There must be justice in 'just transition'?

The goal of energy security must be economic development for all

By Viv Crone

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South Africa's electricity crisis will not be resolved by simply complying with its COP obligations and shifting to renewable power generation – while protecting the employment of coal and power station workers. VIV CRONE explains in detailed, but understandable terms that 'fixing' the electricity system will be a long and very complex process of reaching consensus on the 'mix' of energy sources that can deliver a stable and accessible electricity supply.

THE ELECTRICITY CRISIS

For the past 14 years, South Africa has been experiencing a growing electricity system crisis. This has manifested itself as increasing periods of load shedding, huge Eskom debt and above inflation increases in the price of electricity.

Many "solutions" have been proposed, with the main emphasis being on replacing existing fossil-fuelled facilities with "renewables". The main argument for embracing this solution is the view that renewable generated energy costs less than fossil-fuelled energy, has far lower levels of carbon emissions and is the path chosen by many developed countries.

However, South Africa is unique in several ways. Although it is the most developed African country and has an established industrial capacity, it has one of the highest unemployment rates in the world with almost half the adult population living in poverty (StatsSA, 2019).

Instead of an economic growth rate of at least 5% to alleviate poverty, the current rate is negative, driven by several factors, of which continual load shedding is the most significant.

In 2022, by the end of October, an estimated 7,500 GWh of electricity or ~3.5% of the total electricity demand was unserved i.e. not supplied due to load shedding. This has resulted in a reduction of GDP by ~1.4% so far this year based on an Eskom commissioned survey (Eskom, 2021).

The Energy Availability Factor (EAF) of Eskom's coal fleet has been steadily deteriorating over recent years and is currently below 60%. Without a proper electricity system, the South African economy has no hope of being able to grow sufficiently to reduce and alleviate the poverty suffered by its people.

THE GOAL

A just energy transition should benefit the people of South Africa as a whole and not only the workers and communities involved in the energy industries. Our goal should be to ensure that we have an effective electricity supply system, which is a critical key enabler for a country to develop and prosper. To be effective, the electricity supply must be reliable, affordable, minimise environmental damage and be accessible to all citizens.

A move away from the use of coal as a primary fuel is dictated, but this should not further disadvantage the country.

THE CURRENT ELECTRICITY NETWORK

The current electricity network covers the country and supplies the majority (>80%) of electricity from an Eskom coal-fired fleet of power stations in the northern part of South Africa, with contributions from nuclear (~5%) and IPP renewables (~6%).

Eskom's daily electricity demand fluctuates considerably, peaking in the morning as people become more active and industry starts up and again in the evening as people go home, prepare food and heat their homes. The daily baseload level also varies between 18GW and 21GW and changes slowly depending on the day of the week and the weather.

To build up generating capacity to meet the demand at any time is done by bringing resources that are available online, in increasing cost order, as the demand increases and releasing them as the demand wanes.

The total current installed capacity, including both variable and dispatchable (these terms are explained below), from all generating resources in South Africa is over 58GW, however on any given day up to 20GW of baseload supply may be out of service.

Coupled with the intermittency of the variable renewable energy, pumped storage resource status and availability of diesel for the gas turbine peaking resources, this determines the available electricity generating resources on an ongoing basis.

ELECTRICITY SYSTEM REQUIREMENTS

As the Nuclear Energy Agency has stated, "The continuous availability and affordability of energy and, in particular, electricity is an indispensable condition for modern societies" (2018). To be able to supply the required electrical energy and meet the power demands of a country, the makeup of generation plant available must first have the capacity to generate the ongoing amount of energy

Table 1: Eskom's relative costs of generation resources

Description	Energy Source	% of Total Energy Cost	% of Total Energy	Cost per kWh
Baseload	Coal	64.6%	84.3%	R0.40
Baseload	Nuclear	1.0%	5.3%	R0.10
Peaking	ESKOM Open-cycle Gas Turbines (Diesel)	4.0%	0.7%	R3.12
Peaking	IPP OCGTs (Diesel)	3.4%	0.4%	R4.11
Renewable	IPP	23.0%	5.9%	R2.03
Imported Energy		4.0%	3.4%	R0.60

Source: Eskom Data Portal, 2022

Figure 1: Total installed capacity (MW)

Type	Capacity [MW]
Coal	45,618
OCGT	3,449
Wind	3,322
Hydro	2,290
Nuclear	1,860
Solar PV	1,717
Solar CSP	400
Biomass	71
Landfill gas	26.5
Total Capacity	58,753

Source: Wikipedia list of South African power stations

required and second be able to deliver it at the required power level when required. This is achieved by having a mix of generation technologies.

The fact that the electricity costs in the Eskom electricity system vary by a factor of over 40 times from the lowest cost (nuclear) to the highest cost (3rd party gas turbines) is indicative of the realities of the technology mix and complexity of the system.

The increasing penetration of variable generation technologies, such as wind and solar PV, significantly changes the overall operational requirements of the electricity system. From a system that has a large, generally inflexible baseload component, future requirements will have to include increased flexibility, additional capacity to make up for intermittency of renewables and reduced carbon emissions.

To be practical, affordable and have an acceptable level of risk, this change must take place with careful system planning over a period of tens of years as existing generation facilities that are decommissioned are replaced and additional capacity added to meet the country's growth requirements. This change must be achieved with the lowest risks possible, using well-established and proven technologies and methodologies. High-risk, leading-edge solutions that risk the future failure of South Africa must not be considered.

Electricity supply system complexity

A country-wide electricity supply system is an extremely complex system and is made up of several technologies that ultimately form a "chain" of electricity supply to the end-user.

Focusing on the generation part, a critical characteristic of an electricity supply system is that it must meet the changing demand on a second-by-second basis. This is achieved by the instantaneous conversion of stored energy in many forms into electricity, as it is required, using different generation technologies.

Electricity generation sources fall »

A move away from the use of coal as a primary fuel is dictated, but this should not further disadvantage the country.

Source: Waldo Swiegers

into two main categories. Those whose energy outputs are "dispatchable" and those that are intermittent or "variable". A dispatchable energy source is one whose output can be increased or decreased depending on the current demand. These sources include thermal and nuclear power stations and open-cycle and combined-cycle gas turbines, energy storage systems and hydro power.

The rate of increasing or decreasing output, or ramp-rate, is an important parameter in the overall control of an electricity network. Existing baseload thermal and nuclear power stations have ramp-rates of around 25-30% per hour. More rapid changes in demand are met by "mid-merit" and "peaking" generation facilities. These cost more to run but have much higher ramp-rates. Some gas turbines can ramp from zero to full output in less than five minutes!

Energy storage technologies such as pumped storage hydro and batteries can react very quickly to demand changes but have a limited endurance.

Renewable energy sources such as solar PV and wind are variable and not dispatchable and the weather-dependent energy generated can be used if or when it is available. The remaining or residual load must be covered by dispatchable generation technologies in the electrical system.

The above components of the electricity system have typical lifetimes of 15 to 50/60 years depending on the technology. Thus, technology decisions made have long-term consequences and cannot be rapidly changed or replaced.

The system requirement effects of increasing renewable penetration into an electricity system vary. With a low penetration of variable renewable generation the gap between the demand and the power supplied is met or filled by dispatching the required power and following the load. This load-following requirement is relatively slow and can be met by normal existing coal-fired or nuclear "baseload" power stations. When variable renewable power is a much larger part of the generation resources and the gap between the renewable power and the total power demand is generally smaller but much more variable, filling the gap between the renewable energy power and the demanded power requires power to be supplied from dispatchable sources that can follow the more rapidly changing demand.

South Africa's existing coal-fired fleet was not designed to operate in this new mode and will have to be replaced over time by more flexible dispatchable technology. This change can only be economically and feasibly achieved over the medium to long term.

SOME CHARACTERISTICS OF VARIOUS ESTABLISHED GENERATION SOURCES

Electricity can be generated using many different sources. Each of these technologies has specific characteristics, which make them more or less desirable for a particular country. A sensible "mix" of technologies is necessary to create an effective electricity system so that energy security, flexibility, affordability and environmental criteria are optimised.

DISPATCHABLE TECHNOLOGIES

There are two dispatchable technologies with reduced emission (compared to coal) that are currently discussed as part of South Africa's future energy structure. These are natural gas and "green" hydrogen.

Natural gas

There have been recent sizeable gas field discoveries off the South African west and southern coast with an estimated life of up to 30 years. These include the Brulpadda and Luiperd finds off the coast of Mossel Bay and the Ibhubesi gas field north-west of Saldanha Bay. In addition to these, discoveries off the coast of Mozambique have an estimated economic lifetime of up to 45 years.

Using natural gas to generate electricity produces about 50% less emissions than coal over the lifetime of the generating plant (DBCCA, 2011). Using this resource in conjunction with the well-established open-cycle and combined-cycle gas turbine technology could well provide a viable transition fuel away from coal, increasing flexibility and reducing emissions substantially.

'Green' hydrogen

There has been much recent publicity about using hydrogen produced from excess renewable electricity as a source of fuel with either much reduced or no carbon emissions. The hydrogen could be converted back to electricity on demand using fuel cells or turbines.

A major challenge is the round-trip efficiency of this hydrogen cycle, which is currently between 18% and 46% (S&P Global, 2021), which makes it uneconomical at present. The "hydrogen-economy" may provide part of the electricity grid of the future, but it is still developing and not ready to be a part of a low-risk electricity system solution.

AN ELECTRICITY SUPPLY SYSTEM IS AND ALWAYS WILL BE A COMPROMISE

The ideal electricity supply system would be able to immediately meet the changing electricity demand, occupy no useful space, have very high efficiency, have very low costs, and produce no pollutants or environmental damage. However, engineers who are responsible for the design and successful implementation of an electricity system must find an acceptable compromise between the laws of physics, which are immutable, and practical constraints imposed by finances, environmental damage and the welfare of society.

This means that any solution to the current electricity crisis will be a compromise, and decisions regarding the extent of environmental damage, how money will be available to implement and operate the system and the effects on society such as unemployment, poverty alleviation and general welfare will have to made.

ELECTRICITY REQUIREMENTS TO 2030

Forecast demands growth

Recent electricity demand from Eskom shows a daily power requirement of between ~22GW and a peak of ~35GW (Eskom, 2022). The current plan for South Africa's electricity system is the 2019 Integrated Resource Plan (IRP 2019) (RSA, 2019), which is currently being updated.

IRP 2019 shows a planned total installed capacity of almost 78GW by 2030. Of this 33.3GW is coal fired, 1.8GW is nuclear, ~18GW is wind, 8.3GW is solar PV and 4.6GW is hydropower. This would give a planned penetration of renewables of 40%.

To work towards meeting South Africa's goals of reduced poverty and an economic growth rate of 5% per year, an increase in electricity supply of at least 5% per year is necessary. Thus by 2030, the energy demand is forecast to increase by ~40%. This would require a "steady-state" capacity total of ~40GW and peak capacity of about 50GW.

The difference between the average power and peak power requirements can be met by fast response generation such as a combination of pumped storage, open-cycle gas turbines and other "fast" dispatchable technologies.

Putting this into perspective, and if a system Energy Availability Factor (EAF) of 80% is reached, an additional ~12 to 15 GW of dispatchable equivalent generation capacity must be added by 2030 to meet the predicted demand!

FACTORS TO CONSIDER IN CHOOSING GENERATING TECHNOLOGIES FOR SOUTH AFRICA

Important aspects and characteristics of the various generating technologies need to be taken into consideration in making electricity system technology choice decisions.

Cost of electricity

Several electricity costing methodologies are currently used. The main parameter used to make many long-term technology decisions and comparisons is the Levelised Cost of Electricity (LCOE). LCOE takes the generating plant capital cost, fixed operation and maintenance (O&M) costs, capacity factor and variable costs of fuel (where relevant) and lifetime energy output to calculate the cost of generating electricity. However, the LCOE only covers part of the total electricity costs and using it alone to make technology decisions may have significant negative long-term effects.

For instance, the LCOE does not consider the difference between the system integration costs of dispatchable and variable energy sources. Typically, additional system costs will have to be incurred for variable generating facilities because of their location and variability. These costs may be very significant and particularly applicable to countries planning energy transitions.

Thus, there is a considerable effort being focused on the Full Cost of Electricity (FCEO) to improve the information on which electricity system decisions are made. Although difficult to calculate, unless recognised and tackled, country administrations will not be able to make informed decisions to move towards fully sustainable and secure electricity systems. The FCOE addresses the true cost to society of the provision of electricity and is separated into three areas (Nuclear Energy Agency, 2018). These are:

- Plant-level production costs;
- Grid-level system costs, which include the cost of electricity transport and balancing, the cost of electricity storage and the cost of backup electricity supply equipments; »

- Social costs, including climate change impacts, air pollution, cost of accidents, land use, natural resource depletion and electricity supply security.

Grid-level system costs or electrical system level costs are related to the variability of renewable output and curtailment and re-dispatch costs. Grid connection costs can be significant due to the constraints of the location of renewable generating plants.

Figure 2 shows the results of calculating the full integration costs of different generating technologies with different levels of variable renewable energy technology penetration.

Schernikau (2022) adds further parameters such as the cost of recycling, material input per unit of service (MIPS), equipment lifetime and energy returned on energy invested (ERoEI or eROI). Experience is showing that the cost of the generation of renewable electricity may only be 44% (Murray, 2019) of the total cost of provisioning that energy.

MATERIALS INPUT FOR VARIOUS GENERATION TECHNOLOGIES

Different generation technologies require different amounts of materials.

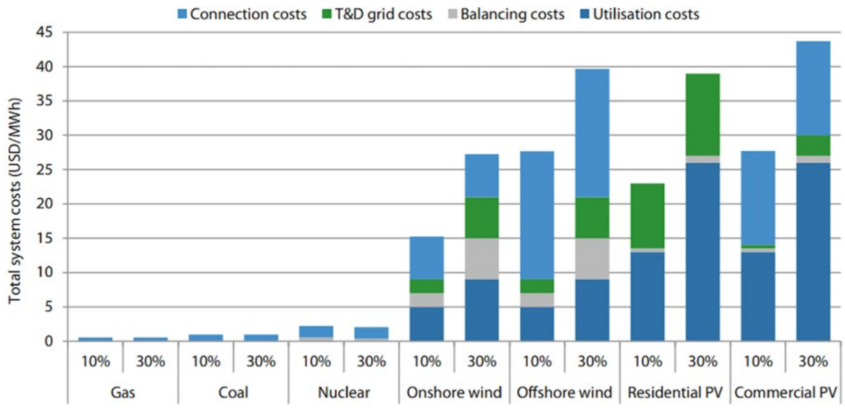
Figure 3 shows various materials required per energy unit generated over the lifetime of a generating resource. From this it is seen that the materials input for wind and solar PV are at least an order of magnitude (i.e. 10 times) larger than for the conventional dispatchable technologies.

Land use intensity

Different generating technologies also have different footprints.

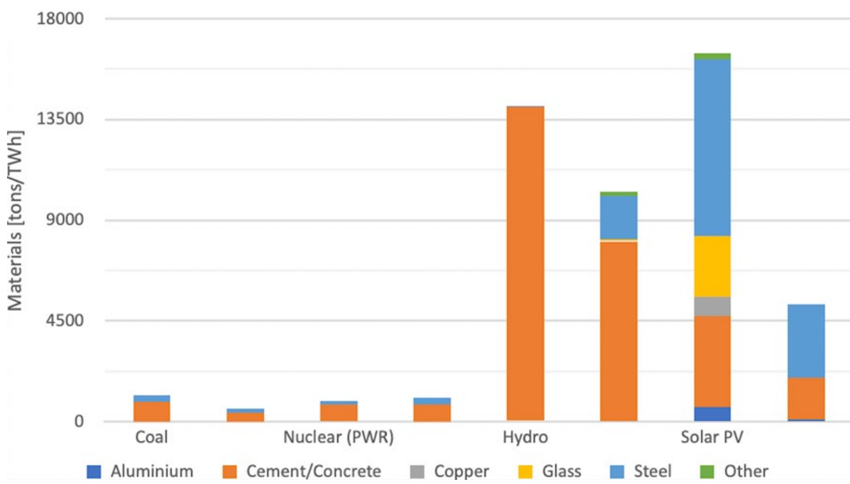
Land use intensity measured as the area per energy output has a range of over 100 times for the different generating technologies ranging from 0.1 m²/MWh for nuclear and 0.2 m²/MWh for underground mining coal-fired plants and gas turbines to 10m²/MWh for solar PV generation.

Figure 2: Grid-level system costs of selected generation technologies



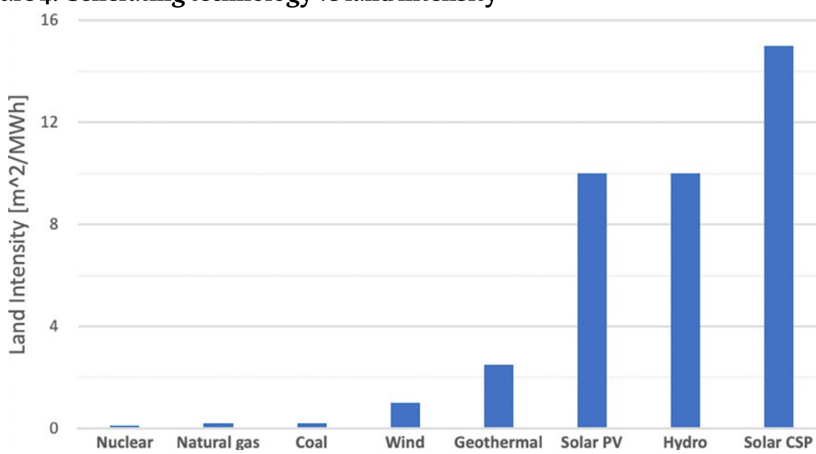
Source: Nuclear Energy Agency, 2018

Figure 3: Material Input in tons per unit of service [TWh]



Source: adapted from DOE Report

Figure 4: Generating technology vs land intensity



Source: International Renewable Energy Agency, 2017

> ... [an] electricity system must find an acceptable compromise between the laws of physics and practical constraints imposed by finances, environment and social welfare.

Cost of unserved energy (COUE) in South Africa

Modern society relies on a continuous supply of electricity with minimal outages to grow and prosper. Typical European countries experience annual outages amounting to less than four hours (Kessides *et al.*, 2007). South Africa had widespread forced outages of over 2,400 hours in the first 10 months of 2022! According to Minnaar and Crafford (2017), the cost of unserved energy (COUE) to the economy averages at R84/kWh. The household COUE is calculated as R6.77 per kWh.

In 2022, load shedding records to the end of October show the energy not supplied due to load shedding was about 7,500 GWh. Assuming that half of this affected commercial enterprises, the cost to the economy was in the order of R300 billion or 6% of expected GDP.

Energy returned on energy invested (ERoEI)

A parameter that gives another insight into electricitysystems is the energy return on investment (ERoEI) or eROI (ExternE,2005). An electricity system can be regarded as an energy gathering and conversion system complying with the law of energy conservation. ERoEI measures the efficiency of an energy "gathering" system. The higher the value of ERoEI, the more energy is returned for that invested in the development of the resource. In essence, the higher the ERoEI the lower economic and environmental costs or lower prices and ›› higher utility. If we choose technologies that give an ERoEI of less than one, we will have an energy deficit. Visit https://euanmearns.com/eroei-for-beginners/ for more on calculating the ERoEI of systems and the ERoEI for different generating technologies.

If the input energy to develop an energy source is too large, there will be little excess energy left for society to use. Weissbach and others (2013) have determined that an ERoEI of about seven is the minimum required for our modern society to function.

Intuitively, this seems to mean that the renewable energy sources are actually expensive and may give some insight into why Germany, with a high penetration of renewables, has the 2nd highest electricity price in the world.

The McKinsey report (2022) states that the estimated capital spending on physical assets for energy and land use between 2021 and 2050 for the transition would amount to $275 trillion (about R4,470 trillion) or $9.2 trillion per year. This is an annual increase of $3.5 trillion, which is equivalent to about 7% of household spending or between 6.8% and 8.8% of GDP.

It is also stated that poorer countries may have to spend 1.5 times more than advanced countries as a share of GDP to support economic growth and to build a low-carbon infrastructure.

CONCLUSION

Currently it seems that the world is rushing headlong into the widespread deployment of solar PV and wind renewables as the solution to transition from fossil fuels. One should remember that these technologies are relatively new when compared to traditional generating technology and that the long-term (i.e. 50-year) effects of using these are not yet fully realised.

What seems clear is that considerable work is required to fully evaluate and understand these technologies, taking into account factors such as their variability, equipment lifetime, the full cost of electricity generated, the return on energy invested, land footprint and base materials input to ensure that they indeed provide a long-term sustainable and viable energy option.

Any plan to achieve electrical energy security should be based on a low-risk approach. It should use existing, proven technology applied by competent people. The temptation to rely on newer, "miracle" technologies such as "green" hydrogen, or excessive penetration of renewables and utility battery storage systems as "the solution" should be avoided until these technologies have properly proven themselves.

An effective long-term solution will involve the application of an appropriate "mix" of generating technologies to effectively meet the requirements. It will have to be an acceptable compromise between the laws of physics and the practical constraints of financial resources, urgency, skills availability and environmental damage to optimise the welfare of South African citizens.

Everyone agrees that a "just energy transition" is required. However, the meaning of this phrase is often limited to the effects of the transition on the energy industry workers and associated communities only. A truly "just" transition must apply to the whole of society. The realisation of energy security and achieving reliable, affordable and accessible electricity must be the primary objective that results in sustainable economic growth and ultimate improvement in the quality of life for *all* citizens.

This is a condensed version of a research paper by Viv Crone. Crone presented his work at an IFAA Forum in December 2022 which can be accessed here.

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