the feeder may need to transfer only 50

MVA minus the load for the customer, thereby reducing technical losses. These benefits depend on the location of the embedded generation in relation to the load it is supplying [9].

Although several other technical and economic implications are identified in the literature, the scope of this study is limited to an investigation of variation in voltage, fault levels, technical losses, thermal loadings and revenue collection by the utility.

2.5 Regulatory impacts

In developed countries, the role of the regulator in embedded generation penetration is to facilitate the uptake of these resources, particularly from renewable energy resources. In European countries, the introduction of incentives such as feed-in tariffs and net billing is one way that regulation is used to facilitate the uptake of embedded generation. Regulatory impacts of embedded generation also affect policy, as pointed out by Maestri and Andrade [19], who state that "*the economic, financial, environmental, social, and regulatory impacts of distributed generation influence energy policymaking*" [21]. In South Africa, the Department of Mineral Resources and Energy (DMRE) announced the removal of the licensing requirement altogether for private embedded generation. The purpose is to add more capacity to the grid, assist in addressing the load shedding problem, and facilitate private sector participation in the development of the electricity infrastructure of the country.

2.6 Environmental impacts

One reason that most countries are introducing regulations to assist in increasing the uptake of embedded generation from renewable energy sources is so that their utilities can meet the country's climate/environmental commitments to net zero greenhouse gas emission targets.

Embedded generation has the advantage of reducing a country's overall greenhouse gas emissions, particularly where embedded generation is mostly based on renewable energy sources. This also leads to cost reductions in the form of lowered carbon tax and increased green credits.

2.7 Summary

Embedded generation has a range of technical effects on the network to which it is connected, both system wide and localised in nature, as well as a number of economic, regulatory and environmental effects. A high penetration of embedded generators introduces challenges to the network, but there are also benefits to the network or utility, especially if the addition of embedded generators is well planned and regulated. Several mitigation strategies may be adopted to ensure the successful development and integration of embedded generation. However, factors such as penetration levels, network configuration, interconnectivity with other networks, the location of the generation facility, and prevailing regulatory frameworks and policies, amongst other factors, determine the solutions a utility can put in place. The benefits highlighted in this chapter include a reduction in technical losses, a deferment of infrastructure expansion projects, and a reduction in overall greenhouse gas emissions.

In the following chapters, a review of the impact of embedded generation in four countries – South Africa, Brazil, Australia and Uganda – is conducted. The aim is to compare approaches, uncover the impact of a high rise of embedded generators on each country and identify critical success factors for regions where penetration is high, well managed and sustainable. The study also seeks to highlight some of the unique structures in each country and the changes in regulation or policies that were put in place to facilitate the successful uptake and sustainability of embedded generation. From this review or benchmark exercise, recommendations will be made for South African stakeholders to consider.

Certain criteria were used to select the countries that would enable meaningful comparison with South Africa. One country from the OECD (Australia) was chosen, one from BRICS (Brazil) that is doing well globally in the uptake and management of embedded generation and has a structure or market size that is somewhat comparable to South Africa and one from Africa (Uganda) that is doing well in either the technical aspect, economic aspect or regulation of embedded generation was chosen. This combination of selected countries was deemed best for comparison and would most generate relevant learnings for South Africa.

CHAPTER 3: ELECTRICITY SECTORS AND STRUCTURES

3.1 Introduction

The literature review presented in Chapter Two provided an overview of the impact of a rise in embedded generation on distributors and their networks. The overview highlighted several technical, economic and regulatory impacts, both at system and local level. The chapter also highlighted the importance of performing a network-specific analysis of the impact of a high rise of embedded generation, because the effects of a rise in the number of embedded generators cannot be assumed. Success depends on a few factors, such as the type of technology used, the generators' location, and the characteristics of the network, amongst other factors.

This chapter presents an overview of the electricity industry in each of the countries under investigation, outlining the structure and markets of the electricity sectors in the various countries. The success of embedded generation is largely dependent on these aspects.

For purposes of comparison, it is important to start with an understanding of the countries being compared. An understanding of the electricity supply structures takes priority because the impact of embedded generation will differ according to context. Any recommendations made for South Africa will have to consider the contexts established in this overview. In terms of the structure of the electricity industry and overall installed generation capacity, South Africa compares well with the other three countries. However, in terms of embedded generation, Brazil and Australia have higher penetration levels, making them suitable sources of learning for South Africa.

3.2 South Africa

3.2.1 The electricity industry

The bulk of electricity in South Africa is supplied by Eskom, a state-owned company that owns and operates a number of coal-fired, gas-fired, hydro and pumped storage power stations, as well as one nuclear power station [22]. The electricity generated by Eskom and a few independent power producers (IPPs), combined with imports from neighbouring countries, is supplied in bulk to distributors, i.e. large metros and other municipalities, for industrial, commercial, residential and other uses [23].

The South African power system is predominantly vertically integrated, with the bulk of baseload capacity generated from a coal fleet situated in the northern and northeastern parts of the country, and a nuclear station in the Western Cape [3][4]. For urban networks, electricity is transported from these stations in bulk through long transmission lines to distribution stations situated near load centres, while for rural networks, stations in remote areas with long radial medium voltage lines supply customers.

In 2014, South Africa received its first round of energy from independent power producers (IPPs), generating electricity from various forms of renewable energy. Since then, IPPs have been selling power to Eskom, which sells it to its customers. There are also some customers connected on the Eskom distribution network and municipal distribution networks who generate for own use or wheel power through the national grid.

Figure 3.1 presents a breakdown of the capacity per technology integrated to the grid that has been procured by Eskom through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) and the Risk Mitigation Independent Power Producer Procurement Programme (RMIPPPP) as of March 2023 [24]. Approximately 6.1 GW of this capacity is generated from renewable energy sources.

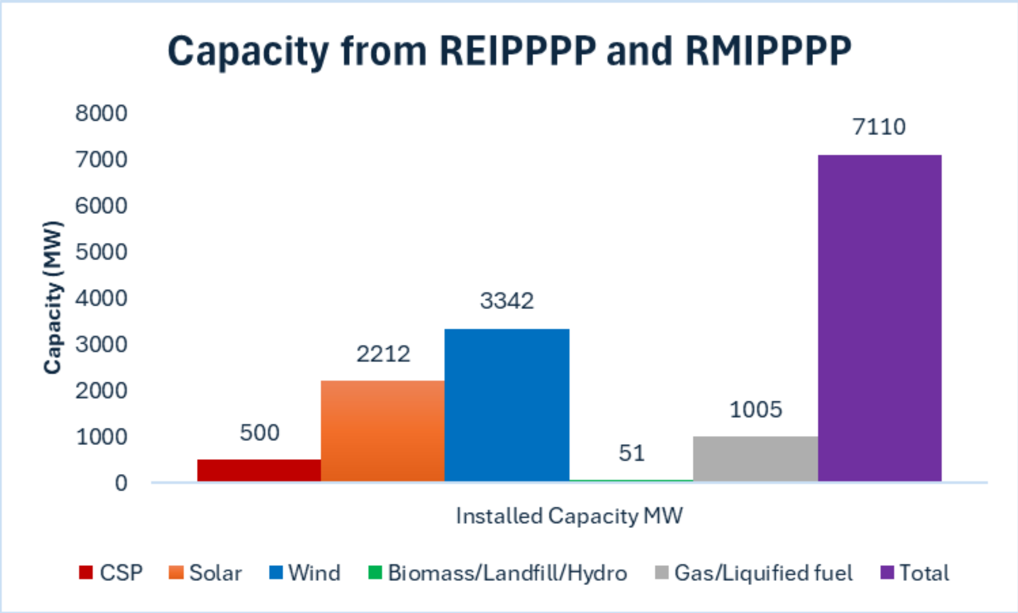


Figure 3.1: Generation capacities from national procurement programmes *(data sourced from [24])*

Table 3.1 shows the electricity generated by Eskom-owned power plants, and the total contribution of various technologies.

Table 3.1: Total installed Eskom capacity *(data sourced from [24])*

Eskom Capacity Table June 2022	2023 Capacity (MW)
Eskom – Coal	39 099
Eskom – Wind	100
Eskom – Nuclear	1854
Eskom – Pump Storage	2724
Eskom – Hydro	602
Eskom – Gas	2409
Total	**46 788**

At the end of March 2022, South Africa had 54 GW of wholesale/public nominal capacity and a peak system demand of 35.0 GW [25]. The 54 GW is made up of 47 GW Eskom generation and 7 GW IPP generation. These capacities exclude distributed generation or generation capacity owned by private entities and used for own use or wheeling through bilateral agreements. Distributed generation is covered in detail in Chapter Four of this study.

Electricity transmission

The South African transmission network covers voltages from 132 kV to 765 kV, and in 2022 was estimated to cover 40 000 km in length. All of this provided by one transmission company, owned by the state-owned entity Eskom, making it a natural monopoly in the industry. As mentioned in Section 3.2.1, Eskom relies on its aging coal fleet situated in the northern and northeastern parts of the country, and a nuclear station in the Western Cape. Power is transported in bulk from these stations through long transmission lines closer to the load centres.

South Africa has plans to transition from coal to renewable energy sources, with most renewable energy sources concentrated in the Northern Cape, Eastern Cape and Western Cape provinces. Currently, the load is concentrated in the northern parts of the country, and challenges are anticipated in terms of evacuating power from the renewable energy sources to where the anticipated load is highest. Transmission network upgrades are required to remove the constraints. Currently, the uptake of new generation capacity in these regions is growing at a faster rate than the transmission network expansion. This is unfortunate, a result of the fact that a great deal of attention has been paid to bringing new generation capacity online, without a concomitant expansion in the transmission network. One learning from this study is that in developed economies the same effort paid to bringing new generation capacity online is made to network upgrades, so that the two are evenly matched and problems are prevented.

Electricity distribution networks

The national utility, Eskom, and about 180 local municipalities are responsible for electricity distribution in South Africa. The distribution network covers voltages from 0 V to 132 kV, with 0 V to 1 kV considered low voltage, 1 to 33 kV considered medium voltage, and 44 kV to 132 kV considered high voltage. The distribution network in South Africa comprises overhead lines and underground cable networks, mostly in rural and urban areas, respectively. For the most part, the Eskom distribution network covers rural areas and smaller towns, and local municipalities cover distribution in the cities [3]. Existing networks are designed for a unidirectional flow of power from the source to the loads. With the introduction of embedded generation, there is bidirectional flow of power, meaning distribution networks are no longer passive

[5][6][7]. Depending on the types of generators, their sizes, locations on the network and the characteristics of the distribution network to which they are connected, their overall impact may be positive or negative.

Challenges facing distributors in South Africa include declining revenues, ageing infrastructure and increasing non-technical losses due to criminal activities and lack of affordability. As a result of continually increasing electricity prices, many customers are opting to generate their own electricity through cost-comparable rooftop PV systems [26].

3.2.2 The electricity market structure

The electricity industry is dominated by Eskom, with Eskom Holdings SOC Ltd being a state-owned company (SOC) as defined in the Companies Act, 2008. It is wholly owned by the South African government and dominates the production of electricity. The company generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers in South Africa, and to municipalities, who in turn redistribute electricity to businesses and households in their areas. The utility also purchases electricity from IPPs in terms of various agreement schemes, and from electricity-generating facilities beyond the country's borders. Figure 3.2 illustrates the structure of the electricity industry in South Africa.

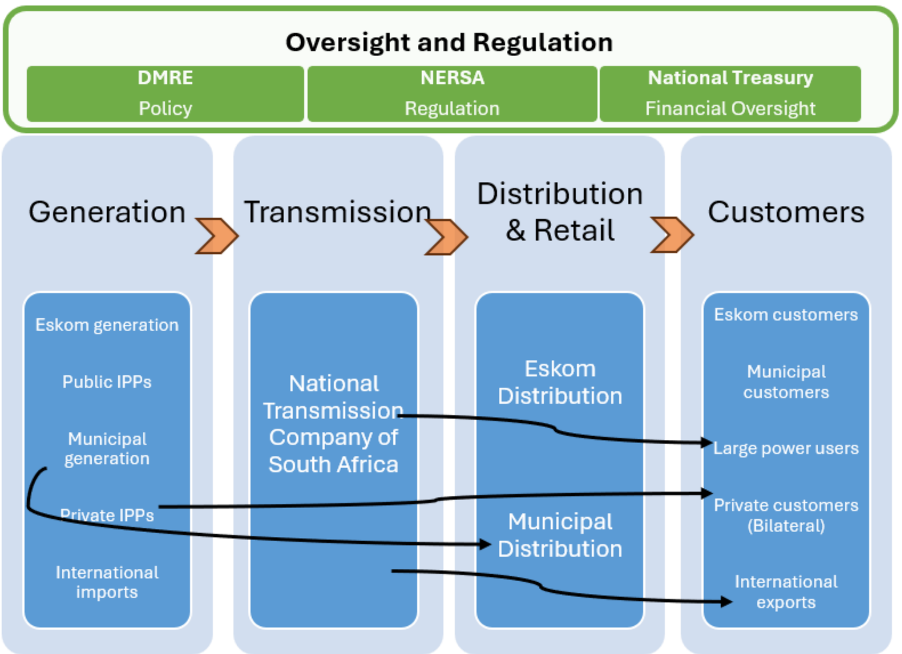


Figure 3.2: The structure of the South African electricity industry

The industry is regulated by the National Energy Regulator of South Africa (NERSA) under the National Energy Regulator Act, Act 4 of 2004, and the Electricity Regulation Act, Act 40 of 2006. NERSA issues licenses, regulatory rules, guidelines and codes under the Act and is also responsible for economic regulation, regulating the price of electricity through its revenue determination process. Eskom owns and operates most generation facilities, with IPPs supplementing capacity largely in the form of wind, solar and gas turbines. Electricity in South Africa is therefore supplied by Eskom's power stations, IPPs and cross-border suppliers through our transmission and distribution networks. Eskom's transmission division is made up of three sections: Transmission Network Planning and Development, System Operation, and Market Operation. In the absence of a fully functional market, the system operator is responsible for the dispatching of power from Eskom generators, and for imports and power purchased through national procurement programmes from IPPs. The company is currently going through a restructuring process, with the transmission section being unbundled to run as a separate, independent unit. Regarding retail, customers either buy electricity directly from Eskom or from redistributors (i.e. metros/municipalities), depending on where they are situated. Most customers in rural areas are supplied by Eskom and customers in urban areas are supplied by municipalities. Eskom is the only buyer of electricity through national procurement programmes.

3.3 Brazil

3.3.1 The Brazilian electricity industry

The Brazilian interconnected electricity system consists mainly of big hydro plants far from load centres, and long transmission lines to substations located near populated areas [18] [19]. From these substations, electricity is distributed through local wiring by distribution agents. In 2018, the total installed generation capacity was approximately 162 GW, and in 2023 it reached 192 GW. The Brazilian electricity matrix comprises 86% renewables, with the main sources being hydro, wind and biomass. Hydroelectricity is dominant, accounting for approximately 60% of the total supply. According to Angelina Galiteva [27], President of the Renewable Energy World Council, Brazil is a reference for the world in renewable energy.

The need for environment preservation has ushered in several restrictions to the construction and operation of hydro plants, reservoirs, transmission lines and substations, mainly in forests but also in urban areas.

Table 3.2 presents the wind and solar power capacity installed in the transmission and distribution grid of the Brazilian power system in December 2019.

Table 3.2: Wind and solar capacity installed in Brazil by December 2019 [27]

Subsystem	Wind Installed Capacity (MW)			Solar Installed Capacity (MW)		
	Transmission	Distribution	Total	Transmission	Distribution	Total
North	426.0	0.0	**426.0**	0.0	92.98	**92.98**
Northeast	11,886.8	2,296.6	**14,183.4**	1,305.04	514.60	**1,819.64**
South	1,996.4	641.6	**2,638.0**	0.0	589.07	**589.07**
Southeast	0.00	28.1	**28.1**	829.12	1,189.14	**2,018.26**
Total	**14,662.08**	**2,966.25**	**17,275.39**	**2,134.16**	**2,385.79**	**4,519.95**

There has been a significant increase in the share of each of the above technologies, as the numbers for 2022 were 7.7 GW and 25 GW for solar and wind, respectively. By the end of 2022, Brazil had a national nominal capacity of 192 GW and a peak system demand of 73 GW [28] [29]. The electricity matrix for each technology is indicated in Figure 3.3.

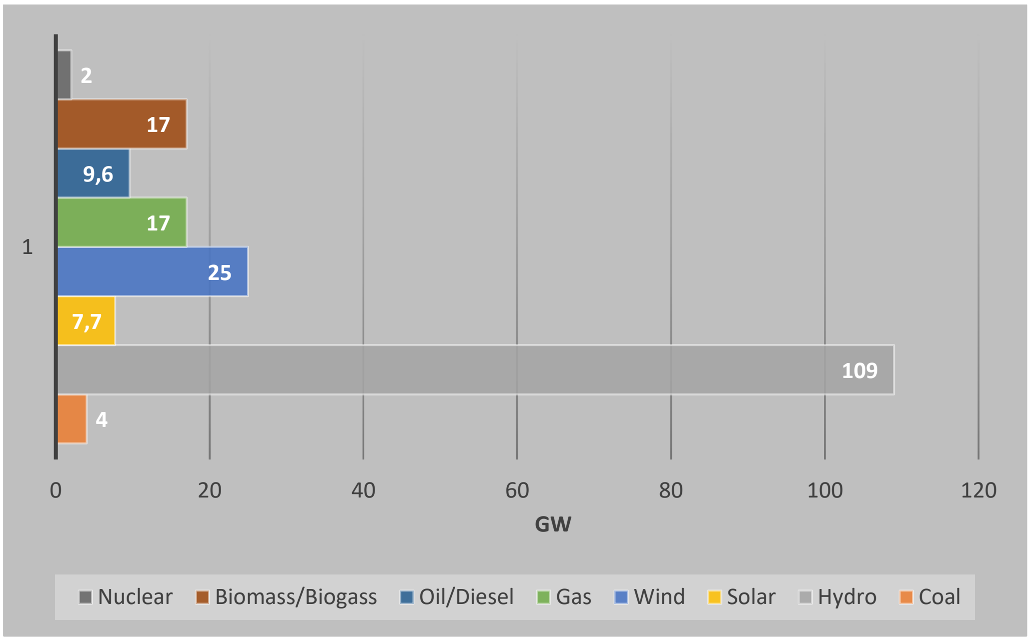


Figure 3.3: Electricity mix share per technology in Brazil *(data sourced from [28] [29])*

Figure 3.4 shows the total percentage contribution of each source to Brazil's electricity supply for 2021 and 2022.

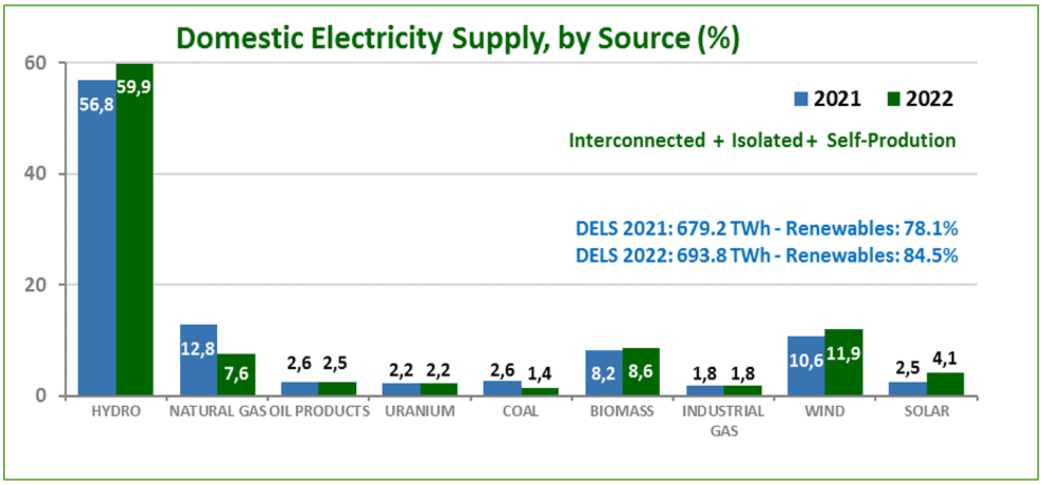


Figure 3.4: Brazil's domestic electricity supply by source [30]

It is worth noting that with the increase in electricity production from renewables, there was a decrease in the usage of coal and natural gas. This is a desirable result as most countries aim to reduce their reliance on coal to meet their climate change goals and to also reduce reliance on gas for affordable electricity prices.

Regarding electricity transmission and distribution networks, Brazil has over 80 million consumers supplied by 50 local distribution companies.

3.3.2 The Brazilian electricity market structure

Brazil's electricity market is governed by national laws, licences, regulations and grid codes. In Brazil's national structure, there is one regulator, one systems operator, and one market operator, with roles disaggregated. The sector comprises the regulated market and the free market, and is split into four parts: generation, transmission, distribution and retail. Generation and retail operate in the competitive market, and transmission and distribution companies operate in the regulated market, being natural monopolies highly regulated by Brazil's regulatory agency, ANEEL. Generators have the freedom to participate/contract in the regulated contracting environment or in the free contracting environment.

In the regulated environment, generators and retailers act on behalf of captive customers, with rules for negotiating in the market set by the regulator. In the free market, there are generators and free customers, and no participation by the regulator. Customers have the freedom to participate in the regulated or free market environment. However, to enjoy this freedom of choice, they must have a demand of over 500kVA – otherwise they remain captive in regulated market.

3.4 Australia

3.4.1 The Australian electricity industry

As in South Africa, Australia's electricity sector has historically been dominated by coal-fired power stations, although the share of renewable energy is growing at a rapid rate. In 2023, coal still dominated power generation, but the country aims to decrease the share of coal in power generation, with plans in place to retire some of these plants.

Figure 3.5 below shows Australia's energy mix in 2021.

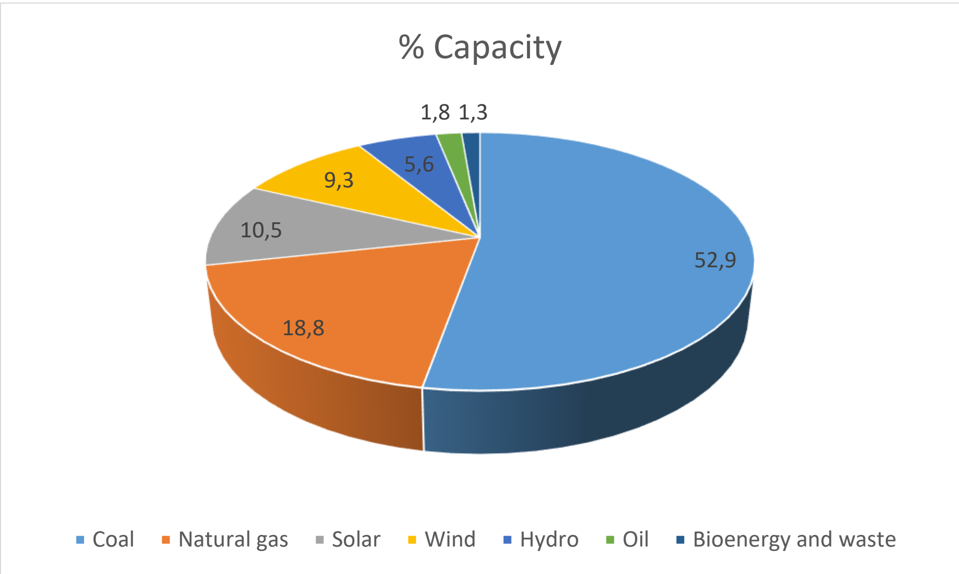


Figure 3.5: Australia's electricity mix by energy source technology in 2021 *(data sourced from [31])*

Over 2.3 million customers had installed solar PV panels in 2021, or roughly 30% of all households in the country [31]. By 30 June 2022, there were over 3.1 million solar power PV systems and more than 4.6 million small-scale renewable installations in the country [32].

In 2022, Australia had an installed capacity of 86.7 GW, with 29% of this capacity generated by variable renewable energy sources. The percentage increased from 10.5% in 2010 to 29% in 2022. 65 GW of the total installed capacity in Australia is for the national energy market (NEM). Since the introduction of variable renewable energy sources in Australia's energy mix in 2000, most of the incremental demand has been met by renewables. This study places a special focus on the impact of a high penetration of embedded generation on the distribution networks in the NEM, since it is the largest integrated power system and wholesale electricity market in Australia [31].

Electricity transmission

As in South Africa, Australia's transmission system consists of long transmission lines connected to large coal-fired power stations located a long way from where people live and work. The network connects to the lower voltage distribution networks close to the load centers. Transmission companies also supply large industrial customers directly. Australia has one of the longest interconnected electricity systems in the world, due to the connection of networks between states. Transmission networks operating in the different states are natural monopolies regulated by the Australian Energy Regulator.

Each state in the NEM has a transmission company responsible for the high voltage transmission lines that link the generation to the local distributors. The transmission companies are Power Link in Queensland (owned by the government), Transgrid in New South Wales and Central Territory (privately owned), AusNet Services (privately owned), ElectraNet (privately owned) and TasNetworks (owned by the government).

The advantage of an interconnected network is the increase in the stability of the power system and the flexibility that is needed for a system with a high penetration of variable renewable energy sources. As in South Africa, Australia has plans to retire most of its coal fleet and replace it with wind and solar generation sources that are variable and intermittent in nature [33]. Australia's electricity structure is transforming towards a decentralised, two-way energy system, driven by the rapid uptake of household and commercial solar generation and energy storage.

Figure 3.6 below presents an overview of Australia's electricity market structure.

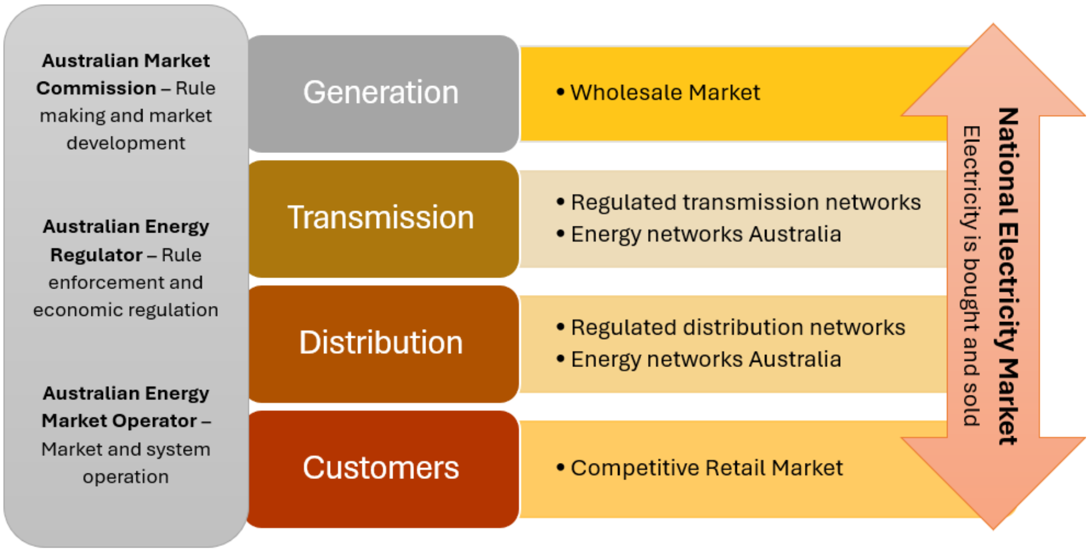


Figure 3.6: Australia's electricity market structure

Electricity distribution networks

As with its transmission networks, distribution networks in Australia are also natural monopolies regulated by the Australian Energy Regulator (AER). These networks transport electricity from the transmission networks to end-use customers. In densely populated areas, cable networks are buried underground, while in sparsely populated areas, the networks run overhead.

> *Distribution network service providers (DNSP) build, maintain and operate the distribution networks; they own the poles and wires that deliver electricity to your home. Embedded generation units often connect directly to the distribution network* [34].

Like in South Africa, behind the meter rooftop solar photovoltaic (PV) systems are embedded within distribution networks, resulting in bidirectional flow of electricity along the networks [35]. Figure 3.7 presents the distribution networks regulated by the AER, showing where each operates, the length of the network and the estimated customer base in each state.

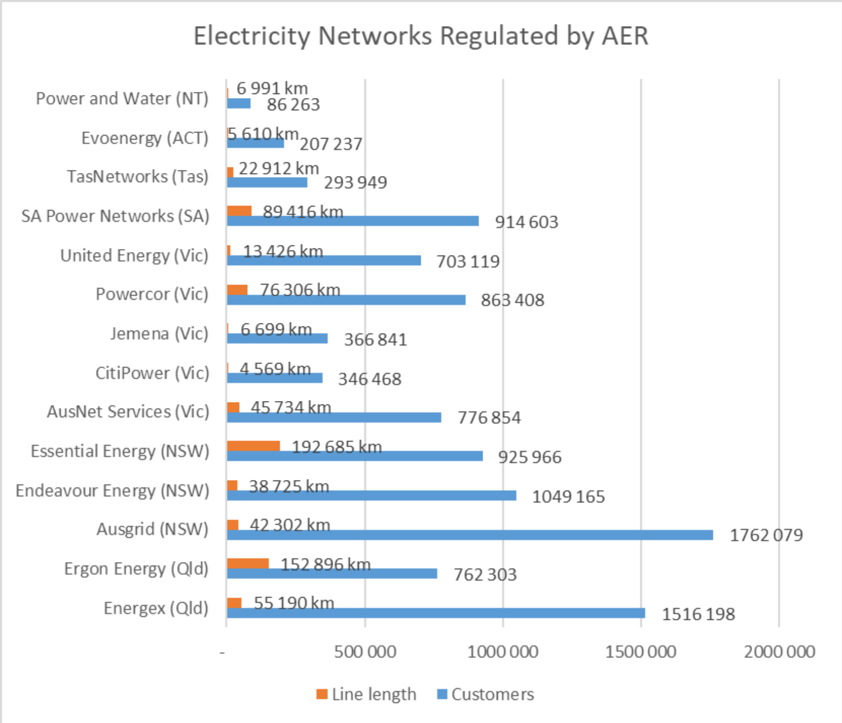


Figure 3.7: Electricity networks regulated by the AER *(adapted from [36])*

In terms of electricity retail, retailers buy wholesale energy from generators through the NEM. They package this energy with transmission and distribution network services and deliver this package directly to households [37].

3.4.2 Australia's electricity market structure

The bulk of electricity in Australia is generated, bought, sold and transported through markets [32]. Australia has three markets/power systems: the National Energy Market (NEM), the Wholesale Electricity Market (WEM) in Western Australia, and the Electricity System and Market in the Northern Territory. The NEM, the biggest market in Australia, is a wholesale electricity market that includes spot, contract and ancillary services, with generators and retailers trading in a competitive market. The NEM runs an integrated electricity system that covers the biggest part of Australia [31], spanning the eastern part, the southern part and Australia's central territories (Queensland, New South Wales, the Australian Capital Territory, South Australia, Victoria and Tasmania). It delivers around 80% of all electricity consumption in Australia [31]. Western Australia and the Northern Territory are not connected to the NEM but have their own electricity systems and regulatory arrangements [32]. Generation and retail are competitive markets, whereas transmission and distribution are natural monopolies.

Retailers buy from these natural monopolies, then resell electricity to businesses and households. There are two ways to buy and sell electricity in the NEM wholesale market: through the spot market and through the contract market [38]. Australia has ordinary customers and market customers, with the designation depending on whether they buy electricity in the NEM or in the spot market.

With transmission and distribution networks being natural industry monopolies, Australia has rules that govern its economic regulation frameworks. These rules enable the regulator to set the maximum revenues that electricity network businesses may charge for the services they provide. Energy ministers are the key decision makers, holding policy and governance responsibilities [32]. The electricity sector is regulated by the Australian Energy Market Commission (AEMC), whose role is to conduct independent reviews and guide government institutions on the development of the electricity market. This means that it conducts regulatory advocacy. It also develops the rules according to which the market must operate. The Australian Energy Regulator (AER) is the regulator of the wholesale electricity and gas markets in Australia. It is part of the Australian Competition and Consumer Commission and enforces the rules established by the Australian Energy Market Commission.

The Australian Electricity Market Operator (AEMO) oversees the management of electricity and gas systems and markets throughout Australia and operates two electricity markets and power systems in Australia: the NEM, and the WEM in Western Australia. Across the NEM, AEMO's role as market and system operator is to assess and negotiate performance standards that could affect power system security. AEMO is also involved in assessing simulation models of power system plants and associated control systems, and commissioning and post-commissioning activities [39].

There are also other important role players in the Australian power sector, such as the Northern Territory Electricity System and Market Operator (NTESMO), responsible for operating the Northern Territory's electricity market and power systems. Western Australia has two separate systems, the Southwest Interconnected System (SWIS) where AEMO operates the wholesale electricity market, and the Northwest Interconnected System (NWIS).

3.5 Uganda

3.5.1 Uganda’s electricity industry

Uganda’s electricity industry is dominated by hydropower, with oil, wind, solar, biofuels and waste adding to the mix. The region has a low electricity access rate because many areas have a low population density, and most people live far from the centralised grid-based power systems. Uganda’s population in 2022 was 47.2 million, with 74% of the population living in rural areas, and only 45% having access to electricity. There are plans for the use of small-scale hydropower dams that could generate over 10 MW as an option to expand electrification. This is considered a cost-effective technology to connect rural populations to decentralised grid-based power systems [40].

Hydropower accounts for about 78.4% of the total installed capacity of 1 404 MW. Electricity generation is diversified across four different sources as follows [41]:

- Hydro: 1 099.7 MW
- Thermal: 100 MW
- Co-generation: 135.9 MW
- Grid-connected solar: 68.4 MW

Total installed capacity is 1 404 MW.

Uganda Electricity Generation Company (UEGCL) is the main generation company in Uganda, having an installed capacity of 613 MW in 2022, or 45% of total installed capacity in Uganda. The company has a targeted capacity of 3500 MW by 2025, according to its National Development Plan (NDP). All big power generation plants belong to UEGCL, but are operated and managed by Eskom, Aggreko and other companies through concessional agreements [42]. The company has two projects that are planned to come online in 2023 with a total capacity of 607 MW. This means that capacity will increase by almost 100% [43]. Figure 3.8 shows the sources of electricity in Uganda.

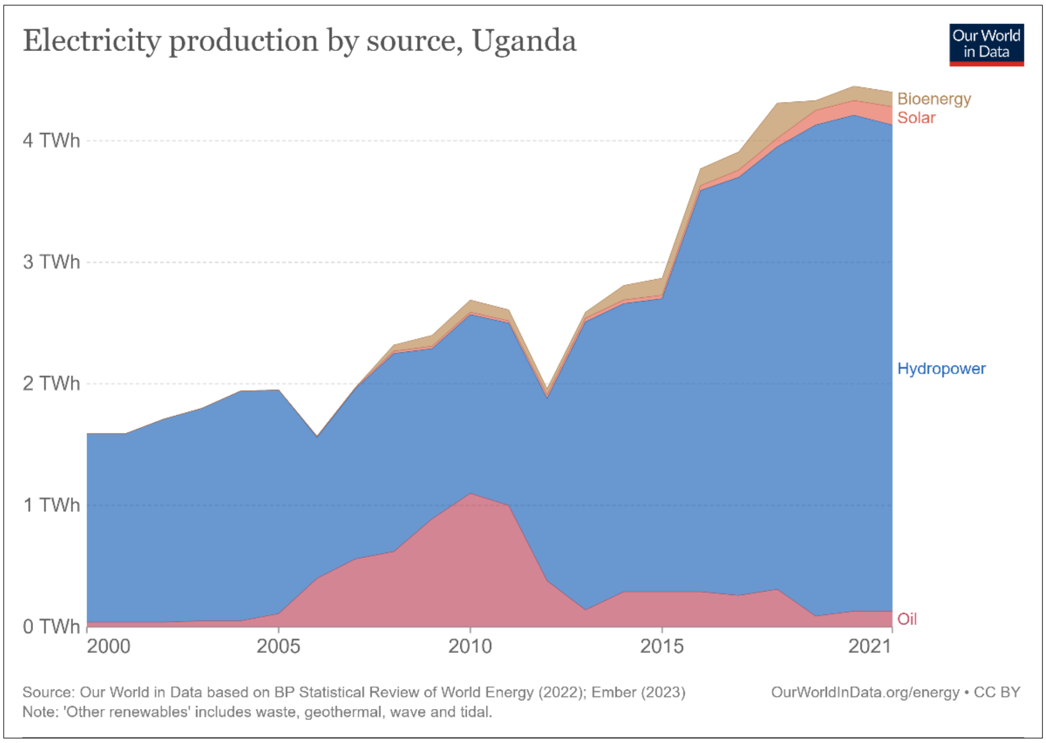


Figure 3.8: Electricity production by source in Uganda [44]

Figure 3.9 shows the share of electricity production provided by each source.

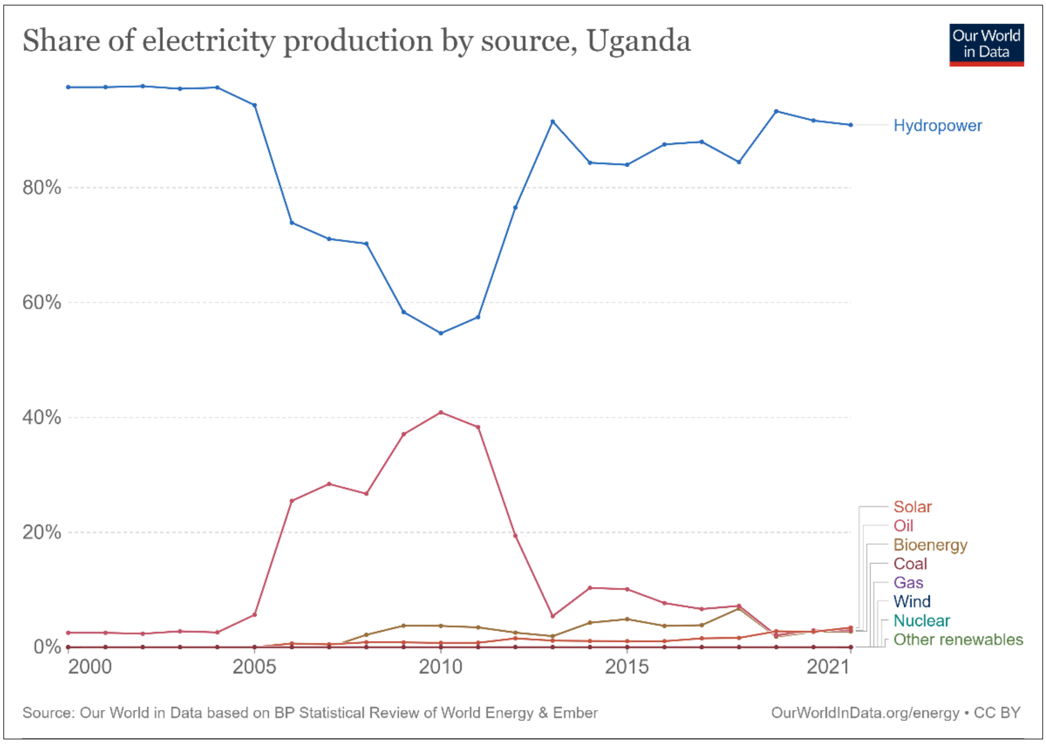


Figure 3.9: Share of electricity production by source [44]

It is interesting to note in Figure 3.9 above that although oil does not form the bulk of the electricity supply in Uganda, the use of oil increased substantially between 2005 and 2013, while hydro reduced during the same period. This is due to the generation shortage and an energy crisis faced by the country during this period due to low water levels of Lake Victoria [45]. However, the country has made significant progress by adding new generation to the national grid through public –private partnerships and now faces new challenges relating to constraints in transmission and distribution systems [45].

Electricity transmission

Uganda Electricity Transmission Company Limited (UETCL) is Uganda's transmission company, responsible for the operation of the transmission system, the day-to-day scheduling and dispatching of power plants, and the management of power purchase agreements with independent power producers.

UETCL has separate licences for the operation of the transmission grid, system operation, import and export of electricity, and bulk supply. The company is the only buyer and bulk supplier of electricity in the country, responsible for buying power from all generators (state owned and independently produced), importing power, and publishing standardised tariffs for renewable energy embedded generation of up to 20 MW capacity. The combined length of the national transmission and distribution lines is 14,312 km.

Electricity distribution

Prior to March 2005, Uganda's main electricity distribution company was Uganda Electricity Distribution Company Ltd (UEDCL). In March 2005, this government-owned entity was concessioned to a company called Umeme Ltd, a consortium belonging to Globeleq UK, for 20 years. In terms of the agreement, UEDCL leases its assets to Umeme, with the concession due to end in March 2025. Umeme Ltd is currently Uganda's main electricity distribution company, empowered to trade and supply electricity at 33 kV and below. As of 31 December 2022, Umeme served over 1.7 million customers categorised into domestic households, commercial enterprises, street lighting and industrial consumers. Since Umeme took over electricity distribution, Uganda's electricity consumers grew from 263,000 in March 2005 to 1.7 million at the end of 2022 [46]. The company operates in three regions: the Northeast region, Western region and Kampala (East and West) region.

The country has nine other smaller licensed electricity distribution operators that serve previously unserved and predominantly rural communities. They operate in various regions of the country, enabling access to electricity to increase significantly. There are some mini-grid distribution systems and one off-grid generation and distribution company, the West Nile Rural Electrification Company Ltd (WENRECO) [46].

WENRECO was formed in 2003 and operates in the West Nile concession area. It is a vertically integrated off-grid system operating on a "build, own and operate" basis (BOO) and initially funded by the Aga Khan Fund for Economic Development (AKFED). UEDCL has an operation and maintenance agreement with WENRECO, according to which UEDCL supervises and monitors the network on behalf of the government of Uganda. Over the years, UEDCL has fulfilled its mandate, supervising the network in the West Nile concession area. The company generates power mainly from mini hydropower stations with an installed capacity of 3.5 MW. The estimated customer base for the entire West Nile region stands at approximately 23 000 customers [47].

3.5.2 Uganda's electricity market structure

Like many other countries, Uganda's electricity sector was initially vertically integrated and run by the Uganda Electricity Board (UEB), a monopoly state-owned entity managing the generation, transmission, distribution, sale, import and export of Uganda's electricity. However, currently Uganda is the only country on the African continent that has a liberalised electricity market. The liberalisation came into effect in 1999 through the implementation of the Electricity Act that mandated the unbundling of the UEB.

Uganda's electricity supply industry is now divided into three divisions:

- Generation (public and private independent power producers (IPPs): UEGCL, Eskom, Isimba, BEL and 40 others).
- Transmission (high voltage transmission, export/import and system operator (66kV to 400kV)).
- Distribution (power distribution to end-users operating between 240 V and 33 kV).

Figure 3.10 shows the structure of Uganda's electricity supply industry.

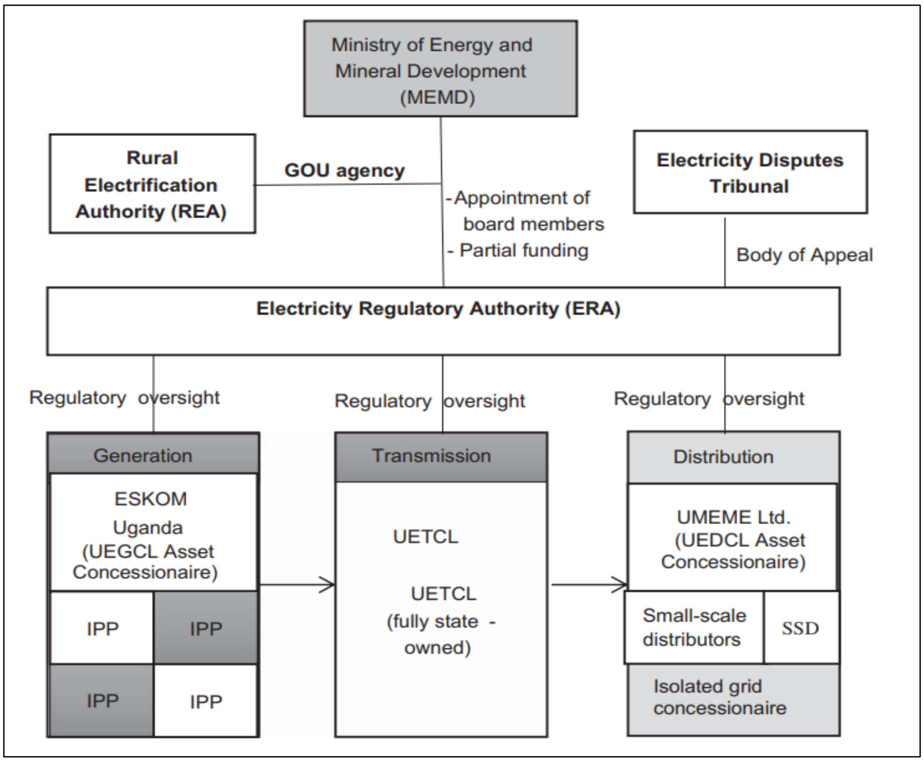


Figure 3.10: The structure of Uganda's power sector [48]

The generation division combines contributions by government-owned power plants, independent power producers (IPPs), and public–private partnerships (PPPs). The transmission division is wholly owned by the government of Uganda. The distribution division, like generation, is liberalised and includes a few private participants as well as a government-owned distribution company, the Uganda Electricity Distribution Company Ltd (UEDCL) [48].

Figure 3.11 below shows the market structure of the Ugandan electricity supply industry.

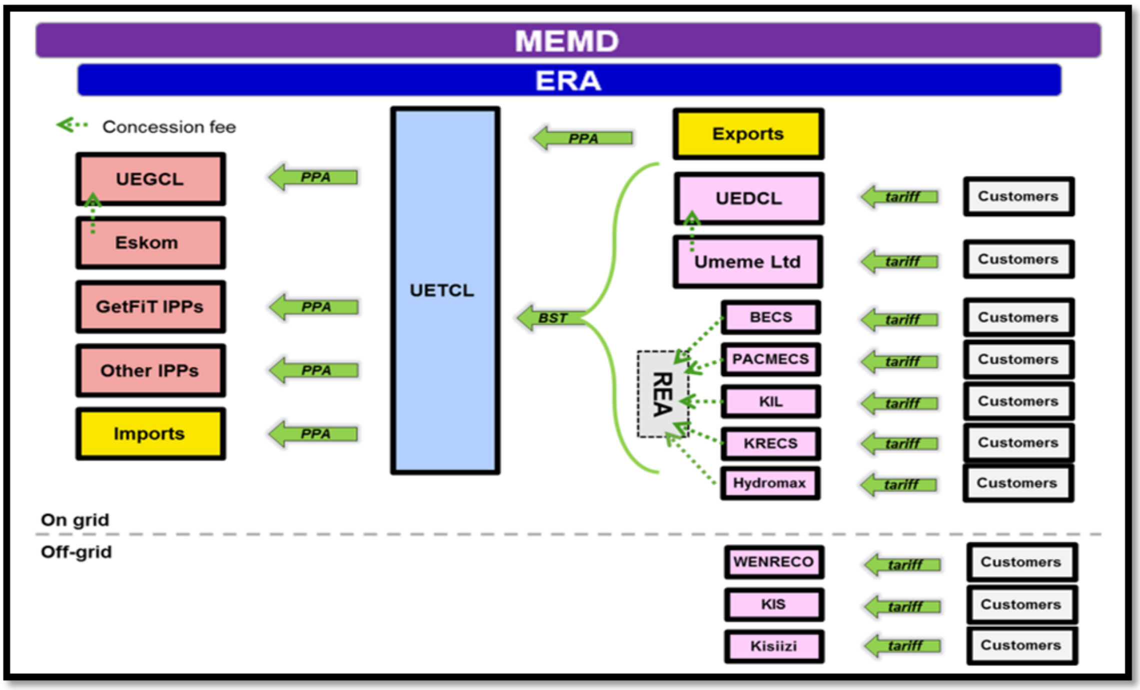


Figure 3.11: The Ugandan electricity market structure [49]

Uganda's current electricity market structure is essentially a single buyer market, in which generation companies sell their power to a single entity that in turn transmits and sells it to distribution companies. This model was introduced in 2001 during a transition from a vertically integrated monopoly model to a more liberalised model. The market is expected to evolve into a wholesale market as of the next restructuring step [50]. This kind of market is one of four possible market types: monopoly markets, single-buyer markets (a purchasing model), wholesale markets and retail markets [51].

3.6 Chapter summary

The main points of comparison covered in this chapter are captured in Table 3.3 on the next page for ease of reference, the Table comprise of a summary of the information contained in this Chapter that was obtained from several sources [24],[25],[28],[29],[31],[36],[41],[46],[52] and [53]. South Africa has a generation capacity and electricity access rate that compares well with that of Brazil, Australia and Uganda. The main difference identified between South Africa and these three countries is in the market design, with South Africa the only country with a structure that is predominantly vertically integrated and not fully unbundled using a single buyer model. Brazil, Australia and Uganda have gone through processes of market reform over the years and have managed to liberalise their markets. Generation and retail are competitive in the other three countries; however, as in South Africa, their transmission and distribution are natural monopolies. Australia and Brazil have high shares of variable renewable energy sources in their electricity mix, i.e. wind and solar, making them a good pick for South Africa to benchmark itself against for the successful development and management of high levels of variable renewable energy embedded generators. Uganda has a very low electricity access rate and penetration of variable renewable energy sources in comparison to South Africa. It is also interesting to note that in terms of the average cost of electricity, South Africa has a lower average cost per kilowatt hour than the other three countries. Some of the reasons for this are uncovered in Chapter Six of this study.

Table 3.3: Summary of electricity industry per country *(data sourced from [24], [25], [28], [29], [31], [36], [41], [46], [52] and [53]).*

	South Africa	Brazil	Australia (NEM)	Uganda
Population	60 mil	214 mil	26 mil	46 mil
Electricity access rate	89.3%	99.5%	100%	22.1%
Electricity structure	Vertically integrated/ partially unbundled	Unbundled	Unbundled	Unbundled
Generation	Monopoly (Regulated)	Competitive (Wholesale)	Competitive (Wholesale)	Competitive (Wholesale)
Coal	39 GW	4 GW	23.2 GW	101 MW
Hydro	4.6 GW	109 GW	8 GW	1099.6 MW
Solar	2.2 GW	7.7 GW	5.2 GW	68.4 MW [43]
CSP	500 MW	-	-	-
Wind	3.3 GW	25 GW	8.8 GW	-
Gas	4 GW	17 GW	5.1 GW	-
Oil/Diesel	1 GW	9.6 GW	7 GW	-
Biomass/Biogass	51 MW	17 GW	0.62 GW	135.5 MW
Nuclear	1.9 GW	2 GW	-	-
Other	-	-	0.46 GW	
Nominal capacity	54 GW (7.1) GW IPPs)	192 GW	88.4 GW (65 GW NEM)	1.404 GW
Peak demand	35 GW	73 GW	32 GW	794 MW
Transmission	Monopoly(Single buyer)	Monopoly	Monopoly	Monopoly(Single buyer)
Length	33 027 km	183 082 km	+-40 000 km	3 431 km
Distribution	Monopoly	Monopoly	Monopoly	Monopoly
Length	+-371 791 km		+-753 462 km	53 733 km
Distributed generation	4.7 GW [52]	19 GW	17 GW	Only utility scale facilities
Retail	Regulated	Regulated & Competitive	Regulated & Competitive	Regulated
Market design	Single buyer model	• Wholesale (central auctions for long-term contracts) • Different suppliers buy from the market and sell	• Wholesale (spot market, contract & ancillary services) • Different suppliers buy from the market and sell	Single buyer model
Embedded generation customers	• Generate for own use, wheeling and bilateral contracts • Sell excess energy to licensees that have approved export tariffs • Licensed entities can participate in the short-term risk mitigation programme	• Generate for own use, wheeling & bilateral contracts • Sell excess energy to distributors through a net metering scheme or net billing scheme for generators up to 5 MW • Generate to participate in the market, for sizes > 500kVA	• Generate for own use, wheeling & bilateral contracts • Generate to participate in the NEM • Different approaches adopted across the different states w.r.t feed in tariffs. Certain states there's approved minimum credit rates, in others customers can search around for competitive rates.	• Generate for own use and to participate in the renewable energy feed-in tariff scheme. This is for generator sizes up to 20 MVA. All generators have to be licensed.
Average electricity price [53]	0.156usd/kwh 0.074usd/kwh	0.171usd/kwh 0.151usd/kwh	0.243usd/kwh 0.309usd/kwh	0.178usd/kwh 0.132usd/kwh
Main Role Players	Eskom, IPPs, NERSA, DMRE	Enel, Cemig, ANEEL, MME, CCEE	NEM, AEMO, AEMC	UECGL, UECDL, UMEME, ERA, MMRE

The following chapter examines the penetration of distributed generation, especially of variable energy sources in each country, along with its impact.

CHAPTER 4: SURVEY OF EMBEDDED GENERATION IN EACH COUNTRY

4.1 Introduction

This chapter provides an overview of the penetration levels of embedded generation in each country under investigation and the changes that each country has implemented to facilitate the uptake of embedded generation and the management thereof. This is achieved first through a survey of embedded generation installed on each country's networks from a specified point in time. The figures documented in this chapter were obtained from publicly available data for each country. The second part of this chapter is a review of the changes in legislation or regulations adopted in each country to facilitate and manage the uptake. For all four countries, a specific time period is considered, especially with regard to the uptake of embedded generation from renewable energy sources, mainly to align with climate change goals.

4.2 Distributed generation in South Africa

South Africa has been experiencing challenges with shortages of supply for several years. Power cuts in the form of load shedding were more frequent in 2023 than in any previous year. According to Eskom's 2021 medium term system adequacy outlook [54], the system has a supply gap of about 2000 MW. To avoid load shedding or a total blackout, the system requires between 2000 and 6000 MW of baseload generation between 2022 and 2026. As a result, in June 2021, the president of South Africa announced the removal of the licencing requirement for private generation of up to 100 MW as an incentive for customers to consider self-generation to reduce demand on the national power system. The limit has since been removed completely as of January 2023 [55].

4.2.1 Embedded generation in legislation

Prior to June 2021, Schedule 2 of the Electricity Regulation Act (Act no. 4 of 2006, "the Act") stated that all generators greater or equal to 1 MW had to obtain a licence to own and operate a generation facility, except for the two scenarios stipulated in the schedule i.e. generators for demonstration purposes and generators with no connection to the national grid. In 2021, Schedule 2 of the Act was changed to allow generators with a capacity of up to 100 MW to generate power for own use and sell to one or more customers without a generation licence from NERSA [1]. In January 2023, the 100 MW restriction was removed, and private generators of any size were allowed to operate without a licence. These facilities now only need to register with NERSA and comply with grid code requirements. This has opened the electricity sector to an unlimited number of private generation facilities.

Embedded or private generation in the country is driven by rising electricity prices, national energy insecurity, dropping technology costs, supportive energy policies, and incentives, all of which are prompting consumers to explore alternative supply options. The aim of the lifting of the licensing requirement is to allow private generators to assist in curbing the electricity supply crisis in the country and to facilitate private sector investment in the electricity sector. The licensing requirement for private generation was viewed as an example of unnecessary red tape that prevented entry for private sector participation.

4.2.2 Embedded generation integration requirements

All generators connected to or seeking connection to the South African transmission or distribution system must meet the following requirements in order to connect:

- Registration or licensing of the generation facility with NERSA.
- A connection permit from the network service provider.
- Compliance with national safety and technical requirements.
- Compliance to the grid code.
- All required permits, such as environmental authorisation, depending on the type, size and location of the generation facility.

4.2.3 Survey of installed embedded generation on South Africa's distribution networks

Distributed generation penetration is a measure of the number of distributed energy resources in a power system in relation to total electricity generation. Since the publication of the Registration Notice in November 2017, the energy regulator, NERSA, has registered 1186 projects under generation for own use and for commercial purposes (i.e., bilateral/wheeling agreements). The total capacity registered by NERSA is currently 5.8 GW; the capacity registered in 2021 was 134 MW, with the capacity skyrocketing in 2022 and 2023, with 1.6 GW and 3.9 GW registered in each year, respectively. This is largely due to the exemption from licensing requirements for generators of up to 100 MW from 2021, and the complete removal of the limit in January 2023. The breakdown of numbers registered each year, and the cumulative capacity is shown in Table 4.1 below.

Table 4.1: Facilities and capacities each year *(data sourced from [56])*

Year	Number of facilities	Total capacity (MW)
2023	281	3887
2022	406	1664
2021	282	134,4
2020	124	52,9
2019	41	22,3
2018	52	25,5
Total	**1186**	**5786**

To date, the Gauteng province has the highest number of registered facilities, with 292 facilities registered, followed by the Western Cape and Northern Cape respectively. Gauteng is the business hub of the country, followed by the Western Cape. Most of the registered facilities in these provinces are for businesses. However, in terms of overall installed/registered capacity, the Northern Cape, Free State and Eastern Cape are the highest, respectively, as Table 4.2 shows.

Table 4.2: Capacities per province *(data sourced from [56])*

Province	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total (#)**	**Total (MW)**
Gauteng	6	14	39	52	109	72	292	344
Limpopo	15	7	4	30	22	22	100	580
Northern Cape	11	6	14	40	57	25	153	1669
Eastern Cape	0	1	15	28	37	23	104	738
Western Cape	3	3	22	45	67	39	179	438
Northwest	3	2	2	21	26	25	79	714
Free State	3	3	7	39	41	25	118	852
Mpumalanga	4	1	5	13	13	19	55	299
Kwa-Zulu Natal	7	4	16	14	34	31	106	154
Total	**52**	**41**	**124**	**282**	**406**	**280**	**1186**	**5786**

In terms of technologies, solar PV technology has the highest number of facilities and the highest capacity, followed by wind technology. Table 4.3 shows the total number of facilities and megawatt capacities of each form of technology currently contributing to the South African electricity supply.

Table 4.3: Total facilities and capacities per technology *(data sourced from [56])*

Technologies	**Number of facilities**	**Total capacity (MW)**
Solar PV	1150	3659
Wind energy	20	1946
Biomass	0	0
Biogas	2	58,2
Landfill gas	3	19,694
Geothermal	0	0
Co-generation	6	74,41
Concentrated solar	0	0
Small hydro	5	28,331
Total	**1186**	**5786**

Since the gazetting of Schedule 2, the energy regulator has registered 135 facilities with capacities greater than 1 MW with a cumulative capacity of 5374 MW. This cumulative capacity makes up 92% of the total capacity registered since 2018.

From these statistics, it is evident that the lifting of the licence requirements is resulting in a high percentage of newly registered facilities. The above statistics do not include rooftops solar systems of less than or equal to 100 kW registered by network services providers. When accounting for all embedded installations, it is therefore reasonable to assume that the total penetration of embedded generation on distribution networks is at least 5.8 GW. However, it must be noted that the registered capacity does not necessarily mean that it has already been connected.

4.2.4 The impact of embedded generation on planning

South Africa's plans with regard to new generation capacity are documented in the integrated resource plan (IRP). The IRP is considered policy as it details the country's rollout plan for new generation capacity up to 2030. The latest IRP 2019, summary of which is shown as Table 4.4, shows new generation capacity for various technologies planned for each year from 2019 to 2030 [57]. Embedded generation forms part of the capacity allocated under the category named "other", i.e., distributed generation, plus co-generation.

Table 4.4: Summary of planned generation capacity as per Table 5 of the IRP 2019 [57]

	Coal (MW)	Coal (Decommissioning) (MW)	Nuclear (MW)	Hydro (MW)	Storage (MW)	Solar PV (MW)	Wind (MW)	CSP (MW)	Gas & Diesel (MW)	Other (Distributed generation, Co-gen, Biomass, Landfill) (MW)
Current Base	37 149		1 806	2 100	2 912	1 474	1 980	300	3 830	499
2019	2 155	-2 373					244	300		Allocation to the extent of the short-term capacity gap
2020	1 433	-557				114	300			
2021	1 433	-1 403				300	818			
2022	711	-844			513	400 1 000	1600			
2023	750	-555				1 000	1600			500
2024			1 860				1600		1 000	500
2025						1 000	1600			500
2026		-1 219					1600			500
2027	750	-847					1600		2 000	500
2028		-475				1 000	1600			500
2029		-1 694			1 575	1 000	1600			500
2030		-1 050		2 500		1 000	1600			500
Total Installed Capacity by 2030	33 364		1 860	4 600	5 00	8 288	17 742	600	6 380	
% Total Installed Capacity	43		2.36	5.84	6.35	10.52	22.53	0.76	8.1	
% Annual Energy Contribution	58.8		4.5	8.4	1.2*	6.3	17.8	0.6	1.3	

Grey	Installed Capacity
Yellow	Committed/ Already Contracted
Red	Capacity Decommissioned
Green	New Additional Capacity
Blue	Extension of Koeberg Plant Design Life
Peach	Includes Distributed Generation Capacity for own use

Capacity listed under the category “other” includes both utility-scale generators and generators producing for own use or to wheel to other customers. Prior to the amendment of schedule 2 of the Act, all new generation capacity including distributed generation needed to be rolled out according to the allocations in Table 4.4. However, with the licensing exemption, private generators no longer need approval from the minister to generate or follow this plan. This introduces challenges from a system operation and planning perspective. With an increase in the number of embedded generators, especially for own-use customers, the system operator is faced with the challenge of lacking access to information, which hinders its ability to do proper forecasting. Registrants are not obligated to share information with the system operator, an aspect of the regulatory frameworks that will have to change so that the system operator is able to plan. An increase in the number of rooftop PV energy sources, most generating less than 100 kW and not registered with NERSA but registered with network service providers (NSPs), has the potential to affect planning on the system operation side if information about sizes and locations is not known. The NSPs are expected to have a database with this information accessible to the system operator for planning and forecasting purposes and to conduct system performance studies, but most of them do not have this database.

Other planning challenges are as follows:

- Most municipal networks are undocumented, and their infrastructure is not in good condition because of lack of maintenance. In such circumstances, conducting grid studies as part of planning become a challenge because of the lack of adequate network data.
- Most planners are used to planning for vertically integrated systems. Now, with distributed generation, generators are emerging from everywhere, and power flows in different directions, making planning extremely challenging.
- Dealing with network congestion and grid capacity allocations is a challenge. Competition for available grid capacity is high, with the relaxation of licensing requirements having resulted in an increase in applications for private generation. Projects are competing for already limited grid capacity, and the current “first come, first served” rule applied by utility companies results in capacity hogging by projects that applied first but are not ready to connect. This negatively affects the efficiency of grid capacity allocation and the ability to effectively offer non-discriminatory access to the grid [58].

- The turnaround time for registered facilities is shorter than the turnaround time for utility-scale IPPs on the national procurement programmes such as REIPPPP and RMIPPPP, owing to the removal of the licensing requirement. The available grid capacity is quickly taken up by private generation while REIPPPP/RMIPPPP projects are still trying to get their projects licensed. The public utility, Eskom, has proposed interim rules stating that capacity should be reserved to shovel ready projects only, and that utility-scale projects participating in the national procurement programmes for the benefit of the general public should be prioritised over private generators [58]. The rules have been welcomed by some industry participants, but also face opposition from private sector participants.

4.2.5 The impact of embedded generation on human resources

Since November 2017, a total of 1186 new facilities have been registered with Eskom and municipal distributors. Most staff were trained for a power system with a unilateral flow of power and were ill-prepared to handle a new, multi-supplier scenario in which the flow of power in the system is bidirectional. Staff are not equipped to deal with the new types of customers and network arrangements, or the high number of applications, which necessitates that utilities increase staff capacity. In essence, lack of resources in terms of numbers and skills is hampering the proper management of additions to the power supply. There is a need for utilities to reskill or upskill their staff and increase their staff complement.

4.2.6 Summary

The electricity industry in South Africa is deregulating. This has benefits such as the promotion of competitiveness in the industry, an increase in private participation, and increased customer choice, to name a few; however, the changes can be disruptive if not done in an orderly manner. Changes in legislation for the benefit of the country should be guided by a clear strategy and a targeted end-state structure for the industry. This would ensure that the changes in legislation are backed by properly updated regulatory tools to facilitate implementation of the changes.

The challenge currently faced by South Africa regarding the high penetration of embedded generation is that the regulatory tools such as rules for participation in the industry are lagging behind developments. There are customers who connect distributed generation (DG) on to the grid without the necessary knowledge, because some utilities do not have a clear procedure or set of connection rules, or customers see the procedure for connecting to the grid as too stringent, and therefore do not attempt to connect, or ignore the rules and connect illegally. Thus, the country loses out on the potentially valuable contributions of prosumers. Prosumer means a customer that generates electricity on their side of the billing meter with an embedded generation facility that is primarily intended to offset part or all of their electricity requirements. The lack of an easy process and transparent rules deters prosumers who produce their own electricity from renewable sources and encourages illegal connections.

There are no national rules or guidelines for the industry. Many of the rules have yet to be developed, since current legislation does not give the energy regulator a mandate over certain activities involving registered/private facilities; instead, the mandate has been given to network service providers. In addition, there is currently no nationally approved compensation scheme for excess energy exported to the grid by embedded generators.

There is a need for the policy maker to ensure that changes in the industry that are meant to assist in the reform of the electricity industry are backed by policy changes that enable implementers of policy to lead the industry in the right direction. The removal of the licensing requirement for generators of up to 100 MW resulted in an increase of the uptake of private generation registered with NERSA from approximately 100 MW by the end of 2020 to 5.8 GW by the end of 2023. This is a 570% increase within a span of three years. The numbers demonstrate that the uptake of embedded generation is largely driven by enabling changes in legislation, policy or regulation. Further enabling changes and clarifications of policies and regulations would enhance the uptake and relieve South Africa's overstrained grid.

4.3 Distributed generation in Brazil

In 2023, Brazil reached a total of 19 GW of installed distributed generation capacity. This is dominated by solar generators, which account for 99% of the distributed generation, while the remaining 1% is from biomass, biogas, small hydro and wind. From these statistics, it is worth noting that the makeup of Brazil's distributed energy sector is entirely from renewable energy sources. Many distributed energy sources in Brazil are connected at distribution level and are low voltage connections.

Challenges experienced by the Brazilian distribution utilities as a result of a high penetration of distributed generation at the initial stages included [59] the following:

- There was a need for the development of connection standards and proceedings.
- Bidirectional meters had to be acquired.
- The billing system and control service had to be adjusted.
- Protection panels for hydraulic and thermal sources had to be developed.
- A georeferenced system had to be implemented, along with new procedures for distributed generation.
- Secure deployment procedures had to be developed.
- Internet sites had to be adjusted for customers to access distributed generation production information.
- There was a need to certify inverters.
- New procedures had to be developed for installation, inspection and commercial sites.
- Workforce training was intense.

4.3.1 The impact of embedded generation on the Brazilian network

Many research papers note that the two important characteristics of renewable energy sources and distributed energy resources that must be considered are their variability and intermittence. These factors raise challenges in resource adequacy assessment and system planning and operation.

According to a number of papers [27] [60] [61], challenges introduced on the Brazilian distribution networks included:

- Planning resource adequacy for the long and short term.
- Providing adequate distribution and transmission facilities to incorporate these sources.
- Mitigating distribution and transmission constraints due to the rapid loss of a large amount of generation.
- Enhancing the flexibility, reliability and security of the distribution and transmission grids.
- Keeping penetration levels of renewable energy sources and distributed energy resources under control.
- Defining the minimum amount of generation capacity to observe the minimum inertia resources.

- Managing increased system reserve and ancillary service requirements.
- Shaping the backbone of future electricity systems, especially in connecting grids.
- Changing the traditional approach and tools to plan and operate the interconnected power system.
- Changing the operational procedures and requirements of grid codes in the face of deep and fast variations of these sources.
- Improving the methods and tools to make both power generation and load forecasts.
- Improving the operational structure of distribution system operators (DSO) and transmission system operators (TSO) considering these issues.
- Increasing DSO and TSO interactions.
- Reducing revenues and negative load growth.
- Changing business and regulatory models and market rules.

The Global Wind Energy Council (GWEC) published an article in 2021 that indicated that solar and wind generation in Brazil was estimated to reach 19 GW in 2024 [62]; however, Brazil reached this target by March 2023. The article also highlights that Brazil has the highest capacity factor of wind generation in the world, as shown in Table 4.5 below.

Table 4.5: Wind generation capacity factor per country *(adapted from [27])*

<table>
<tr><th>COUNTRY</th><th>CAPACITY FACTOR</th><th>COUNTRY</th><th>CAPACITY FACTOR</th></tr>
<tr><td>BRAZIL</td><td>42%</td><td>POLAND</td><td>26%</td></tr>
<tr><td>TURKEY</td><td>37%</td><td>JAPAN</td><td rowspan="2">25%</td></tr>
<tr><td>MEXICO</td><td>35%</td><td>ROMANIA</td></tr>
<tr><td>USA</td><td rowspan="2">33%</td><td>SPAIN</td><td rowspan="2">24%</td></tr>
<tr><td>AUSTRALIA</td><td>HOLLAND</td></tr>
<tr><td>PORTUGAL</td><td rowspan="3">29%</td><td>ITALY</td><td>22%</td></tr>
<tr><td>DENMARK</td><td>FRANCE</td><td>21%</td></tr>
<tr><td>UK</td><td>CHINA</td><td>20%</td></tr>
<tr><td>SWEDEN</td><td rowspan="2">27%</td><td>GERMANY</td><td rowspan="2">19%</td></tr>
<tr><td>CANADA</td><td>INDIA</td></tr>
</table>

Wind generation introduces challenges such as over-frequency and under-frequency on the network:

- Over-frequency is caused by a surplus generation in cases of loss of load and restrictions on exporting to other areas. Generation curtailment can be used in such cases.
- Under-frequency is caused in cases where there is loss of a large amount of wind generation and restrictions on importing from other areas. Load reduction or demand-side management strategies may be used in such cases.

To deal with the challenges introduced by wind generation mentioned above, Brazil implemented the following:

- It established or reinforced interconnections with other areas or regions.
- It enhanced technical standards to strengthen wind turbines, ensuring they can withstand impacts from the power system.
- It mandated a minimum level of inertia from other generation sources to ensure transient and dynamic stability.

4.3.2 Embedded generation in legislation

In 2012, Brazil published Normative Resolution 482/2012, which outlined general connection conditions for mini distributed generation (<100 kW) and micro distributed generation (>100 kW<1 MW). It also introduced a net-metering scheme. In 2015 the regulation was revised to make the mini distributed generation limit <75 kW and, for micro distributed generation, >75 kW<5 MW, collectively called small-distributed generation.

Distributed generators were authorised to generate electricity without the need for an enabling legal title (concession, permission or authorisation), as long as the person or entity applied to the distributor for the connection of the generating plant and fulfilled other regulatory requirements.

Unlike other legal regimes for generation, provided for directly by law, small-distributed generation was provided for exclusively by regulation (REN 482/2012 – REN482/2015 – REN 482/2022) and could, in theory, be amended at any time by the regulatory body, ANEEL, or even lose its effectiveness by a law that would be enacted to the contrary. To resolve the issue of insecurity, Federal Law no. 14,300 was finally enacted, on 6 January 2022, which established the special legal regime for small distributed generators in national law [63] [64].

Federal Law No. 14,300 of 6 January 2022 [64] introduced substantial changes to the energy compensation system for distributed generation, previously dealt with by Normative Resolution No. 482/2022. The new law updated the requirements applicable to consumers such as the modalities of energy surplus compensation, the legal framework for energy credits, and the methodology for compensation for electricity consumed, amongst others [64].

4.3.3 Embedded generation integration requirements

In order for generators to connect to the Brazilian networks, the generating plants must meet the technical standards required by the power authorities and that the connection meets the requirements in the Distribution Procedure Module 3 – Access to the Distribution System, created by the regulatory body, ANEEL [65].

Generating plants must also obtain a concession, authorisation or communication from ANEEL before generating electricity or integrating it to national networks. The type of regulatory licence provided depends on the energy source technology, size, environmental impact and targeted end users. Hydropower plants require concessions and other energy sources, such as small hydro, thermal, biomass, wind and solar, are subject to an authorisation regime conducted by ANEEL. All these types of facilities may participate in power auctions to sell their production on the regulated market or the free market. Small plants do not need authorisation but require a communication from ANEEL. Small plants are those with an installed capacity of up to 5 MW.

Table 4.6 summarises the regulatory licences required to generate electricity in Brazil [66] [67].

Table 4.6: Brazil's regulatory licences required to generate electricity *[67]*

Regulatory licences needed by power generation companies		
Power source	**Installed capacity**	**Regulatory licence**
Power source	Installed capacity	Regulatory licence
Hydropower	Greater than 50MW	Concession for use of public asset (preceded by a public auction)
	Greater than 5MW but not greater than 50MW	Authorisation
	Up to 5MW	Communication
Thermal power plants and renewable energy (except hydropower)	Greater than 5MW	Authorisation
	Up to 5MW	Communication

In terms of market participation, generators of up to 500 kVA are not required to register as energy market participants with Brazil's chamber of electric energy commercialisation, CCEE. Since 1 January 2023, consumers who wish to participate in the free electricity market need to have a minimum load of 500 kVA to participate.

4.3.4 A review of distributed generation in Brazil

As of 31 March 2023, Brazil has had an installed capacity of 19 GW of distributed generation, with more than 1.8 million customers participating in this sector, according to the Brazilian Electricity Regulatory Agency, ANEEL. Most of this capacity is from solar photovoltaic. Solar PV dominates the distributed generation space, while hydroelectricity dominates the centralised generation space. According to a report published by the US Energy Information Administration (EIA), solar PV accounts for 99% of all privately generated electricity produced in Brazil, while small hydro and wind account for the remaining 1% [68]. In the centralised generation space, hydroelectricity dominates at 58.6%, followed by wind at 16.3%, biomass at 7.6% and utility scale photovoltaic at 4.1% [69].

Figure 4.1 below presents the cumulative distributed generation capacity in Brazil since 2013. Data for 2023 includes systems installed up to 31 March 2023. The year marked by an exceptionally high addition of capacity is 2022, when approximately 7.5 GW of distributed generation was added to the grid. The number of systems producing the 19 GW of capacity is approximately 1.8 million [70]. According to ABGD [71], the 19 GW capacity supply approximately 20 million people.

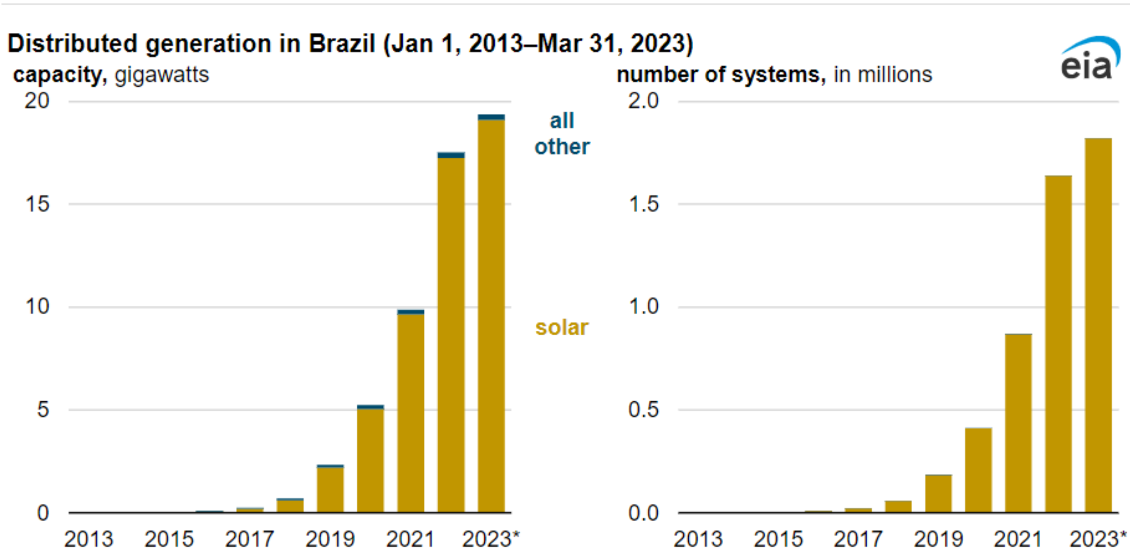


Figure 4.1: Distributed generation in Brazil, 2013 to 2023 [70]

Figure 4.2 below shows solar PV distributed generation capacity by state in Brazil. The three dominating states are Sao Paulo, Minas Gerais and Rio, as expected, because these states are economic hubs of the country with higher population numbers than the others.

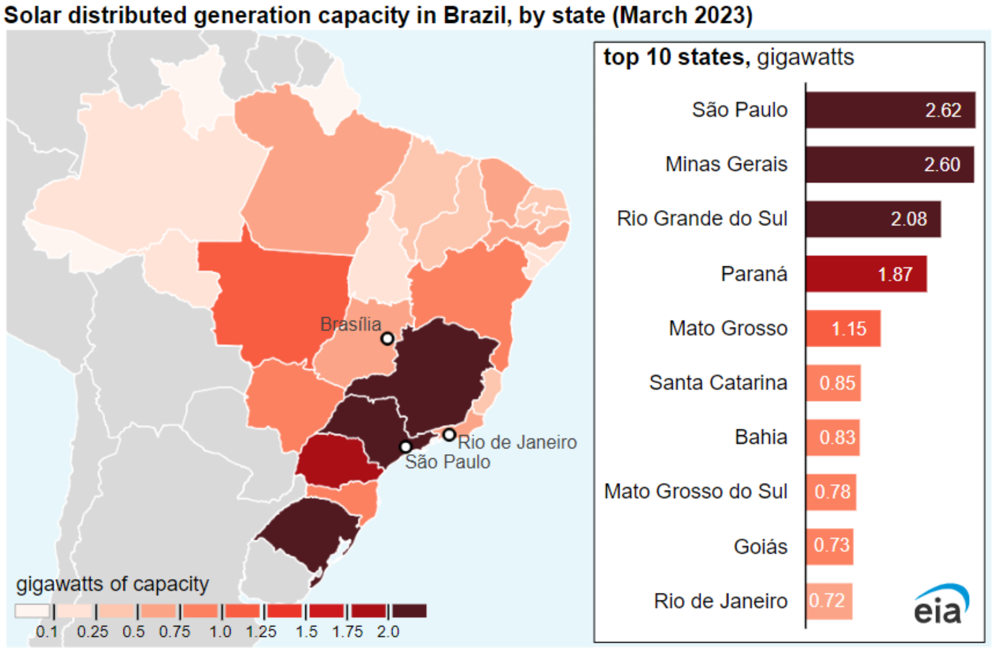


Figure 4.2: Solar distributed generation capacity in Brazil by state [70]

4.3.5 The benefits of distributed generation in Brazil

Distributed generation in Brazil offers financial savings, promotes socio-environmental awareness, and increases self-sustainability. The benefits it introduces to the electrical system include [21]:

- Delaying investments in transmission and distribution network expansion.
- Reducing environmental impact.
- Lowering network load.
- Decreasing energy losses, especially in long-distance transmission of energy.
- Diversifying the energy matrix.

4.3.6 Summary

Electricity planning goals in Brazil are the responsibility of the Ministry of Mining and Energy, which has identified a need for a comprehensive legal and regulatory framework, including long-term energy planning for non-conventional energy generation to thrive. The growth of distributed generation in Brazil was motivated by regulatory changes and decreased technology and deployment costs. In 2012, through Resolution 482/2012, the country established and introduced interconnection standards for small-scale generators and a compensation mechanism for power that is fed back to the grid. The resolution has been updated over the years. Resolution 687/2015 introduced a compensation mechanism for distributed generation, according to which all customers with generating facilities of up to 5 MW receive energy credits in proportion to the surplus of energy they inject into the distribution network. Generators with a capacity of up to 500 kVA can connect to the distribution system across the country through a net metering mechanism without the need to register as an energy market participant with the CCEE. The net metering regulation does not allow for the commercialisation of electricity.

The success of distributed generation in Brazil is clearly underpinned by clear regulatory frameworks that are regularly updated as the energy landscape in the country evolves. The latest development is the enactment of Law No. 14,300 of 6 January 2022, which provides certainty and security for participants. The frameworks are not necessarily perfect but are effective in guiding and ensuring order in the development of the distributed energy sector in Brazil.

4.4 Distributed generation in Australia

According to the National Energy Regulator of Australia [2], the Australian distribution network, like the South African distribution network, was originally designed to deliver electricity in one direction from a centralised generation region, maintaining safety, reliability and security of supply. Today, Australia has one of the highest penetrations of renewable energy resources in the world, in the form of distributed generation, particularly from solar PV for households and businesses.

4.4.1 A review of embedded generation in Australia

Figure 4.3 below presents the distributed generation penetration levels in each state in the Australian national electricity market (NEM).

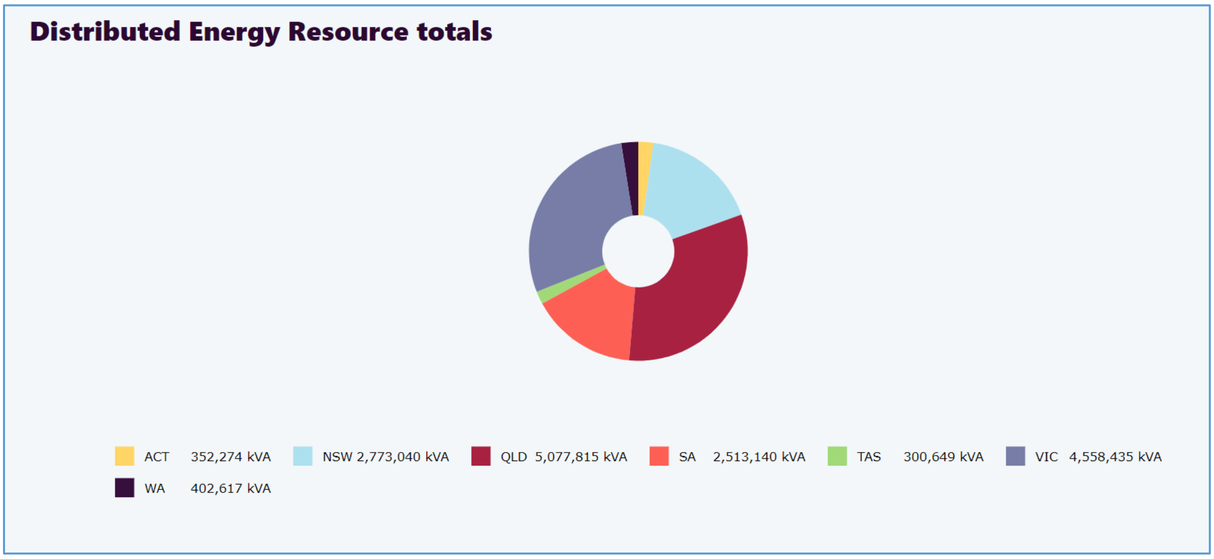


Figure 4.3: Distributed energy resource totals by state in Australia [72]

In 2023, the total amount of distributed energy resources connected on the NEM integrated system had risen to 16 GW. Queensland, Victoria, New South Wales and South Australia have the highest penetration levels. Figure 4.4 shows the additions each year.

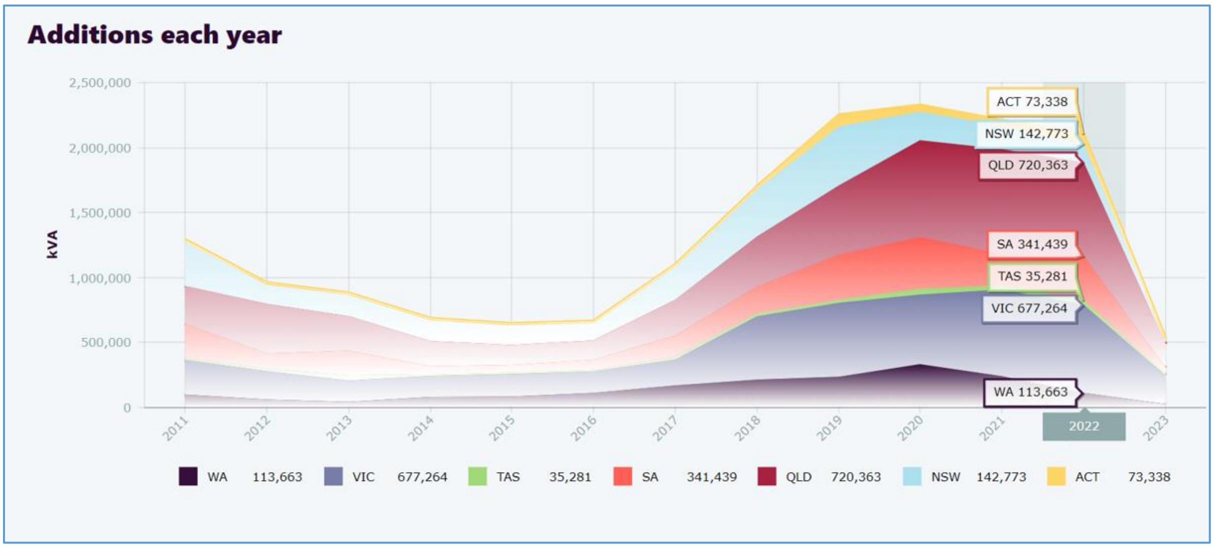


Figure 4.4: DER capacity added each year per state [72]

In 2022, about 2.1 GW was added to the system, although the highest addition to date was in 2020 during Covid-19, of 2.3 GW. Figure 4.5 shows DER capacity by year per state.

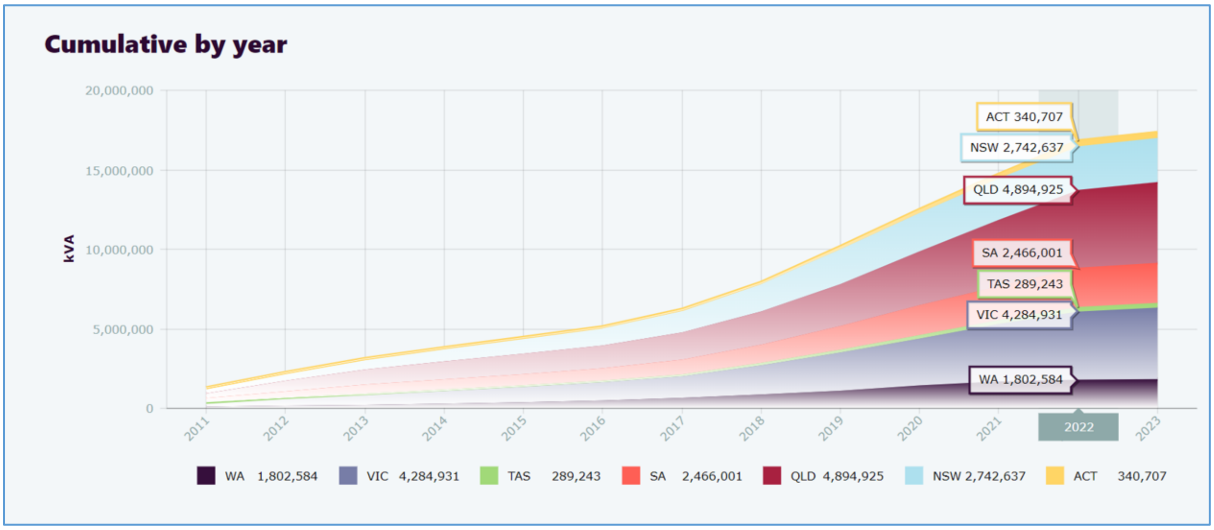
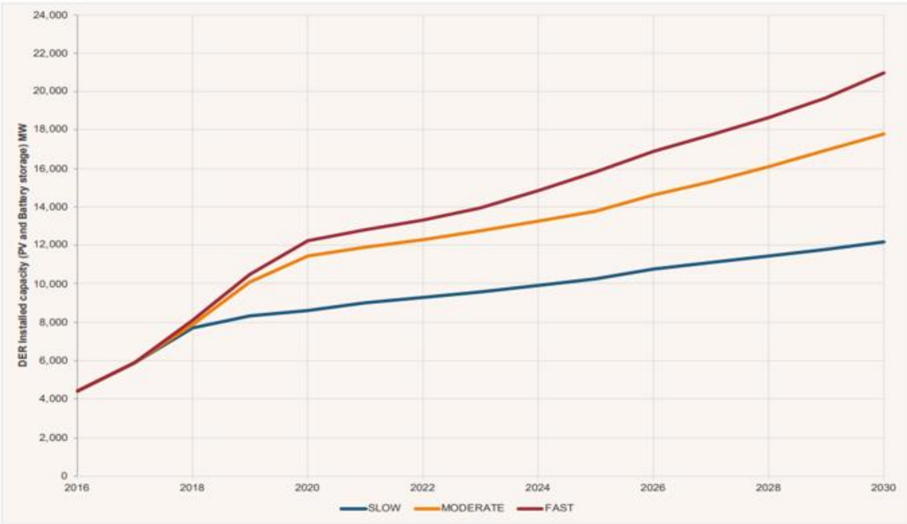


Figure 4.5: DER cumulative capacity by year per state [72]

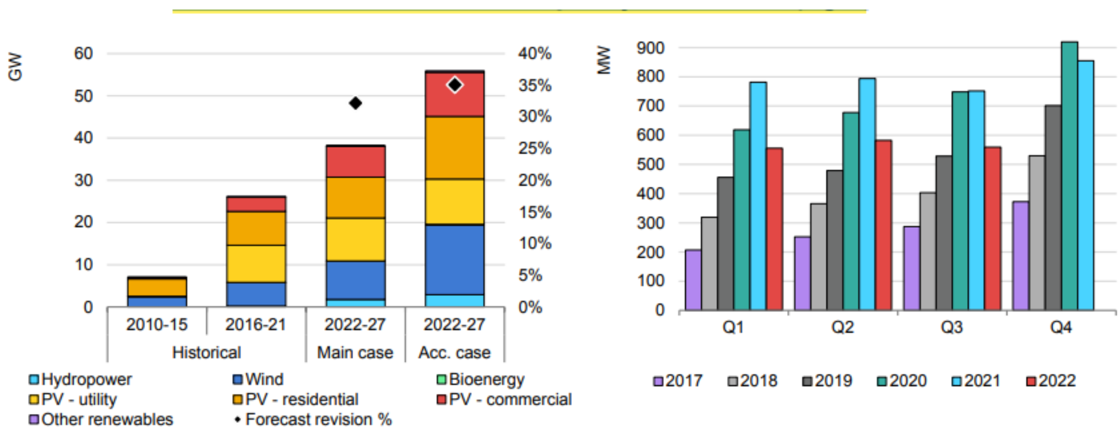
The cumulative capacity in 2022 was 16,8 GW, a rise from 12 GW in 2020. In 2018, the cumulative capacity was 8 GW, and at the end of 2022, the cumulative capacity was 16,8 GW. This is an increase of approximately 100% on the December 2018 levels.



Forecast provided to AEMO by the CSIRO for the 2018 Electricity Statement of Opportunities (ESOO), includes residential and business installations up to 30 MW in size.

Figure 4.6: Forecasted installed capacity of DER in the NEM [73]

The installed capacity in 2022 surpassed the 2018 forecasted capacity by close to 4 GW (moderate scenario). As indicated in Figure 4.6 these numbers include residential and business installations up to 30 MW.



Notes: Acc. case = accelerated case; GW = gigawatt; PV = photovoltaics; MW = megawatt.
Source: IEA, (2022b).

Figure 4.7: Renewable energy source capacity (DER plus utility scale) [73]

Australia currently has a capacity of close to 40 GW from renewable energy sources. This includes not only distributed generation but also centralised generation at utility scale. The data shown by figure 4.7 is for the whole of Australia, and not exclusive to the NEM.

4.4.2 Distributed generation integration requirements in Australia

In order to integrate with any of the networks in Australia, generators must meet the requirements outlined in the National Electricity Rules developed by the Australian Energy Market Commission (AEMC). As in South Africa, compliance to the grid code is a requirement for connecting to the transmission or distribution system. In 2018, Australia developed connection guidelines for distributed generation, which provides the framework and main principles to be applied or adopted by network service providers that allow distributed generators to connect to their networks. Australia has categorised distributed generation based on the size of the generation facility. Integration requirements vary according to these categories. The categories are listed below with basic information for each.

4.4.3 Categories of embedded generation in Australia [74]

- *Basic micro EG connection:* Specifies the technical requirements for connection of a micro EG generating unit of up to 30 kVA three phase, or 10 kVA per phase to a distribution network.

- *Low voltage connection:* Specifies the technical requirements for connection of a generating unit (which is not a basic micro-EG generating unit) to a low voltage distribution network.

- *Medium voltage connection:* Specifies the technical requirements for connection of a generating unit (which is not a basic micro-EG generating unit) to a medium voltage distribution network.

- *High voltage connection:* Specifies the technical requirements for connection to a generating unit (which is not a basic micro-EG generating unit) to the high voltage distribution, for which the generator is not required to register with AEMO (typically less than 5 MW).

The framework also outlines the responsibilities of the network service providers and the responsibilities of customers.

4.4.4 Challenges and proposed solutions

To manage the integration of variable renewable energy sources into the grid, Australia has been implementing several strategies, as the retirement of traditional coal-fired power plants is occurring more quickly than expected.

The AEMO proposed a distributed energy resource (DER) programme in 2019. The DER programme aims to deliver a broad suite of work required to integrate distributed energy suppliers to maximise consumer value, as illustrated in Figure 4.8 below. This report contributes to the “Standards” and “Operations” streams shown in the fifth and sixth columns in the figure.

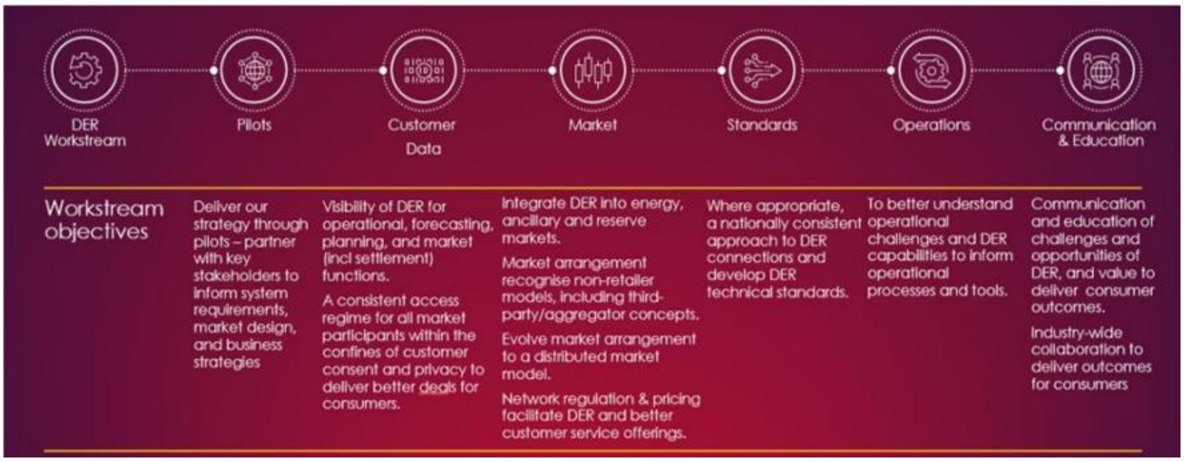


Figure 4.8: Australia’s distributed energy resources (DER) programme [75]

Table 4.7 below outlines the challenges that have been identified by Australia regarding the integration of renewable energy resources for both centralised and distributed energy resources. It also indicates proposed or implemented solutions for each challenge identified.

Table 4.7: DER challenges and proposed mitigation strategies in Australia *(data sourced from [76])*

Item	Challenge	Identified/implemented solution
1	The retirement of large coal-fired power plants is causing a lack of inertia, network support, and ancillary services, leading to increased system stabilization costs as the NEM transforms.	• The Energy Security Board has conducted extensive regulatory analysis for integrating renewable energy growth into the NEM. • The Australian Energy Market Commission (AEMC) proposed the introduction of five-minute settlement and new ancillary service market rules. • The government is focused on advancing electricity interconnections and reinforcing grids for reliable renewable energy integration.
2	The nature of the NEM is that it is "stringy", meaning that it is long; voltage drops over long distances and voltage control diminishes, requiring regular points of injection along the paths.	• The introduction of Renewable Energy Zones (REZs) and the development of an Integrated System Plan (ISP) aim to support the growth of renewable energy generation. The AEMO's ISP outlines coordinated plans for REZs, where the grid will be upgraded to accommodate more renewable power. In October 2021, the National Cabinet adopted REZ planning rules and an interim framework for addressing network planning challenges. The Electricity Security Board (ESB) has also proposed transmission access reforms and a Congestion Management Model to enhance investment certainty, reduce access risks, improve efficiency, and promote technologies that help alleviate congestion.
3	The need for sources of flexibility, the system requires flexibility through large-scale storage, interconnections, and peak generation. The AEMO must assess costs, availability, and maturity of necessary systems	• Execution of related grid expansion projects to strengthen grid interconnections to meet flexibility needs.

4	Insufficient operational reserves caused major incidents like the South Australia Blackout and the 2022 NEM energy crisis.	• The Australian government adjusted multiple ride-through requirements for renewables to address the lack of adequate operational reserves, which resulted in the South Australia Blackout and the NEM 2022 energy crisis.
5	The need to continually improve forecasting methods for variable renewables for efficient system operations and balancing of demand and supply.	• The sizing of operational reserves and the regulatory framework for balancing responsibilities and procurement has been modified in the NEM. This will assist with the issue of lack of additional reserves and forecasting challenges.
6	The need for continual assessment of the impacts of increasing distributed Solar PV on the power distribution network, as it affects grid stability.	• An implementation plan to improve the integration of distributed energy resources (DER). • To date, several rule changes have been implemented to support DER integration. They include backstop measures, such as remote disconnection of rooftop solar in emergencies, minimum technical standards to ensure that inverter-based DER can withstand voltage disturbances, and access and pricing reforms to make the system more cost-reflective. Investments were also made in digitalisation.
7	Substantial efforts are necessary at both transmission and distribution levels to accommodate small-scale technologies and decentralized generation, grid systems must be adapted with public engagement and long-term planning.	• Introduction of ambitious targets and increased funding for clean energy, investments in resilient grids to cope with climate change, and repurposing old coal plant sites for renewable energy projects.
8	There is now a need for new design standards and reinforcements along the grids to cater for this system that is no longer passive but dynamic.	• New market rules were introduced allowing distributors to charge for exporting electricity to the grid.
9	The evolving energy system has a significant impact on the market design and operations of the NEM.	• Enhancements to the AEMO's procedures to increase the transparency of generator availability and improve the range of information available to the AEMO on generator availability in the medium term.

10	New solar PV capacity has put pressure on the distribution system due rising self-consumption and exported power as hosting limits are exceeded/thermal limits [31].	• New market rules were introduced allowing distributors to charge for exporting electricity to the grid. • Australia has a Distributed Energy Resource Programme and register, whereby information regarding all the DER devices connected at residential and business locations is collected using a register for record purposes (https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program)
11	Demand uncertainty	• In 2018, the AEMC made a rule to establish a DER register. The register is up and running, falling under the standards value chain of the DER programme. This particular project aimed to address the issue of the predictability and visibility of DERs.
12	Network management (voltage fluctuations and balance, network losses, power quality, network protection and safety and fault management): In most cases, the risks require a situation-specific analysis. Risk mitigation strategies and implementation usually depend on the size and location of the embedded generation; the characteristics of the network configuration, environment and loading; and the existing level of penetration of embedded generation. The issues require networks to undertake robust connection assessments to ensure that connections do not risk safety, quality and reliability of supply.	• AEMO has a DER programme to address the technical and operational challenges that increasing amounts of distributed energy resources are having on the Australian energy system. AEMO has established the National Electricity Market (NEM) Distributed Energy Resources (DER) programme. • Australia also has a tool used by registrants to perform simulations of their models prior to submission in order to reduce the number of iterations to the system operator. This helps facilitate access and does away with unnecessary delays or project redundancy.
13	Lack of predictability and visibility of DERs makes it difficult for electricity system planning and forecasting	• In 2018, AEMC made a rule to establish a DER register. The register is up and running, falling under the standards value chain of the DER programme. This project aimed to address the issue of predictability and visibility of DERs.

4.4.5 Summary

The uptake of embedded generation in Australia is mainly driven by the country's commitment to clean energy targets. The country incentivises distributed energy resources, particularly those derived from renewable energy resources. In most cases, the technical impact of embedded generation on the network and the way in which it is managed in terms of voltage regulation, network losses, power quality, network protection and safety and fault management require situation-specific analysis. The risk mitigation strategies and implementation usually depend on the size and location of the embedded generation, the characteristics of the network configuration, environment and loading, and the existing level of penetration of embedded generation. The many issues raised by the addition of DER require networks to undertake robust connection assessments to ensure that connections do not risk safety, quality and reliability of supply. Solutions introduced in Australia to deal with predictability and visibility of DERs include the DER register, and solutions introduced to deal with inertia challenges include the enactment of strict performance standards.

4.5 Distributed generation in Uganda

Uganda introduced two policies in 2007 to facilitate investment in renewable energy generation and the uptake of renewables by consumers. At the time of the writing of this dissertation (2023), all distributed generation in Uganda was from renewable energy sources. These are typically small hydro, largely dictated by the geographical location of rivers; solar, near load centres and substations; and biomass (bagasse), these are all co-generation plants. All the distributed generation plants are connected to the 33 kV distribution network.

4.5.1 Impact of embedded generation on the Ugandan distribution network

Uganda has very low levels of distributed generation penetration; therefore, the impact of embedded generation on the distribution networks is not yet evident or is minimal. This is understandable, given the fact that the country in general has a low electricity penetration level. The impact on the distribution networks is expected to be like that of the other countries under investigation because Uganda also has a predominantly radial network, designed to transport electricity from centralised power generation facilities through the transmission network to the load centres [49].

4.5.2 A review of embedded generation in Uganda

In terms of the right of access, distributors are mandated to provide non-discriminatory access and connect licensed renewable energy embedded generation plants to the grid in their areas of supply [1] [76].

Uganda currently has embedded generation in the form of four co-generators licensed to generate for own use and to sell excess electricity to the grid [41]. The country also has a few off-grid systems supplying customers in remote areas who lack access to the national grid. By the end of 2022, the number of off-grid systems was thirteen, with a total capacity of approximately 14 MW. The technologies they employ are varied, and include small hydro, biomass, thermal, diesel, solar PV, and others [41]. The 65.8 MW solar PV capacity highlighted in Section 3.5.1 is made up of utility-scale solar PV plants.

4.5.3 Impact on human resources/planning

Capacity building for purposes of empowering staff is one of the most important first steps towards successful deployment and management of renewable energy sources embedded generation [77]. Distributors in Uganda are also aware of the great need to equip staff to handle different technologies for power generation at distribution level. This will be followed by exploits in different renewable energy sources covering solar, geothermal, wind, and possibly nuclear.

4.6 Chapter summary

The electricity industries in South Africa, Brazil, Australia and Uganda are undergoing a transformation from a centralised system of generation, transmission and distribution, monopolised by one or a few players, to a system of increasing decentralisation. The transformation is largely driven by decarbonisation goals in Brazil and Australia, and lack of adequate generation capacity to meet demand in South Africa and a lack of adequate network infrastructure to increase electricity access in Uganda. This change is allowing more players, including retail customers, to connect to and take part in current and new energy markets. As a result, utilities are shifting from just providing network services with one-way power flow to connection providers, enabling two-way power flow between multiple embedded generators and load.

The rate of distributed generation uptake and the transformation of the various network businesses differ among networks as a result of the varying penetration levels of distributed generation resources and varying network characteristics. Each network responds to challenges differently, resulting in a range of technical requirements and connection processes on the part of distributors. Although these requirements are consistent with the duties of distributors, there have been inconsistencies among networks and a lack of clarity for customers. These issues can be addressed through the introduction of clear national guidelines for connections, such as the guidelines and technical requirements produced by Energy Networks in Australia [74]. These ensure a uniform and standardised way of dealing with distributed generation and avoid confusion in the electricity distribution sector. The objective of such guidelines is to facilitate the fair and efficient integration of DER into the grid from the perspective of both the utility and its customers.

Table 4.8 below presents a summary of the different policy documents, regulatory frameworks and pieces of legislation for embedded generation in each country reviewed in this chapter.

The contents of some of these critical documents are covered in detail in the following chapter.

Table 4.8: Legislation, policies and regulatory frameworks for DER per country

Country	Distributed generation capacity (2022/2023)	Enabling law or regulatory frameworks	Reason behind the accelerated uptake
South Africa	4.7 GW [52]	Amendment of Schedule 2 of the ERA, NERSA's SSEG Draft Rules, RPP Code, IRP 2019, NRS 097	Capacity shortages (load shedding)/ Increasing electricity prices Clean energy targets
Brazil	19 GW [70]	REN 482/2012,2015,2022 Federal Law No. 14,300, of 6 January 2022	Clean energy targets Incentives
Australia	17 GW [72]	National Electricity Rules Australia Electricity Act 1994	Clean energy targets Incentives
Uganda	*68.4 MW [43]	Renewable Energy Policy (2007), Electricity Act of 1999, Electricity (Primary Grid Code) Regulations of Uganda, 2003	Electricity access goals/ electrification targets REFIT Programme GET FIT Programme
* Uganda only has utility scale renewable energy generation			

CHAPTER 5: LEGISLATION, POLICIES AND REGULATIONS

5.1 Introduction

The previous chapter focused mainly on the numbers of embedded generation that have been added to the system in each country of interest since the implementation of changes in legislation and regulations. These changes were designed to drive diversity in the energy mix and address capacity shortages in each country. The chapter dealt with the changes in legislation and regulations briefly. This chapter provides a detailed review of the enabling legislation, policies and regulations put in place in each country to facilitate the uptake of embedded generation. The review seeks to highlight the changes that contributed to the success of embedded generation uptake, those that did not achieve the stated aims, and the nature of any other changes introduced to manage those aspects that were initially deemed unsuccessful.

5.2 South Africa: Enabling legislation, policies and regulations

The Department of Mineral Resources and Energy (DMRE) is the policy maker for the mining and energy sector of South Africa. Its mandate is to create an enabling environment for investments in these sectors. The National Energy Regulator of South Africa (NERSA) implements national policy, such as the 2019 Integrated Resource Plan (IRP) and the Electricity Pricing Policy (EPP). Both policy documents are derived from the Electricity Regulation Act. Once gazetted, IRP 2019 became a policy document for NERSA to implement by concurring to the procurement of new generation capacity through Section 34 determinations issued by the minister of mineral resources and energy in accordance with section 34 of the Electricity Regulation Act, and subsequently to licence new generation facilities and monitor their compliance with licensing conditions, in order to satisfy the objects of the Electricity Regulation Act. Similarly, NERSA has implemented the EPP by coming up with methodologies for the economic regulation of the electricity sector. It determines electricity pricing and tariffs.

5.2.1 Enabling legislation for embedded generation

Prior to November 2017, all generators were required to hold a licence for the ownership and operation of a generation facility, except in the following cases:

- A generation facility constructed and operated for demonstration purposes.
- A generation facility constructed and operated for own use.
- A non-grid-tied generation facility, except in the case of commercial use, which still required a licence.

In November 2017, through Government Gazette no. 41237, the DMRE amended Schedule 2 of the Act. An amendment was made to the above exemptions, to allow grid-tied generators with an installed capacity of up to 1 MW supplying one or more customers to operate without a licence. These entities still needed to register with NERSA and comply with the code.

A further amendment was made in August 2021, through Government Gazette no. 45266, when the exemption from licensing was increased to 100 MW. As before, these entities still needed to register with NERSA and comply with the code. In January 2023, Schedule 2 was amended again, through Government Gazette no. 47877. Generation facilities with or without storage, irrespective of size, with a point of connection operated to supply electricity to one or more customers through wheeling, and those not intending to import or export electricity, were now exempt from the requirement to hold a licence, but still had register with NERSA and comply with the code.

These changes in legislation were enacted in order to facilitate the uptake of private generation in South Africa, particularly from renewable energy sources, to assist with the capacity shortages the country faces and also to facilitate investment in private generation. The requirement to hold a generation licence by private entities that are not part of any of the national procurement programme was considered onerous and a major barrier to connecting new generation capacity on the grid. Pursuant to these amendments, NERSA amended the registration procedure by reducing the timelines for registration from 60 days to 45 days.

5.2.2 Regulatory tools and frameworks

Embedded generation rules

There are currently no NERSA-approved rules that guide and govern embedded generation (small or large), except those prescribed in the NERSA codes. However, a series of specifications, such as the NRS 097 series, cover technical requirements, some of which are derived from the codes. The NRS 097-2-3 specification prides a simplified connection criteria for smaller generators (<100 kW). Most utilities or network service providers have mandatory interconnection rules derived from the NERSA codes, the NRS series, and other international best practice standards.

In 2011, NERSA approved the document *Standard Conditions for Embedded Generation within Municipal Boundaries*, according to which embedded generators of up to 100 kW may be registered by municipalities and sell power to them. This left projects of between 100 kW and 1 MW with no legal framework for implementation. It was therefore proposed that NERSA develop rules for small-scale embedded generators (i.e., generators up to 1 MW). In 2015, NERSA drafted the regulatory rules to manage the connection of these generators, with the intention of introducing standardised tariff schemes for the generators that would be exporting excess electricity to the grid. Since the drafting took place prior to the amendment of Schedule 2 in 2017, these generators were not expected to have a licence or to register with the regulator because they were for own use. NERSA consulted on the rules but did not publish them because these entities were neither licenced nor registered; therefore, they were outside of NERSA's jurisdiction. NERSA indicated that it would wait for the amendment of Schedule 2 by the DMRE, which would provide the necessary policy framework within which small-scale embedded generation regulatory rules would be formulated by NERSA and applied.

The new regulations were first published in 2017, as indicated in Section 5.1.1 above. However, to date, the rules have not been published by NERSA and were subsequently overtaken by events, as the limit for private embedded generation was removed completely in January 2023. The rules were specifically for small-scale embedded generation of up to 1 MW; now there is no longer such a limit.

Grid codes

The renewable energy power plant grid code (the RPP code) is a regulatory tool published by NERSA to facilitate the connection of renewable energy sources. It was first published in 2014, with the aim of facilitating connection of renewable energy power plants and investment in private generation. The primary objective of the RPP code is to specify minimum technical and design grid connection requirements for generators and loads connected to or seeking connection to the South African electricity transmission system or distribution system. The code is enforced through the licensing requirements of network service providers and the registration of other participants.

In the preamble part of the code, embedded generation is defined as any form of generation embedded or connected to the distribution system. In South Africa, the distribution system or network is defined as any network with system voltages of up to 132 kV. Embedded generators connecting to any of the South African networks are expected to comply with the codes, as stipulated in Schedule 2 of the Act.

Technical and regulatory requirements for connecting any form of generation onto the distribution networks are outlined in the codes, national standards and utility-specific standards. In the codes, generators are categorised based on size, technology, connection voltage and sometimes even location on the network. The applicability of the requirements is according to the categories. There are no specified limits in terms of the number of generators that may be connected, their sizes, technology, voltage level, or point of connection. The limits are determined by the network condition/configuration at the point where the generator is to connect.

The technical requirements specified in the codes/standards are meant to ensure that there is orderly development, and safe and efficient operation of the power system. They are also meant to ensure that the interests of current and future customers are safeguarded.

Depending on their sizes, technology, voltage level and point of connection, generators are required to provide grid support to ensure system stability. Requirements for grid support include, but are not limited to:

- reactive power control capability
- active power control capability
- voltage control.

Some of these requirements have led to complaints from the industry that the codes are too stringent, preventing private generators from gaining access to distribution and transmission networks. The challenge for the NERSA is to balance facilitation of entry with the need to protect and maintain the integrity of the network.

Some of the challenges are associated with the fact that the codes were drafted with the idea that generators would be injecting all power produced on to the grid. With distributed generation involving generation for own consumption as well, some stakeholders are of the view that some of the requirements are not necessary for generation facilities that are not exporting power on to the grid. Therefore, there is a need for NERSA to review the codes and amend them so that they cater for three scenarios of embedded generation: generating for own use (zero export), generating for own use and exporting excess power on to the grid, and generating specifically for injection on to the grid.

Feed-in tariffs, net metering or net billing regulations

Together with about 35 municipalities across South Africa, Eskom has introduced rules and regulations to allow small scale embedded generators (SSEG) to connect to their networks and feed excess electricity back on to the grid. Eskom and some of the municipalities have NERSA-approved tariffs in place that they use to credit customers who feed power back on to the grid. In 2021, NERSA made a decision to desist from approving new applications for SSEG tariffs, because, according to the Electricity Regulation Act, its mandate to approve tariffs is limited to licensed entities and does apply for registered entities.

In February 2023, because of the energy crisis being faced by the country, the President of South Africa, Cyril Ramaphosa, established the National Energy Crisis Committee (NECOM), mandated to implement an energy action plan in order to end load shedding. The net billing scheme was one of the mechanisms identified by NECOM to encourage customers to install private generation and export excess energy on to the grid, and thus reduce load shedding.

On 5 April 2023, NERSA developed draft net billing rules and published them on its website to solicit input from industry stakeholders. The rules would assist in standardising the compensation mechanisms applied by distributors for energy exported on to the grid, as currently some utilities are allowing customers to export to the grid at a tariff approved by the regulator, while others are not allowing it and do not have approved rates for exported energy. NERSA consulted stakeholders on the net billing rules; however, the rules have not been promulgated. NERSA developed the net billing rules in accordance with the Disaster Management Act regulations, the regulations were promulgated in February 2023 and subsequently terminated in April 2023. At the time of the research study, South Africa does not have an approved national compensation scheme for distributors.

IRP 2019

As indicated in Section 4.2.4, IRP 2019 is a policy document by the DMRE that contains the country's plans regarding new generation, detailing the country's expected generation and demand patterns up to 2030. Embedded generation forms part of the capacity allocated under the column "other" of Table 4.5, i.e., distributed generation plus co-generation. Capacity under the category "other" includes both utility-scale generators and generators producing for own use or to wheel to other customers. Prior to the amendment of Schedule 2 in 2021, the capacity under this column needed a Section 34 determination to be procured, or exemption by the Minister of Mineral Resources and Energy. With the removal of the capacity limit for private generators, there is no need for private generators to obtain the minister's approval for this capacity.

5.2.4 Electricity pricing policy requirements

The electricity pricing policy aims to regulate electricity pricing in South Africa. It further guides NERSA in regulating the implementation of the Electricity Regulation Act of 2006 and clarifies applicable policy positions [78].

The removal of the licence requirement has ushered in several challenges to the regulator. Its role as far as registrants are concerned is no longer clear; according to the ERA, NERSA's role and mandate in regulating prices and tariffs is limited to licensed entities. The energy regulator is currently not approving tariffs for embedded generation involved in bilateral agreements or wheeling.

Municipalities face a number of challenges, too. One is the need to obtain approval by National Treasury (NT) and to go through a tendering process before any procurement of services may take place. Privately registered generators connected to the municipal network who wish to sell excess power to the municipalities also find it difficult to do so without an approved tariff, due to bylaws such as the Public Finance Management Act (PFMA) and Municipal Finance Management Act (MFMA). The PFMA applies to the national and provincial spheres of government, and the MFMA applies to the local sphere of government.

5.3 Brazil: Embedded generation in legislation, policies and regulations

As in South Africa, Brazil's Ministry of Mines and Energy (MME) is the government entity responsible for formulating public policies in the mining and energy sector in Brazil. The Brazilian Electricity Regulatory Agency, ANEEL, is the regulatory agency, created by Law no. 9,427/1996, and responsible for implementing policies and guidelines developed by the MME. Based on the national policy and guidelines outlined by the MME, the agency develops rules and regulations that it uses to regulate the activities of the industry, i.e., generation, transmission, distribution and trading activities. The agency is responsible for granting concessions and authorisations for listed activities. The type of regulatory licence required (concession, authorisation or communication) depends on the plant's installed capacity, technology, and size of reservoir (for hydropower plants).

As indicated in Section 4.3.3 of this study, embedded generators of up to 5 MW do not need a concession or authorisation; they need only a communication to and from the agency. However, any embedded generator providing greater than 5 MW needs either a concession or authorisation from the agency, depending on the size and energy source technology.

5.3.1 Enabling legislation for embedded generation

Section 4.3.2 of this study lists and discusses in sufficient detail the legislation that has been used in Brazil to facilitate the uptake of embedded generation, Normative Resolution 482/2012 and its subsequent revisions outline general connection conditions for small-scale embedded generation of up to 5 MW and also introduce the net-metering scheme. Recent developments were introduced through Federal Law no. 14,300, enacted on 6 January 2022, which establishes a special legal regime for small-distributed generators in national law and proposes a move away from the net metering scheme to a net billing scheme [64].

5.3.2 Changes to regulations and policies to manage impact

The evolution of the distributed energy sector is being led by Brazil's energy regulator, ANEEL. It has clear rules for distributed generation and a clear framework on the requirements for participation. The success of renewable energy and distributed energy resources is largely dependent on regulatory changes that support the integration of these resources. Over a decade ago, Brazil introduced net metering as an incentive for self-generation [79]. ANEEL also introduced Resolution 482/2012 to give energy credits to all customers with generation facilities of up to 5 MW, applicable only to renewable energy projects. The incentive is meant to help the country with its reduction of greenhouse gas emissions and the attainment of its climate change goals.

5.3.3 Feed-in tariffs, net metering and net billing schemes

According to the net metering scheme currently in operation (but soon to be replaced by the net billing regime according Federal Law no. 14,300), if the energy produced exceeds the amount consumed in a certain month, the consumer obtains a credit that must be used within five years. Under this incentive scheme, customers are given permission to use the system/network as a battery storage system for a period of five years, a system also referred to as energy banking. PV systems below 5 MW will be eligible for net metering until 2045, and a grid fee for prosumers is required as of 2023.

To date, Brazilian rules have allowed for the offsetting of energy credits from distributed energy resources. With the new rules, the net billing regime will ensure that compensation is given based on the cost of supply. With the publication of the new law, prosumers will have a new tariff system. The transitional period for the new system for existing customers will last until 2045 and will apply to all who seek access within 12 months of publication of the new law. New customers who file for access after 12 months of the publication will be subject to the new rules. Incentives or benefits of the new system are determined by the National Energy Policy Council; however, the necessary regulatory changes and rules to enable policy are determined by the regulator agency, ANEEL [80]. Generators of more than 5 MW who wish to sell energy back to the grid must be authorised by ANEEL and trade in the market.

5.4 Australia: Embedded generation in legislation, policies and regulations

5.4.1 The national electricity market (NEM)

The national electricity market (NEM) is operated and regulated by three institutional bodies: the Australian Electricity Market Operator (AEMO), the Australian Energy Market Commission (AEMC) and the Australian Energy Regulator (AER). The three institutions work collaboratively to support efficient investment in and operation of the Australian electricity system. A fourth institutional body was introduced in 2017: the Energy Security Board (ESB). Its main focus is energy security matters. It drives market design discussions in Australia, working collaboratively with the AEMC, the AER and the AEMO.

5.4.2 The Australian Electricity Market Operator (AEMC)

The main functions and powers of the Australian Electricity Market Operator (AEMC) are rulemaking functions and powers, as prescribed under the National Electricity Law. The AEMC is also responsible for the establishment of a reliability panel, which has responsibility for monitoring, reviewing and reporting on the safety, security and reliability of the national electricity system.

5.4.3 The Australian Energy Regulator (AER)

The Australian Energy Regulator (AER) was established under the Competition and Consumer Act 2010 [62]. Its functions and powers are regulatory in nature, and include:

- Monitoring compliance with the national electricity laws and rules and instituting and conducting proceedings.
- Making and monitoring compliance with network revenue or pricing determinations.
- Regulating retail electricity markets under the NECF.

Chapter 6 of the National Electricity Rules for connection types and processes (made by the AEMC) sets out the regulatory framework for the AER to apply in the economic regulation of transmission and distribution network service providers. The AER also has the responsibility for network price regulation and oversight of network access in the Northern Territory, which does not fall within the National electricity market (NEM).

5.4.4 The Australian Energy Market Operator (AEMO)

The statutory functions of the Australian Energy Market Operator (AEMO) involve, primarily: the operation and administration of the wholesale exchange in the NEM; maintaining and improving power system security; planning for the development of the transmission grid; and providing “shared transmission services” using each participating jurisdiction’s transmission system.

5.4.5 Changes to regulations or policies to facilitate the uptake of DERs

In Australia, the deployment of embedded generation, particularly from renewable energy sources, is driven by states’ and territories’ targets, auction programmes, reverse auction programmes, and feed-in programmes. The overarching goal is to meet decarbonisation targets. The Commonwealth renewable energy target scheme and its renewable energy portfolio standard are the main national scheme for supporting the deployment of renewable energy to meet the country’s decarbonisation commitment to reduce GHG emissions by 43% by 2030.

In 2014, the National Electricity Rules were amended to accommodate the effective and efficient deployment of embedded generation. The main objective of the amendment was to reduce any barriers to connecting embedded generation to distribution networks, as identified by the proponents.

Proponents suggested that the AEMC should amend the rules to include:

- A more transparent connection process with defined timeframes.
- The introduction of a technical standard for embedded generators.
- Exemption for embedded generators from the requirement to pay shared network augmentation costs.
- Automatic access for embedded generators.
- The right of embedded generators to export electricity to the distribution network.
- Permission for network service providers to charge a fee-for-service to provide services to embedded generation proponents at the project development stage.

The final draft rule [81], as published by the AEMC, included the following:

- An amended connection process, including more prescriptive timeframes for generators of 10 kW to 30 MW.
- An obligation on distribution network service providers (DNSPs) to create a public register of completed projects. This register will include details about the generating plants and associated equipment connected to the DNSP’s network over the past five years and will be updated annually.The register aims to offer potential connection applicants current information about the types of generating plants and their connection configurations on the DNSP's network.
- DNSPs are also required to publish an annual distribution planning report. These reports must detail any factors that could significantly affect the network, such as fault levels, voltage levels, and the quality of supply to other users.
- The stipulation that costs of network augmentation due to embedded generation connection should be borne by the primary beneficiary of the augmentation, who, with the DNSP, is best placed to manage them.

The publication stated that if consumers were left bearing the augmentation costs associated with an embedded generator's automatic right to export electricity, the rule would be unlikely to lead to efficient investment in the distribution network or embedded generation, or be in the long-term interests of consumers [81].

Generators with a nameplate rating of less than 5 MW are exempt from registering with the commission, while generators with a nameplate rating of 5 MW and above are expected to register with the commission. The technical requirements did not initially apply to generators that are exempt, but an amendment of the NER included the requirement that these generators also comply. Technical requirements for generators of 5 MW or less were previously determined by DNSPs, based on network and jurisdictional requirements. This made matters difficult because there was no standard set of requirements [67].

5.5 Uganda: Embedded generation in legislation, policies and regulations

As in South Africa, Uganda’s Ministry of Energy and Mineral Development (MEMD) is the policy maker for the country’s electricity sector, responsible for initiating legislation and for policy formulation, promotion, coordination, monitoring and evaluation. MEMD’s mandate is the establishment and promotion of the development of energy and mineral resources for social and economic development. The MEMD and the Electricity Regulatory Authority (ERA) work together to create an enabling environment in order to attract investment in the energy sector, particularly in renewable energy resources. As the regulating authority, the ERA is accountable to the MEMD.

ERA is Uganda's electricity regulatory authority, having an overall supervisory role in the industry. It regulates electricity generation, transmission, distribution, retail, import, and export of electricity and is mandated by the Electricity Act, 1999, to issue licences with licence conditions for these activities. As with all energy regulators, the ERA is also responsible for economic regulation in the electricity sector through the establishment of tariff structures, approval of rates and charges, and the promotion of fair competition in the liberalised market [49].

Uganda introduced the Renewable Energy Policy in 2007 to facilitate investment in renewable energy generation and the uptake of renewables by consumers. Under this policy, a renewable energy feed-in tariff (REFIT) to facilitate the uptake of embedded generation from renewable energy resources was introduced. Subsequent to the introduction of the REFIT programme, the GET FIT (Global Energy Transfer Feed in Tariff) programme was introduced, which is a grant based premium payment paid as a top up on the initial REFIT. In 2023, all distributed generation in Uganda is from renewable energy sources.

Through the Amendment of the Electricity Act of 2022, the structure of the industry was changed from a single buyer model to one characterised by an open relationship between generators, transmission operators, distributors and customers [82]. The Electricity Regulatory Authority is currently formulating regulations to operationalise the new industry structure while protecting the underlying economic fundamentals of existing contracts in the Ugandan electricity supply industry [82].

5.6 Chapter summary

According to Maestri and Andrade [21], any study of the impacts of embedded generation diffusion on distributors and their networks requires an analysis of the basic regulatory framework of the country's current electricity sector. The review conducted in this chapter follows this guideline. An understanding of the regulations in each investigated country is essential to an understanding of what works and what does not work in the rollout of embedded generation and offers clues as to what may be needed in South Africa.

The changes introduced through regulations or policy determine the effect of embedded generation on distributors and their networks. This impact may be positive or negative, depending on a number of technical, economic and regulatory aspects.

The review has shown that the main driver of policy change in Brazil and Australia for the acceleration of embedded generation, particularly from renewable energy sources, is the need to meet climate change goals. Hence, most of the changes, especially incentives, explicitly apply to embedded generation from renewable sources. In some cases, the changes are introduced for a specified period until the targets are met. They are then re-evaluated.

South Africa's drive to remove barriers to access are primarily driven by the need to add new generation capacity to close the energy gap and unlock investment in private generation. South Africa is also working towards reducing GHG emissions in order to meet its climate change goals; however, addressing capacity shortages is currently a more pressing need. That is why, in the changes made to incentivise private generation, there is no requirement that the capacity be generated from renewable energy sources.

Similarly, Uganda's policy changes for accelerating the uptake of embedded generation are mainly driven by the need to increase the country's installed capacity. In Uganda, the electricity access rate is still very low, especially in rural areas, where the load is far from where power is generated, and populations are sparse, which raises the costs of connection. It is envisaged that the introduction of embedded generators will assist in addressing this problem, because embedded generators are usually located close to the point of consumption. Unfortunately, there is insufficient information from Uganda to compare Uganda and South Africa's initiatives to facilitate the uptake of embedded generation. The only verifiable fact is that Uganda introduced two policies in 2007 to facilitate investment in renewable energy generation and the uptake of renewables by consumers, as stated in Section 5.5. One noteworthy programme being implemented is the REFIT programme.

CHAPTER 6: THE ECONOMIC IMPACTS OF EMBEDDED GENERATION

6.1 Introduction

Chapter Five described the ways in which each investigated country is facilitating the uptake of embedded generation while ensuring that it is not disruptive. The main goals of the changes made in legislation were to ensure that the interests of customers, service providers and investors are catered for, to meet net zero carbon emission targets, and to facilitate investment in private generation. This chapter focuses on measures put in place to ensure the sustainability of service providers, good business cases for investors, and benefits for customers. It highlights the idea that it is important to ensure that the uptake of embedded generators does not negatively affect customers who do not benefit from embedded generation. It is also important to ensure that service providers are able to sustain their operations, and that there is a good business case for investors. Thus, the economic perspective on embedded generation is multifaceted. Below, economic aspects are examined in relation to each country.

6.2 South Africa

In South Africa, there is general concern among utilities/distributors that a high penetration of embedded generation will affect their revenue as a result of reduced sales. While this may turn out to be true, distributors will nonetheless benefit from a reduction in the need for bulk energy purchases, which could potentially cancel the effect on revenue. Currently, South Africa does not have an approved national framework for net billing/net metering or feed-in tariffs. Only the public utility Eskom and a few municipalities have implemented mechanisms to offset the bill for customers through an export tariff approved by NERSA. Therefore, there is no real incentive for private generators to install embedded generation, except for those serviced by distributors who have NERSA-approved export tariffs. The only incentives for those not licensed to participate in the national procurement scheme to install embedded generation are:

- Reduction of the electricity bill.
- Continuity of supply during load shedding for those who couple their generation with storage.

Because of persistent supply constraints resulting in load shedding, the country has established an emergency committee, NECOM, to deal with the energy crisis [83]. NECOM's top five priorities include facilitating private sector to investment in new energy sources, fast-tracking the addition of new power from wind, solar, gas and battery storage and encouraging people to install solar PV on their homes and businesses [83]. The committee established nine workstreams that focuses on several initiatives to meet its top five priorities. The workstream that is most applicable to this study is workstream number three which focuses on measures to ensure private investment in new generation capacity as well as to facilitate commercial and residential installations of small-scale embedded generation which includes the implementation of a national compensation scheme and introduction of tax incentives for SSEGs [84]. The proposed compensation framework is for a net billing scheme to incentivise customers who feed energy on to the grid. Most importantly, the framework will ensure that there is standardisation among distributors in terms of how energy exported to the grid is compensated and will ensure that all distributors offer this option to their customers. However, a compensation scheme will only be an incentive to customers if their energy is credited at a retail rate (net metering) and not in terms of wholesale/avoided cost (net billing). In order for a compensation scheme that credits customers at the retail rate to work, there needs to be funding from the government to cover any shortfall on the utility side so that utilities/licensees remain sustainable. This is because net metering tends to favour customers at the expense of utilities/licensees.

6.2.1 Socialisation of costs incurred due to embedded generation

A concern among customers who do not own private generation and distributors is that with the decrease in sales due to private generation, the distributors will not be able to fully recover costs of making supply available whenever it is needed by customers with own generation. In South Africa, most customers with embedded generation are small power users whose tariffs are not unbundled. There is therefore a risk that customers with their own generation will not contribute fully to the distributors' fixed costs when some fixed costs are bundled with energy charges. The concern is a valid one; the implication is that this cost will be borne by customers without embedded generation. There is a need for the tariffs of all customer categories to be fully unbundled to reflect both the fixed and variable costs as separate charges, to ensure that the utility properly recovers the cost of providing the service to all customers. They need to prevent a situation where customers without private generation subsidise those with private generation.

Most distributors that allow energy exports have an alternative tariff for customers who install private generation. This is fully unbundled to reflect fixed costs. However, this notion has not been received positively by customers wishing to install private generation. They submit that the fixed charges were introduced to penalise customers with own generation. However, the need for fully unbundled tariffs is a critical step that needs to be undertaken, whether or not customers install private generation. There is a general need for all groups of customers to understand the costs associated with the electricity service they receive and for service providers to properly recover costs for providing their service.

6.2.2 Embedded generation tariff structure

The structure of the tariff that most distributors use for customers with embedded generation is as follows:

Prosumer Tariff = Fixed Costs + Energy rate kWh consumed – Credit rate* kWh exported*

Credit rate: This rate may be based on the retail rate for the net metering scheme or on avoided costs for the net billing scheme.

There is also a requirement by some distributors that customers with embedded generation that are not on a time-of-use tariff move to time-of-use tariffs. Most customer categories in South Africa already have an unbundled tariff, except for most residential customers, for whom fixed costs are bundled with the energy rate. Hence there is the requirement that these customers be moved to an alternative tariff.

6.2.3 Deferred infrastructure upgrades resulting in savings for the utility

Savings on infrastructure developments will depend on the issue of grid parity. South Africa does not yet have significant numbers of embedded generators to be able to see infrastructure upgrades being deferred and resulting in savings for the utility. For embedded generation (from renewable energy sources) to result in savings for the utility, it needs to be coupled with storage to help reduce peak demand. As seen in Section 4.1.3 and Table 4.3, most electricity resources coming online are from solar PV. Owing to the duck curve effect, they do not assist with peak demand if they are not coupled with storage. The country does not have enough resources yet to reduce peak demand in such a way that new energy generators result in deferment of infrastructure development.

Currently, a big issue in South Africa is that of grid capacity allocations. The transmission grid is constrained, especially in the Northern, Eastern and Western Cape provinces. These are the regions with a high concentration of renewable resources in terms of solar and wind, with most of the utility-scale power plants participating in the national procurement programmes situated in these regions. The challenge is that with the removal of the licensing requirement for private generation, embedded generation projects move at a faster rate than that of power plants participating in national procurement programmes. By the time plants in the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) are ready to go to budget quotation stage, the capacity that was available on the grid is no longer available, as it has been allocated to private generators.

In light of this difficulty, Eskom recently reviewed its rules for grid capacity allocation. One of the proposed amendments to the rules is that utility-scale power plants participating in the national procurement programme be given priority over private generation [58]. Another major amendment is that grid capacity will be allocated based on a “first ready, first served” principle and not on the principle of “first come, first served”, as in the past [58]. The main point of contention from industry participants is that a big upfront financial commitment is required to get to project readiness stage, which is disadvantageous if, at the time of readiness to connect, they are notified that there is no capacity on the grid to do so.

6.2.4 Summary

The economic effects of embedded generation at distribution level for South Africa concern the effect these facilities have on utility revenues, customers without embedded generation, and public and private procurement programmes. These aspects will need attention before embedded generation can be deemed economically viable.

6.3 Brazil

According to Bradshaw [85], distributed generation and its pricing in Brazil still requires alignment between the interests of distributors and the interests of consumers. The regulatory agency of the electricity sector is responsible for such an alignment. The aim of Normative Resolution 482/2012 issued by the Brazilian National Electricity Regulation Agency was to regulate the access and compensation of energy produced by small-scale embedded generators distributing to the electricity system. The resolution states that compensation for these facilities will be through a net metering scheme [21].

As highlighted under Section 6.2 on South Africa, with net metering, prosumers are compensated for their excess energy by the utility at retail value, although the scheme does not deal with monetary compensation, but energy credits. For every kilowatt hour injected into the grid by the prosumer, they are able to draw this energy from the grid at a later time within a certain time period. With net billing, on the other hand, the energy is compensated not at its retail value but at its wholesale value (also known as purchase costs or avoided costs). Net metering incentivises customers to opt for own generation, while net billing does not really offer any added incentive except for the fact that energy produced does not go to waste, since it can be banked through the grid. According to Heideier, et al [86], the increase in distributed generation in Brazil especially from photovoltaic technologies has both positive and negative effects. The positive effects pertain to electricity tariffs, tax collection, reduction in emission of greenhouse gases, tax relief and job creation.

As in South Africa, Brazilian electricity distributors are inserted in the natural monopoly market and are highly regulated. With the growth of distributed generation, there is also the issue of the economic and financial burden that prosumers may cause to other energy consumers [61]. Until January 2023, the electricity distributor experienced two types of revenue reduction; one through the compensation mechanism for distributed generation through net metering, and the other through the reduction in energy consumption itself, since prosumers are producing their own electricity.

Because of this, the Brazilian government enacted a new law changing the compensation scheme from net metering to net billing. Federal Law No. 14,300 of 6 January 2022 introduces net billing, which is more favourable to utilities, as it ensures that energy is compensated for based on cost of supply or avoided costs. This supports the notion posited by Maestri and Andrade [21] that "the regulation of the energy distribution sector may allow for periodic and exceptional tariff adjustments to re-establish the distributors' economic and financial equilibrium, which could compromise the reasonableness of tariffs for other energy consumers".

Customers in the regulated market without own generation are concerned about being proportionally more responsible for certain charges and maintenance costs of the distribution and transmission grid. The distributor has observed a reduction in the distribution market in recent years, since, with distributed generation, the distributor sells less electricity to prosumers [64]. With the reduction in electricity sales, there is a risk that customers who own private generation will evade a certain portion of the distributor's fixed costs. This tends to happen if the tariffs for this category of customers are not fully unbundled to reflect both the fixed and variable costs as separate charges.

To facilitate the uptake of embedded generation from renewable energy sources, Brazil introduced net metering in 2012 as a compensation scheme for energy exported to the grid by distributed generators. However, this was at the expense of utilities and customers who did not have embedded generation [61]. Now that distributed generation has reached desired targets and even exceeded expectations, Brazil has evaluated its initial decision and realised that most utilities are suffering under the net metering scheme. Through a new law, prosumers will no longer be compensated based on the net metering scheme but under the net billing scheme, which will reduce the negative effect on utilities. A clear plan and timelines for the transition have been put in place to give effect to this new law.

6.4 Australia

Australia's energy networks are natural monopolies subject to strict economic regulation. Under the national electricity laws, the Australian Energy Market Commission devised a set of "National Electricity Rules" that are used to govern the energy networks. The revenue most energy networks are allowed to earn (and therefore the prices they charge) is governed by the Australian Energy Regulator and is revised every five years [33].

6.4.1 Network connection and expansion costs

The AEMC recently amended the NER, as part of its stakeholder participation process, some stakeholders were proposing that embedded generators be exempt from paying shared network costs.

The draft rule published by the commission [81] makes the following points:

- *[It] clarifies that DNSPs may charge an enquiry fee that is no more than necessary to recover the reasonable costs of all work anticipated to arise from investigating and responding to a request to connect, or for a detailed enquiry response;*
- *[It] does not exempt embedded generators from paying for shared network expansion costs;*
- *[It] obliges DNSPs to provide an itemised statement of connection costs in its detailed enquiry response and offer to connect.*

The AEMC's draft rule determination states that exempting embedded generators from paying shared network expansion costs would result in other network users covering these costs, creating a cross-subsidy. This would not give proper cost-reflective price signals for a connection applicant. The allocation of costs to the party that benefits from the expenditure is likely to provide appropriate price signals, according to the commission. This will encourage generators to choose the location for their facilities efficiently and wisely.

6.4.2 The impact on electricity prices

As indicated in the preceding sections, Australia has one of the highest shares of renewable energy sources in its energy mix. Recent studies have shown that the price of solar PV and wind have dropped over the years as technologies continue to advance and deployment increases. However, it is concerning that despite these developments, the country has one of the highest prices for electricity. According to the IEA [31], prices in the NEM were 212 USD/MWh in 2021, slightly above the IEA average of 205 USD/MWh, and in June 2022, wholesale prices (on a weighted weekly average) in the NEM reached more than 300 AUD/MWh.

The deployment of embedded generation from renewable energy sources assists with the reduction of GHG emissions and achieving climate change targets, but this may be coming at the expense of consumers. Renewable energy sources need to be paired with storage or flexible resources such as gas to continuously meet demand. In Australia, gas is the primary contributor to the high price of electricity and was the main reason for the energy crisis experienced in 2022.

6.4.3 A review of economic impacts according to scholarly articles

Lilley, et al. [74] conducted a study titled '*An economic evaluation of the potential for distributed energy in Australia'.* Based on their study, the economic impact of distributed generation may be summarised as: savings made due to deferred infrastructure expenditure; savings made, or costs incurred due to losses; savings made due to GHG emission reductions; the cost of compensating for the effects of distributed generation on the network; and a reduction in spot prices due to changes in merit order dispatch. Specific points from the study are highlighted below [87]:

- DG can lead to significant economic savings by reducing the need for large-scale power plants and transmission infrastructure; however, it may increase system-wide losses due to altered power flows, which could require new techniques to manage in the future.
- DG can also stabilize wholesale energy prices by lowering volatility.

- DG has the potential to reduce greenhouse gas emissions, particularly by minimizing system losses. However, these environmental benefits must be weighed against the economic savings that come with more DG uptake.
- Depending on the type and quantity of technology installed, DG can defer the need for network expansion, which has been a major factor in increasing electricity prices.
- DG can reduce peak demand through local energy generation or active management, which reduces the need for additional network capacity and results in financial savings.
- It is likely that high penetration of DG will lead to increased two-way flow of electricity in distribution networks. This could lead to fluctuating voltage levels and changes to fault current levels, which could require additional investment to address.
- Modelling suggests that even small amounts of DG can influence electricity prices by altering the merit order dispatch in the spot market, this change can have both positive and negative impact on network losses.
- Furthermore, the drop in average spot prices suggests that investing in low-emission technologies, supported by a carbon pricing mechanism, could lower overall energy costs in the NEM.
- The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is conducting ongoing research with the intention to develop an economic framework for evaluating the impacts of DG on electricity networks, which considers the technical challenges of determining the true value of DG on electricity networks and possible changes to technical, policy and regulatory settings.

The economic impact of distributed generation on spot prices in the energy market, particularly its potential to alter merit order dispatch and affect electricity prices, has not been highlighted in the cases of South Africa and Brazil. This study considers the economic impact of embedded generation at a high level, but it is evident that there is a need for an in-depth study and modelling to really understand and properly qualify and quantify the impact.

6.5 Uganda

According to the authors in [48], Uganda is the first country on the African continent to liberalise its electricity market, whereby generation, transmission and distribution utilities are unbundled and offering private participation for generation and distribution of power. It converted from a vertically integrated bundled electricity market to a liberalised one in 2001, through the Electricity Act of 1999. Uganda is also one of a few countries on the African continent with unbundled cost-reflective tariffs.

In 2007, under the Renewable Energy Policy, Uganda introduced a renewable energy feed-in tariff (REFIT) to facilitate the uptake of embedded generation from renewable energy sources. REFIT is a regulatory framework established and introduced to encourage and support private sector participation in power generation from renewable energy technologies [76]. It is managed and implemented by ERA as part of its mandate under the Electricity Act of 1999. Responsibilities of the ERA outlined in [76] include establishing and reviewing the tariff structure for priority renewable energy technologies; managing and administering the feed-in tariffs; and developing and reviewing the REFIT guidelines. The REFIT guidelines specify the following:

- Applicability of the programme, i.e. small-scale renewable energy systems.
- Prescribed priority technologies.
- Applicable capacities, i.e., greater than 0.5 MW and less than 20 MW.
- Limits for annual capacity allocations for technologies that participate in the programme, to curb electricity prices and to ensure that cheaper and cleaner technologies are dispatched first.

The aim of the above criteria is to limit excessive increases in consumer electricity prices and to limit the impacts of intermittent and non-firm power on energy security and power quality.

The system operator has the responsibility of publishing the REFIT tariffs for priority technologies, as approved by the ERA; as the single buyer, it issues and signs standardised power purchase agreements with qualifying renewable energy generators; and it is obliged to purchase power generated under the REFIT from licensed renewable energy generators. It is also obliged to connect licensed renewable energy plants to the grid and to transmit purchased electricity from renewable energy generators licensed under the REFIT programme [42].

Uganda has national approved feed-in tariffs and clear guidelines for participation in the REFIT programme, published by the regulatory agency. This makes it easier for the industry to participate in the scheme and to monitor the effects. However, despite having a clear regulatory framework for embedded generation, uptake remains low in the country.

In terms of electricity prices, Uganda remains to be one of the countries in Sub-Saharan Africa with higher electricity rates, in 2018 consumers were spending approximately 4.5% of their monthly household income on electricity [48]. The reason for the higher electricity rates despite having a liberalised market (where there's competition) is that since the energy crisis that the country experienced around 2005, the country's focus was on addressing capacity shortages by bringing new generation capacity online. From 2013 a few capacities were added to the system and now Uganda has excess power due to a lower electricity access rate. The infrastructure for generation was built to solve capacity shortages and must be paid for irrespective of whether the capacity they produce is used or not [45]. Constraints in transmission and distribution systems are the main reasons for the lower electricity access rate in the country together with the fact that the country has a lot of sparsely populated areas and communities living far from the main electricity sources. The uptake of more embedded generation will assist in increasing the electricity access rate by bringing capacity closer to where it is consumed and as a result reducing electricity prices. Therefore, Uganda is also amongst the countries that made the mistake of focusing on the expansion of generation infrastructure and did not put the same focus on the transmission and distribution systems.

6.6 Chapter summary

As seen in this chapter, countries such as Australia have a high share of embedded renewable energy sources in their mix and deploy flexible resources such as gas to supplement their renewable resources. However, the result of this workable scheme is that electricity prices are exceptionally high. It is therefore important for South Africa to conduct a holistic review of the factors that contribute to the success of embedded generation in each country, and factor in learnings from this review in its own plans for the roll-out of embedded generation. Meeting targets that the country has committed to in terms of sustainable development goals might only be attainable at the expense of consumers, who may be forced to pay high electricity prices. Given the current high price of electricity and recent pricing hikes in South Africa, it is unlikely that further loading of prices will be acceptable to consumers. There is a possibility that a high share of embedded generation, particularly from renewable energy sources, is a cost effective and "no regret" option for meeting climate change goals. However, the cost might still be too high for consumers, owing to the expense of flexible options that may have to be implemented concurrently to ensure continuity of supply.

Because of South Africa's relatively lower penetration levels and current grid capacity constraints, positive economic impacts such as savings attributed to deferred infrastructure development are not yet visible. The lack of national rules for embedded generation and an approved national compensation scheme for capacity exported to the grid is hindering the orderly development and operation of the electricity infrastructure. The drive for South Africa is to add more capacity to the grid. There is therefore a need for a national compensation mechanism to incentivise private generation. Added incentives could be introduced for capacity generated from renewable energy sources. However, until the country's demand requirements have been met, capacity should be sourced from any technology. As in Brazil, a compensation scheme could be introduced for a defined period to close the energy gap, which could be revised once the goal has been reached, or if it becomes evident that it is not viable or sustainable for the customer or the utility.

From the review, it is also evident that for any compensation mechanism to have a positive impact (whether feed-in tariffs, net billing or net metering), there is a need for unbundled tariffs to ensure that each customer contributes to their share of the fixed costs.

There is also a need for other government agencies to work with the regulator to ensure that electricity is affordable for customers and that utilities remain sustainable, through the introduction of premiums or subsidies, where necessary. Another positive impact of embedded generation highlighted from Australia's scenario is the ability of embedded generation to alter spot prices by changing the merit order dispatch of plants.

Finally, what has clearly emerged is that policy changes or regulations introduced by each country to spur the growth of embedded renewable generation have determined the nature of the economic effects.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

The primary aim of this dissertation was to conduct a review of the impact of increased levels of embedded generators on South Africa’s distribution networks in light of the experiences of three other countries, and to make recommendations based on what has worked, what has not worked, and what seems most suited to the South African context. A comparative analysis was conducted, comparing the impact of embedded generation on South Africa’s distribution networks with the impact on distribution networks in Australia, Brazil and Uganda. The dissertation has a high-level focus on the technical, economic and regulatory impacts. A review of each country was conducted to identify critical success factors for these countries in the uptake of embedded generation and to make recommendations for adoption by South Africa.

7.2 Conclusion

From the technical aspect, the study has shown that embedded generation, while introducing challenges to the electricity grid, also brings benefits such as reduced technical losses, deferred infrastructure expansion, and a decrease in greenhouse gas emissions. Its success depends on effective planning, up to date regulatory frameworks, and mitigating strategies tailored to local conditions. Factors such as penetration levels, network configuration, and regulatory structures significantly influence the integration process [4].

South Africa, Brazil, Australia and Uganda have historical vertically integrated power networks that are undergoing reforms, their power systems now experience bi-directional flow of power, not just a unilateral flow due to the presence of embedded generation particularly from renewable energy sources. The technical impact of embedded generation on local networks in these countries is like that of South Africa. However, the solutions to be implemented to manage the effects of embedded generation are dependent on the penetration level, the availability of flexible resources, and whether the country enjoys interconnectivity with other countries.

Network-specific studies are needed to effectively manage the effects of a high penetration of embedded generators, which can be positive or negative depending on penetration levels, size, type and location of the resources and network topology, to name a few aspects. Australia's DER register, where all embedded generators in the country are captured, irrespective of their size, location, technology, and whether they are export or non-export, is a useful tool to ensure the predictability and visibility of these generators for safe and efficient operation of the system. For proper network-specific analysis, models that reflect the behaviour of the plant on site are required, data captured in the DER register will assist in coming up with accurate network models.

In terms of the regulatory impacts, it has been shown in the study that countries with clear and regularly updated regulatory frameworks, like Brazil and Australia, have been successful in encouraging the growth of embedded generation, particularly from renewable sources. In contrast, South Africa faces challenges due to the lack of a consistent and up-to-date regulatory framework for embedded generation. The absence of national rules or guidelines for grid connection, and a compensation mechanism for excess energy prevents South Africa from fully benefiting from embedded generation.

A consistent and up to date regulatory framework is dependent on a clear market structure. Embedded generation is thriving in Australia and Brazil due to clear market structures, defined participation rules, and well-established compensation mechanisms for excess power fed into the grid. These countries have liberalised their energy markets, which has encouraged competition and supported the growth of distributed generation. From the onset, Brazil identified a need for a comprehensive legal and regulatory framework and a long-term energy plan for decentralised energy generation to thrive. The country has clear rules for distributed generation and a clear framework on the requirements for participation. A net-metering scheme was introduced to incentivise own generation; once the penetration levels had increased satisfactorily, especially for rooftop solar, ANEEL reviewed its decision, and replaced it with a net billing scheme. Incentives or subsidies for distributed generation are funded by the National Energy Policy Council, ANEEL maintains active oversight of its distributed generation, updating frameworks as and when needed.

In contrast, South Africa's market structure is still largely vertically integrated, with Eskom still dominating the generation sector. While the REIPPPP has successfully attracted utility-scale generators, private unlicensed generators lack incentives to install generators and export power back to the grid. The absence of a standardised compensation mechanism for excess energy and a defined market for private generators has slowed the country's progress in renewable energy embedded generation uptake compared to Australia and Brazil.

Lastly an economic impact review of embedded generators was also conducted, the main aim of conducting an economic impact review of high levels of embedded generation is the need to ensure that:

- There is a good business case for customers who install embedded generation and feed excess power back on to the grid. Also, that these customers pay for their portion of the utility's fixed costs for providing them with back-up power.
- The distributors to which these generation facilities are connected can recover all costs associated with the services they provide, i.e., for customers with or without embedded generation. There is a need to ensure that the utilities remain sustainable.
- Customers without embedded generation are not negatively affected because of the activities of customers with embedded generation. Those without embedded generation should not carry all utility's fixed cost and in effect subsidise the customers who have embedded generation.

A review of the compensation mechanisms and tariff structures was conducted to examine what has been implemented in the other countries under review, to ensure that the above conditions are met. The review has shown that Brazil began with net metering as a compensation scheme for excess energy fed back to the grid and used this system for several years. However, it has recently revised its decision to compensate via a net metering mechanism, and has adopted a net billing compensation mechanism, based on cost-of-supply studies. This decision was taken after certain renewable energy targets were met and upon realisation that net-metering compromises the sustainability of the distribution utilities.

It has also been determined from the study that the economic impact of high levels of embedded generation on the utility and its customers is largely influenced by what is allowed in policy or regulations in each country. Brazil and Australia’s uptake of embedded generation is high and growing at a rapid rate as a direct result of strategies that have been put in place to incentivise the uptake of rooftop solar by residential and commercial customers. The strategies were enabled through appropriate policy decisions and these countries have introduced sufficient incentives to encourage uptake to meet climate change targets. The compensation mechanisms introduced included net metering, net billing and feed-in tariffs depending on each country's priorities. Uganda's REFIT program is also well structured with the aim to accelerate renewable energy private generation, though uptake has been slow in Uganda; it remains a good incentive for private sector participation and customer involvement.

South Africa has a plan to introduce a standardised compensation mechanism for excess power fed to the grid by embedded generators, this is a step in the right direction as it aligns with international best practices.

7.3 Recommendations

Technical, legislative and regulatory recommendations:

Clear policies and regulations are required as the foundation for developing and managing embedded generation, they will set the framework for participation, define compensation mechanisms, ensure efficient and orderly development of the industry as it deregulates. A well-defined liberalised market structure is also required to enable competition and encourage participation from both private and public participants. The Electricity Regulation Act and the Electricity Pricing Policy are being amended in South Africa, policy makers, NERSA & other stakeholders should propose amendments aimed at providing a clear electricity market structure that the country is working towards and removing regulatory barriers to ensure a smooth transition. Even though the sector is deregulating, there is still a need for NERSA to provide guidance to licensees to ensure that the process of deregulation is not disruptive.

It is also recommended that NERSA introduces national guidelines or rules for embedded generator connection and management to ensure standardisation of processes amongst distributors and reduction of illegal connections, this is similar to what was done by Energy Networks Australia [31] [67].

In addition to the national guidelines or rules for embedded generation, like Brazil's energy regulator, NERSA should determine a sustainable compensation mechanism for excess generation exported to the grid and develop rules for the compensation scheme. In collaboration with the appropriate government agencies (DMRE & NT), consider incentives or premiums that can be introduced to make the scheme appealing to both network service providers and consumers. If the intention is to align the scheme with a particular generation capacity target or climate change target, it should ensure that the rules clearly indicate how long the scheme will run for.

The South African Grid Code mandates licensed generation facilities to provide generation data to NERSA and the System Operator. However, there is no provision in the Codes for provision of information by unlicensed generators. NERSA should create a national register, like Australia's DER register, for all embedded generation information to be captured to ensure predictability and visibility for safe system operation. The register must be accessible to all electricity industry participants.

As more variable renewable embedded generators are added to the system in South Africa, it is recommended that through proper planning, South Africa must strengthen interconnectivity with other countries. A good example of a reliable interconnection agreement is the South Africa–Mozambique Cahora Bassa DC line.

Economic Recommendations:

With the rising cost of electricity, South Africa must ensure that embedded generation does not disproportionately burden consumers. Regulatory measures should include the introduction of unbundled tariffs for all customer categories, so all customers contribute fairly to grid maintenance/fixed costs. Other factors that may increase the cost of electricity should also be monitored; Australia's experience show that integrating high shares of renewable energy into the grid with extensive reliance on other countries for sources of flexible generation such as gas could result in elevated electricity costs.

In terms of the compensation mechanism, it is recommended that South Africa adopts a net-billing compensation scheme for excess power exported to the grid to ensure revenue neutrality for the distributors, sustainability for both distributors and customers, and fairness. Indication is that South Africa is on track in this regard because NERSA published a consultation paper in March 2023 on Net billing rules.

Brazil's energy reforms, especially regarding net metering and compensation for surplus generation, provide valuable lessons for South Africa. As in Brazil, the compensation scheme could initially focus on incentivising private generation to address the country's energy capacity gap and then evolve over time as generation capacity and renewable energy integration increase.

Although South Africa needs to focus on increasing overall generation capacity, there should be targeted incentives for embedded generation from renewable energy sources to align with global decarbonization goals and ensure that the country meets its climate change commitments.

In conclusion, a well-planned and regulated approach to embedded generation, considering the experiences of other countries, could help South Africa overcome its energy challenges, stimulate economic growth, and contribute to meeting climate goals.

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