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SAIEE THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | JUNE 2023

POWER

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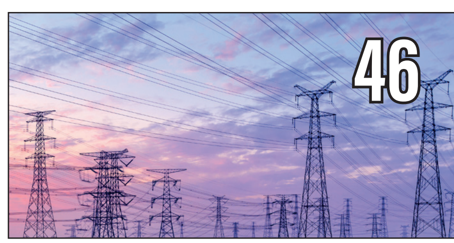

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Dear **watt**now reader,

With electricity and global power issues on everyone's lips, I thought it pertinent to bring you this issue.

Our first feature article discusses South Africa's power crisis, described as "a perfect storm". Several factors have converged to reach this point: an ageing and inadequately maintained fleet of coal power stations, delays in upgrading the Koeberg nuclear power station and significant failures at the recently built Medupi and Kusile coal power stations. Read it on page 20.

The International Energy Agency's Electricity Market Report 2023 deeply analyses current policies, trends and market developments. It also provides forecasts through 2025 for electricity demand, supply and CO_2 emissions – with a detailed study of the evolving generation mix. This year's report contains a comprehensive analysis of European developments, which faced various energy crises in 2022. The Asia Pacific region also receives special focus, with its fast-growing electricity demand and accelerating clean energy deployment. Read it on page 24.

"A Review of Solid-State Transformer for Smart Energy" looks at the smart grid, the backbone of modern electrical power infrastructure. Read it on page 46.

In current affairs, the SAIEE has updated our member benefits to give our valued members more 'mile for their buck'. Find the information on page 14.

The July issue features Communications, and the deadline is 19 June 2023. Please send your paper/article to: minx@saiee.org.za.

Herewith the June issue; enjoy the read!

Minx

INDUSTRYAFFAIRS

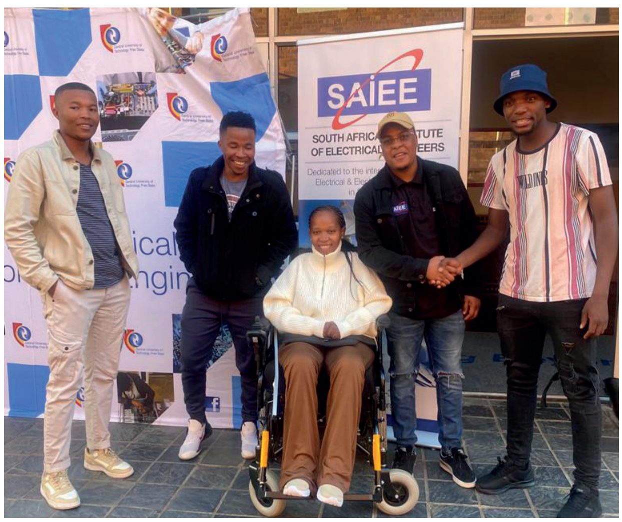
SAIEE Presidents visits Freestate Centre

SAIEE President, Prof Jan de Kock, visited the Freestate Centre on his inaugural tour and was eagerly welcomed by the Freestate Centre committee members and the CUT Student Chapter.

Mr Sindile Nyangintsimbi, Deputy Chairman of the Student Chapter, welcomed all the guests. Former Chairman, Mr Thanbang Motau, introduced Prof de Kock, who presented his inaugural talk on Load-shedding - can South Africa be Saved?

After Prof de Kock's presentation, Ms Joy Morakane, Chairperson of the CUT Student Chapter, gave him a thank-you gift.

Mr Motoloki Lephoi, the chairperson of the Freestate Centre, closed the event and thanked everyone for their attendance. wn



SAIEE appoints 2023 Honorary Vice President

At the May 2023 Council meeting, SAIEE Council members voted Mr Tom Eichbaum as the 2023 Honorary Vice President.

Tom became an SAIEE member in 1978 and upgraded to a Fellow of the SAIEE in 2005.

He specialised in Project Management in Engineering, Procurement and Construction Projects and completed various projects in various Energy and Industrial Projects fields.

He obtained his BSc in Electrical Engineering from the University of KwaZulu Natal in 1978. He furthered his studies and received an MBA in Technology Management (co-branded by the Association of Professional Engineers, Scientists and Managers Australia (Apesma) and the La Trobe University in Melbourne in 2003. wn

Data Centre Expert Jonathan Duncan Joins Vertiv Africa Engineering and Technical Team

Vertiv (NYSE: VRT), a global provider of critical digital infrastructure and continuity solutions, has appointed Jonathan Duncan as application engineering and technical solutions director for Africa. In this capacity, Duncan will report directly to Vertiv's managing director for Africa, Wojtek Piorko.

"With more than 25 years within the critical power and cooling industry, including extensive team leadership and sales expertise within the data centre segment, as well as senior operations and multi-territory responsibilities, Jonathan is an excellent addition to Vertiv's management team within Africa," says Piorko.

"Further to his deep capabilities, Jonathan also has significant experience in working on ground across the entire African and Middle Eastern region, including South Africa, Egypt, Dubai and Saudi Arabia, as well as a short stint in Europe, before his return to Johannesburg.

"Vertiv is building presence within Africa and it is an exciting time to continue driving this growth in the region with dedicated focus, accountability, and responsibility. We welcome Jonathan to the local Vertiv team and wish him every success in his new role," Piorko adds.

Duncan takes charge of all the technical solutions, activities and sales support for Vertiv Africa as of May 2023.

"Demand for data centre infrastructure is growing dramatically within Africa, with serious capacity development still expected to come as businesses continue to make their transition to the cloud," says Duncan. "Vertiv is well positioned to assist local organisations in their digital transformation journey, and, in my new position, I look forward to playing a role in our 'Africa for Africa' focused approach to this business." wn

Jonathan Duncan
Application Engineer & Technical Solutions Director

Wide-ranging energy solutions and expertise: Danfoss celebrates 30 years in South Africa

From left: Roy Naidoo, Sales Director Danfoss Climate Solutions, South Africa; Ziad Al Bawaliz, Regional President for Turkey, Middle East and Africa; Emil Berning, Country Manager for Sub-Saharan Africa; and Shikantha Naidoo,S enior Country Sales Manager Danfoss Drives, South Africa.

Danfoss, a multi-national Danish engineering company, is celebrating its 30th anniversary in South Africa, marking three decades of growth and expansion in the region. Founded in 1933 by Danish engineer Mads Clausen, Danfoss has evolved into a global enterprise employing over 42,000 individuals worldwide. The company has recently focused on integrating its local presence in South Africa, following several strategic acquisitions, with the aim of leveraging its operations in the country to drive further expansion throughout Africa.

Danfoss offers a wide range of energy solutions and expertise, with a strong commitment to energy efficiency and decarbonisation. The company's portfolio includes solutions for reducing power consumption, minimising food loss and waste, improving cooling and heating systems, optimising wastewater treatment, and enhancing mining productivity. The company has embraced an "energy efficiency first" principle and is actively working towards achieving carbon neutrality in its global operations by 2030. In South Africa, Danfoss aims to be the preferred partner for decarbonisation initiatives.

"To mark 30 years of pioneering sustainable growth together, and looking forward to going from strength to strength, both locally and on the continent, we crowned this anniversary with a local celebration for our partners, customers and colleagues, in which Danfoss honoured local traditions within the ongoing priority of 'engineering South Africa's tomorrow'", said Emil Berning, Country Manager for Sub-Saharan Africa.

This mission aligns with the company's core values of increasing machine productivity, reducing emissions, lowering energy consumption, and promoting electrification. The celebration of this milestone reaffirmed Danfoss's commitment to continued growth and innovation in South Africa and across the continent.

Danfoss solutions find applications in various industries, including refrigeration, air conditioning, heating, power conversion, motor control, industrial machinery, automotive, marine, and off- and on-highway equipment. The company also provides solutions for renewable energy sources like solar and wind power, as well as district-energy infrastructure for cities.

Ziad Al Bawaliz, the Regional President for Turkey, Middle East and Africa, highlighted the importance of engineering in driving society forward and addressing key global challenges such as urbanisation, climate change, food and water supply, digitaliation and electrification.

With South Africa as a strategic hub, Danfoss looks to expand its operations throughout Africa and continue its commitment to engineering a greener tomorrow. wn

MUT Lecturer Awarded PhD in Medical Biochemistry

Lecturer in Organic Chemistry at Mangosuthu University of Technology's (MUT) Faculty of Natural Sciences, Dr Ayanda Magwenyane, said it was a dream come true to graduate with a PhD from UKZN. His study employed a molecular dynamic simulation approach to explore heat shock protein 90 (Hsp90) as an anti-cancer target for drug discovery. His study found three new potent Hsp90 inhibitors (ZINC15905860, ZINC13120102 and ZINC20411962) to be stable in the binding site. Society stands to benefit from this research as it contributes to an overview of the various computational models used in the development of anticancer medicines.

Passionate about saving lives and easing South Africa's disease burden, the 31-year-old from the rural community of eNadi, Kwamnyandu in Pietermaritzburg explained that although cancer is a complicated disease, most human cancers share basic features such as self-supply of growth signals, resistance to growth inhibitors, evasion of programmed cell death, unlimited replication potential, prolonged angiogenesis, and tissue invasion and metastasis.

Co-supervised by senior lecturers in Medicinal Chemistry at UKZN Drs Hezekiel Kumalo and Ndumiso Mhlongo, Magwenyane's novel research was informed by a remarkable number of Hsp90 client proteins being involved in the development of cancer cell characteristics. 'Hsp90 is a molecular chaperone that is conserved from bacteria to humans and facilitates the maturation of substrates (or clients) that are involved in many different cellular pathways,' he said.

'It was not an easy journey. The COVID-19 pandemic broke out in the middle of the study, and much motivation was required to keep going amidst the trauma and the lockdowns,' said Magwenyane. He added that his supervisors kept him motivated.

Dr Ayanda Magwenyane

'I also made sure that I participated in the workshops and retreats offered by UKZN to learn how to succeed and survive while studying.'

A devout Christian, when not hard at work, he enjoys reading and watching informative documentaries and movies. 'I also like to talk to young people, motivating them that they should always strive to become better than yesterday.' wn

It's Not That Easy Being Green

BY: Andrew Cooper Pr.Eng, MBA, B.Sc, B.Comm, CEM, CPEnMS, CMVP
Strategic Energy Management Specialist

Kermit the Frog famously sang, "It's not easy being green". When you think about it, that statement has so much truth. You could even paraphrase that to say, "It's not easy continually improving efficiency and reducing greenhouse gases (GHGs)", which is, in a way, linked to being green.
Much energy waste results from our bad habits, old practices and our "quick fix" culture. After years of talking about it, even writing about it, I still continually catch myself using the hot water tap when I do not need the hot water… even though I know better.

Changing habits, practices and cultures, like being green, is difficult. It is easier to crank up the compressed air pressure, or add a new compressor, rather than fix all the compressed air leaks in the existing system. Reusing an old design is easier than modifying it to "design in" efficiency.

Making a change rather than following a change management process is easier. It is easier to revert to the status quo rather than try to improve the system.

It is easier to idle a vehicle to get it warm and toasty (or cool and comfy, depending on where you are and the time of year) rather than getting into a cold (or hot) car and driving off. It is easier to leave a building, an office or a room and leave the lights on rather than turn the lights off. It is much easier to leave the light switches that way rather than arrange, order and install an occupancy sensor or photocell.

Comfort, ease and the status quo serve instant gratification, but there are negative consequences for taking the road most travelled. It is not up to one of us. It is up to all of us to change our habits, up our expectations, choose the best solution, not the easy one, and do everything more efficiently.

Will it be easy? No, like being green, it will not be easy. It will most likely be a difficult and rocky road, but worthwhile things are seldom easy, and the results will be worth it. wn

Lighting lives by giving energy to libraries

NESTLÉ BAR▪ONE announces a bold campaign to tackle loadshedding and raise the bar for students who #NEEDENERGY, at libraries across the country.

South Africans are bright thinkers. Even in the darkest hours of loadshedding, we look for smart solutions that help us see the light. According to Career Portal, universities have adjusted their academic programmes to be in line with the loadshedding schedule and others plan to implement hybrid teaching and learning methods. While this may be helpful, what can be done for those who #NeedEnergy now?

A MOVE IN THE BRIGHT DIRECTION

For the next five weeks, from 29 May to the 30th of June, NESTLÉ BAR▪ONE #needenergy – Light up the library initiative, is keeping the lights on through generator power in four libraries across South Africa to ensure that the communities – and students relying on these libraries continue to get the full services that the libraries offer. These libraries have been selected based on the most urgent needs; Winterveld Library in Tshwane has been without power since 2019, the Randburg Library in Johannesburg uses portable lights during loadshedding, and Beacon Bay Library in East London and Musgrave Library in Durban issue books manually during loadshedding. Each library is forced to capture relevant information manually which poses a significant risk to the facility's administrative maintenance. These are just a few examples of the issues faced by these facilities, resulting in a backlog of activities that need to be carried out to assist those needing the library.

BAR▪ONE is asking South Africa to retweet and share #needenergy one million times. Why? Because once the big goal is reached, BAR▪ONE will commit to installing solar energy into each of these libraries at a cost of R1 million. Each retweet and share is equivalent to #1Bar = R1. This will give the libraries reliable power into the foreseeable future.

"The NESTLÉ BAR▪ONE #needenergy – Light up the library initiative is about lighting lives by keeping the lights on. We understand the challenges posed by loadshedding for communities and especially the youth and how it affects their ability for them to perform at their optimum when it comes to their studies – especially at this time when they are preparing to write their mid-year exams. There are very few resources consistently available for learners during loadshedding and that is one of the direct reasons behind this campaign." says Zumi Njongwe, Business Executive Officer for Confectionary at Nestlé East and Southern Africa (ESAR).

DOING WHAT FEELS LIGHT

The campaign is supported by several leading youth voices that include DJ Sbu, Oskido, Sheldon Tatchell, Kovini Moodley, Mashudu Modau and leading Maskandi artist Khuzani Mpungose. From a creative perspective, creative expressionists such as, Gomora duo Lerato Mokoka and Sicelo Buthelezi, as well as Tik Tok stars Siphosethu Nkosi and Mess Jilla.

'I am an advocate for never letting my circumstances prevent me from fulfilling my dream. I believe that one is born clever, and we all can achieve what we set our visions on. This initiative by BAR▪ONE shows that South African brands understand the challenges that youth face and give back in a meaningful and impactful way. Libraries need energy to fuel the dreams of our youth – and I am encouraging every South African to get behind the campaign – one million shares and retweets. We can make this happen!" affirms, DJ Sbu.

"For more than 50 years, BAR▪ONE has been one of South Africa's favorite snack, offering an energy boost to active movers and shakers as they meet their demanding schedules and find success. Now, we're raising the bar even further", concludes Njongwe.

Help light up lives and give the libraries energy by visiting our Twitter page at Twitter. Retweet the pinned post or just reshare and tweet #needsenergy. Follow BAR.ONE on socials; Instagram: BARONE_SA, Twitter: @BarOne_SA and Facebook: BAR ONE. wn

CHIETA forges ahead with bridging the digital divide as it opens a SMART Skills Centre in Gqeberha

Yershen Pillay, CHIETA CEO.

The Chemical Industries Education and Training Authority (CHIETA) is continuing to blaze ahead with its mission to bridge the digital divide between rural and urban communities by opening yet another SMART Skills Centre that will aid in the acceleration of basic digital skills.

The SMART Skills Centre is located at the Port Elizabeth TVET College Iqhayiya campus, which is situated in the rural area of Gqeberha, which ensures easy accessibility for the local community and surrounding schools.

As part of the partnership with CHIETA, the college will provide infrastructure and security for the centre, while NEMISA will provide online learning programmes and MICT SETA will be responsible for providing ICT-related programmes. Further programmes will be determined and established once the specific needs of the community have been identified.

"This latest SMART Skills Centre is another tangible step by CHIETA towards our goal of ushering a new dawn for digital skills development and training for rural communities aimed at narrowing the digital divide that is still prevalent in our country," says CHIETA CEO Yershen Pillay.

"We envisage that the rollout of CHIETA SMART Skills Centres will ultimately contribute towards advancing rural communities' employability within various economic sectors, as it will enable skills development in line with the demands of emerging technologies and the 4IR."

Pillay adds that CHIETA is delighted to have taken a leading role in revolutionising digital skills development and training in South Africa by recognising the need to establish and roll out skills development platforms aligned to 4IR focus areas. This will play a major role in the reskilling and enhancing of the sector's workforce for jobs in the digital era, in response to rapid evolution of technology.

The SMART Skills Centre is equipped with 12 training pods, three virtual reality pods and a smart boardroom. All programmes offered at the centre will free and accessible to nearby rural communities, who will also receive access to social media platforms, free data and career guidance exhibitions. An electronic booking process will ensure that all community members have equal access to the centre and its services.

"As with all other CHIETA SMART Skills Centres, this centre's uniqueness lies in its accessibility to rural communities and the augmented reality or virtual reality-based training initiatives for artisans. Intelligent systems are fast becoming integrated into every aspect of our lives, which is bringing significant cultural and societal change on a global scale. It is important that we keep up with this trend in order to develop a future-ready workforce."

Other than offering programmes that will advance skills development for unemployed youth based on various technologies, including block chain, artificial intelligence, software development and data science, the centre will also provide access to online learning platforms that will guide local youth to start up successful and scalable data-driven commercial businesses. This enterprise will ultimately provide technological solutions that respond to needs of the local economy. wn

INDUSTRY AFFAIRS

Menlo Electric Brings Quality Solar Modules to South Africa Thanks to Cooperation with JA Solar

From left: Heino Louw, General Manager of South Africa at Menlo Electric, Bartosz Majewski, CEO at Menlo Electric, Marcin Zienkiewicz, Head of Procurement and Trading at Menlo Electric, Daniel Pasker, Head of Sales, Southern and East Africa at JA Solar, Hadyr Adebayo Koumakpai, General Manager of Africa at JA Solar.

Menlo Electric South Africa has become an official distributor of JA Solar, one of the world's leading manufacturers of high-performance solar products. This partnership marks a step forward in South Africa for both solar-focused brands at a key time, when transitioning to a more sustainable energy system is top of mind for all South Africans.

This partnership was solidified by a signing ceremony between the leadership of the two teams that occurred at The Future Energy Show in Johannesburg in April. Commenting on the partnership, Heino Louw, General Manager of Menlo Electric South Africa, said: "We are excited to partner with JA Solar, a company that shares our commitment to innovation and sustainability. With their high-quality products and our expertise in the South African market, we are confident that we can provide customers with the best possible solutions for their solar needs."

JA Solar, a Chinese-based company, is one of the world's leading manufacturers of high-performance solar products having been named a Global Top 500 New Energy Enterprises for multiple consecutive years. With the company's focus on innovation, quality, and sustainability, they have established themselves as a trusted provider of solar modules, cells, and inverters.

The partnership with Menlo Electric South Africa marks a significant milestone for JA Solar, as it expands its reach in the growing South African solar market. Menlo Electric South Africa, with their extensive network and experience in the industry, will provide JA Solar with a strong local presence and a reliable distribution network.

"We are excited to be entering the South African market at a time when the energy transition is picking up momentum within the country. I believe that Menlo Electric is the right company to partner with because of its extensive warehouse network, tailored logistics and convenient delivery methods." explained Daniel Pasker, Head of Sales – Southern and East Africa at JA Solar explained.

The partnership will also benefit customers in South Africa, who will now have access to JA Solar's cutting-edge solar technology and a range of high-performance products. With Menlo Electric South Africa's reputation for quality and customer service, customers can expect a seamless experience from start to finish.

This partnership comes at a critical time for South Africa, as the country seeks to transition to a more sustainable and resilient energy system. Solar power has the potential to play a significant role in this transition, as it is a clean and renewable source of energy that can help reduce the country's dependence on fossil fuels. wn

Reducing the cost of wind turbine foundations

Non-linear finite element analysis (NL-FEA) can save up to 30% in steel reinforcement costs for concrete structures for wind turbine foundations. Leading consulting engineering and infrastructure advisory firm Zutari is already achieving this cost-saving level on a renewable energy project in Madagascar, says Professor Pierre van der Spuy, Associate, Zutari.

Sourcing materials for such a remote location is logistically complex, adding significantly to the total project cost. Any possible saving has a much more significant impact than the material cost alone. While NL-FEA is not intended as a mainstream design solution, it is ideal for once-off structures like wind turbine foundations. Given the large number of renewable energy projects South Africa plans to have up and running within the next couple of years, optimising these at the design stage will fast-track the rollout and reduce costs.

A standard wind turbine foundation contains about 120 kg of reinforcement per cubic metre of concrete, equating to about R1.5 million of reinforcement per foundation. Using NL-FEA design to reduce the reinforcement per foundation by up to 30% for a wind farm of 30 wind turbines equates to a staggering R13.5 million saving, plus a significant reduction in the carbon footprint. "We are trying to be more accurate in looking at prestressed or reinforced concrete structures to reduce the project risk. The result is considerable savings for both client and contractor," says Professor van der Spuy.

Conventional FEA packages operate in the linear-elastic regime of concrete and other materials. On the other hand, NL-FEA develops accurate material models for concrete that consider softening post-yield until ultimate failure occurs.

Prof Pierre van der Spuy
Associate | Zutari

"Rather than being conservative in our approach towards concrete structures, we aim to be more accurate," highlights Professor van der Spuy. Concrete is a non-linear material that resists tension but endures compression. Therefore, capturing its true behaviour as a material is difficult with conventional FEA packages.

"By adopting NL-FEA instead, we can utilise the material's true properties in a way that cannot be done otherwise in a linear method or through hand calculations, both methods that err on the side of caution," says Professor van der Spuy.

NL-FEA dives into the heart of concrete, presenting opportunities in other areas like forensics. "Fortunately, concrete structures do not collapse that often. In such situations, we can look at the behaviour of a specific part of a structure and achieve much more accurate results than with standard methodologies," says Professor van der Spuy.

Another application is bridge engineering, where many of South Africa's bridges are 50, 60 and even 70 years old. Assessing these structures using conventional methods often recommends that they be demolished or strengthened as they no longer comply with modern criteria and standards. However, NL-FEA is far more refined and accurate in looking at particular sections only, preventing the entire structure from being condemned. It is even possible to apply NL-FEA to other concrete-intensive infrastructures such as dam walls, which typically have heat problems as the concrete hydrates. "The software even allows us to model cooling pipes in concrete," says Professor van der Spuy. Regarding wind turbine foundations, NL-FEA design can be used to tweak the geometry so that any heat build-up is dissipated toward the edges.

"It is a bit more effort from the design perspective, but the benefit is so vast from a construction perspective that additional design costs are easily offset." Zutari is not reinventing the wheel, as a European company is already using the method for wind turbine foundation design. "We are bringing this methodology to the local market as an affordable design option with significant benefits," concludes Professor van der Spuy. wn

2023 SAIEE Membership Benefits update

DEAR SAIEE MEMBER,

With great excitement, I am writing this letter to update you on the recently approved membership benefits. The SAIEE Council meeting of 5 May 2023 approved a tabled report on the stratified membership benefits, allocating benefits according to grades and addressing known membership complaints. This also talks to our strategy document, which specified some shortfalls in our current operating model, and this effort sets out to address those shortfalls.

The changes herein aim to set out compelling reasons to become an SAIEE member and why members should upgrade to the next membership grade when they are eligible to:

- First and foremost, the fee payable to upgrade to the next membership grade, once eligible to do so, has been scrapped. Effective immediately, there is no cost to upgrade, which augers well with members eligible to upgrade and who are already paying the next grade's fees.

- Secondly, not only has the upgrade fee been scrapped, but you will also receive/get a once-off discount on your annual fees on the year you upgrade. The quantum of the discount is dependent on the number of years that you have been a member of the institute. Below is the table that depicts the quantum of the discount you will receive upon upgrade.

LENGTH OF MEMBERSHIP	ONCE-OFF MEMBERSHIP FEE DISCOUNT UPON UPGRADE
10 – 19 years	5%
20 - 39 years	10%
40+ years	15%

- We will implement a jobs portal wherein members can browse available positions within various Corporates and Corporate Partners. This will be ideal for you if you are looking for that long-time coming change in your career. Together with job listings, Work Integrated Learning (WIL) opportunities for Student members will also be listed on the portal.

- We are establishing a free mentorship program wherein qualified and experienced SAIEE members will provide a mentorship service to SAIEE members who require it. This offer will be exclusive to SAIEE members.

- SAIEE members who are service providers can list their areas of specialization and offerings on the SAIEE Services Directory, which will be accessible to the wider public. This will be a free service to market your business/ services as a service provider.

- Every quarter, we will host an SAIEE Technical Talk (ST-Talks) event featuring a topical subject and an impactful presenter/speaker. We will host these in a hybrid format to enable those out of town to attend. These events will address a need which is the very essence of the objective of our voluntary association: Networking.

- Since we are always looking to provide you with improved benefits, SAIEE members who attend courses offered by the SAIEE Training Academy will get Charge reward points.

- SAIEE members will receive a gift every time they celebrate a decade/multiple decades of SAIEE membership. Once implemented, the gifts will not be backdated.

- SAIEE members will have access to international journals, which the SAIEE will get access to. This will be a great way to keep you as a member abreast of technology and information.

- When calling for bursary applications, SAIEE members and their immediate family will be given preference on SAIEE-provided bursaries. This benefit excludes bursaries managed on behalf of third parties.

The table on the next page shows the approved benefits.

We will embark on the modernization and digitization of the SAIEE starting in the current year. The above-stratified membership benefits will be implemented into the website as part of the digitization project, which is envisaged to be completed in 2024. Upon completing the project, you can exercise those benefits as a member in a refreshingly different environment.

LEANETSE MATUTOANE | CEO | SAIEE

2023 SAIEE MEMBER BENEFITS

STUDENT MEMBER

- Jobs portal for WIL
- Mentorship
- Exclusive Networking Events
- CPD training discounts
- Charge Reward Programme earnings
- Bursary programme
- Publication access (**wattnow** & ARJ)
- Site visits
- SAIEE Centres

ASSOCIATE MEMBER

- Jobs portal access
- Mentorship
- Exclusive Networking Events
- CPD training discounts
- Charge Reward Programme earnings
- Bursary programme
- Publication access (**wattnow** & ARJ)
- Site visits
- SAIEE Centres

MEMBER

- Jobs portal access
- Mentorship
- Exclusive Networking Events
- CPD training discounts
- Charge Reward Programme earnings
- Long standing member gifts
- Bursary programme
- Publication access (**wattnow** & ARJ)
- Site visits
- SAIEE Centres

SENIOR MEMBER

- Jobs portal access
- Services Directory
- Mentorship
- Exclusive Networking Events
- CPD training discounts
- Charge Reward Programme earnings
- Long standing member gifts
- Bursary programme
- Publication access (**wattnow** & ARJ)
- Site visits
- SAIEE Centres
- Eligibility for nomination as Center Chair

FELLOW

- Jobs portal access
- Services Directory
- Mentorship
- Exclusive Networking Events
- CPD training discounts
- Charge Reward Programme earnings
- Long standing member gifts
- Bursary programme
- Publication access (**wattnow** & ARJ)
- Site visits
- SAIEE Centres
- Eligibility for nomination as Center Chair
- Eligibility for nomination as an Office Bearer

MEMBERSHIP UPGRADE DISCOUNT STRUCTURE

LENGTH OF MEMBERSHIP	DISCOUNT UPON UPGRADE
10 - 19 years	5%
20 -39 years	10%
40+ years	15%

Become a member today and start earning the rewards!

The South African Institute of Electrical Engineers | T: 011 487 3003 | www.saiee.org.za

"Nigeria's industry is rising to the twin challenge of decarbonisation and energy security"

Wale Yusuff, the Managing Director of Wärtsilä in Nigeria, explains how businesses operating in energy-intensive industries like cement or steel invest in flexible engine technologies to secure reliable and efficient power while setting the perfect stage to make good on their decarbonisation objectives.

Nigeria is a major industrial hub. It is home to energy-intensive manufacturing businesses whose operations, and growth potential, are constrained by the weakness of the country's electricity supply. To mitigate this, industrial companies have been building their power generation capabilities, but the result has often been the reliance on expensive and polluting diesel generators. As such, the industrial sector represents one of the country's largest sources of greenhouse gas emissions.

In most African countries, developing renewable energy capacity is a competitive solution that industrials can adopt to lower their environmental impact and energy costs. But things aren't as clear-cut in Nigeria. Most of its industrial activity is in the south, a region where wind and solar resources are often unavailable in the right quantity to make renewables competitive at today's equipment prices.

It leaves industrials with a twin challenge to meet. First and foremost, they need to secure their own reliable and affordable power capacity by buying electricity from an independent power producer or building their own "captive" plant. Second, they need to integrate decarbonisation into their overall energy strategy. Both objectives are not contradictory. By making smart technology choices, forward-looking businesses like BUA Cement, African Foundries, Lafarge, Wempco, Nestle and Flour Mills have found a way to hit these two birds with one stone. Here is how.

Securing a reliable supply of electricity

Mitigating power generation risk is critical to Nigeria's industrial growth. As one of the world's largest producers of liquified natural gas (LNG), Nigeria is strongly interested in developing its utilisation to power local industries.

Fuel-flexible engine technology provides a great hedge against fuel supply risk as it can operate on multiple types of fuels, from gas to heavy or light fuel oil, and switch between fuels while operating. This fuel flexibility is also a key enabler to the decarbonisation strategy of industrials, as engine power plants can be converted to run on sustainable fuels like biofuels and green hydrogen, ammonia, or methanol when these become available. That's why flexible engine power plants have emerged as the technology of choice for Nigeria's industries.

Thanks to their modular design, Wärtsilä engine power plants are easy to construct, fully scalable and can be deployed in phases. They have the flexibility to be ramped up or down quickly to adjust to demand, they have a high operating efficiency even at partial load and are designed to cope with regular stops and starts. This very high

Wale Yusuff, Managing Director, Wärtsilä Nigeria.

operating flexibility is also needed to integrate intermittent renewable energy capacity into the power mix. Moreover, they require much less water to function than competing power technologies, which is an important water conservation consideration in light of Nigeria's long dry seasons.

With all these attributes, flexible engine power plants offer a cost-effective solution to meet energy demand in the short term and environmental objectives in the longer term.

BUA Cement PLC, one of Nigeria's largest cement producers, is one example of an energy-intensive industrial company which has invested in securing its own flexible and reliable power supply and decreasing its carbon footprint. As the demand for cement is increasing every year, BUA has taken advantage of the modularity of engine technology to increase its power capacity in stages. The company is installing a 70 MW power plant for line 4 in its Sokoto cement plant, NW Nigeria. This is in addition to a 50 MW power plant commissioned two years earlier for line 3 of the same cement plant. Future expansion plans include another 70MW for its OBU line 3 cement plant in Edo State SW by the end of 2023.

The plants feature Wärtsilä 34 DF dual-fuel engines operating primarily with LNG and PNG but with the flexibility to switch to an alternative fuel should there be interruptions to the gas supply, quality, or pressure. Moreover, the Wärtsilä engines' operational flexibility provides future-proofing advantages by enabling the potential integration of renewable energy further down the line.

PAVING THE WAY FOR RENEWABLES

Nigeria's long-term energy strategy has defined the rapid deployment of renewables and strengthening the power transmission network as key objectives. By investing in gas engine power plants, energy-intensive industries will decrease their carbon footprint and free up resources for the government to expand the transmission network, enabling the entire country to benefit from the natural gas reserves located in the south and renewable resources in the north. But it must also overcome the specific challenges of the tropical monsoon climate in the industrialised south of the country, where the solar and wind potential is 30% and 40% lower than in the hot and semi-arid conditions in the north.

Paras Energy sets an example of how this can work. Since installing a 132 MW Wärtsilä gas engine power plant in Ikorodu in Lagos State and Ogijo in Ogun State, Paras Energy is supplying the company's steel production needs as well as providing power to the Nigerian grid to support over 20,000 homes annually. The company is now commissioning a 10 MW solar power plant in Suleja, and a 5 MW solar rooftop system for commercial and industrial customers is under development.

Flexible engine power plants represent a smart and future-proof investment for Nigeria's energy-intensive industries. They offer the efficient power capabilities needed to offset the shortcomings of the national power grid, strengthen their global competitiveness, and reduce their GHG emissions today and tomorrow. By working towards the country's decarbonisation targets, the smart energy investments made by industry will benefit the country. wn

Milken-Motsepe Prize in Green Energy Semi-Finalists Announced

20 teams to share $400,000 in funding to develop and test innovative green energy technologies around the world

The Milken Institute and the Motsepe Foundation today announced the 20 teams receiving Design Round prizes for the Milken–Motsepe Prize in Green Energy and advancing to the Semi-finalist Round. At this stage, each semi-finalist team will receive $20,000 to develop further and test their designs anywhere in the world. The semi-finalist teams will also have complimentary access to a Stanford Online course to help build their businesses.

The competition will ultimately award US$2 million in prizes and additional benefits for entrepreneurs expanding access to reliable, affordable, and sustainable electricity in Africa.

More than 3,800 people from over 120 countries have registered their interest in the competition, which launched in November 2022. Over 160 registrants, representing 36 countries across six continents, submitted technological design and business model proposals. From these proposals, the judges selected the 20 most transformative ideas.

"Access to electricity is vital to transforming societies—from health care to education to economic growth. We are excited to see these semi-finalists bringing new ideas to the forefront to light the way to a sustainable future," said Dr Precious Moloi-Motsepe, co-founder and CEO of the Motsepe Foundation. "As recently proven by the winners of the Milken–Motsepe Prize in AgriTech, innovators have the power to create transformative solutions to challenges once thought impossible. We have no doubt these semi-finalists will do the same."

An independent panel of expert judges determined the 20 teams receiving funding. The teams have four months to demonstrate the effectiveness of their ideas in field tests, which will be evaluated for their ability to:

Generate off-grid electricity using green energy sources;

Provide affordable and reliable electricity to energy-poor communities, including in rural areas, using innovative technologies; and

Develop a technological and business approach that is scalable across Africa.

These teams represent 12 countries across three continents. Their innovations include potential breakthroughs in wind, solar, hydro, and geothermal electricity generation and energy storage and distribution. After the Semi-finalist Round, five finalist teams will be selected to conduct another round of field tests in Africa.

"The innovation competition encourages entrepreneurs to be creative and expansive," said Dr Emily Musil Church, senior director at the Milken Institute's Center for Strategic Philanthropy. "By allowing field tests anywhere in the world in the first round, the competition allows flexibility for teams to take strategic risks. This is the heart of the innovation competition model: to reward innovators who take bold action."

In May 2024, the judges will award a $1 million Grand Prize. A Runner-Up Prize of $250,000 will also be awarded.

View the names of the semi-finalist teams. wn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South Africa's power crisis: going off the grid works for the wealthy

– BUT COULD DEEPEN INJUSTICE FOR THE POOR

South Africa's current electricity crisis has been described as "a perfect storm". A number of factors have converged to reach this point: an ageing and inadequately maintained fleet of coal power stations, delays in upgrading the Koeberg nuclear power station and significant failures at the recently built Medupi and Kusile coal power stations.

By: Christina Culwick Fatti & Samkelisiwe Khanyile

Since the beginning of 2022, power utility Eskom's inability to meet the country's electricity demand has resulted in unprecedented loadshedding (scheduled power cuts). In 2022, electricity interruptions totalled 3,775 hours over 205 days. The situation almost certainly will not improve any time soon.

At the same time, Gauteng – South Africa's most populous province and its economic hub – has experienced critical water supply issues. In late 2022 and early 2023, the combined impact of heat waves, intermittent pumping of water because of electricity interruptions and infrastructure failure has led to demand outstripping water supply. Residents of Gauteng's biggest municipalities have experienced near-daily low water pressure or water cuts.

Many private individuals and businesses are investing in alternative electricity and water sources. The exact number is uncertain – most systems are not registered.

Alternative investments include water tanks, boreholes, solar panels and diesel generators. These solutions cost anywhere from R4,000 (about US$220) for rainwater tanks and up to R180,000 (almost US$10,000) for a borehole.

The cost of installing residential solar panels is anywhere from R8,000 (about US$440) to R10,000 (around US$550) per kWp (a measure of how high the panels' power output is). Inverters and batteries are also pricey. Even with financing options, most households can't afford alternatives.

These investments are generally efforts to maintain a level of normality and to survive through unreliable water and electricity supply. But the cumulative effect of these individual actions could have significant consequences for inequality and service provision for the poor. South Africa is already one of the most unequal countries in the world.

Poor people are less able to afford alternatives for power and water. There's also the risk that municipalities will gradually be unable to cross-subsidise services to the poor as they lose revenue from wealthy consumers.

Social justice considerations have been at the forefront of South Africa's just transition from coal-based to renewable electricity generation. But this has largely focused on the labour force and affected communities. Less attention has been paid to the justice implications of electricity distribution.

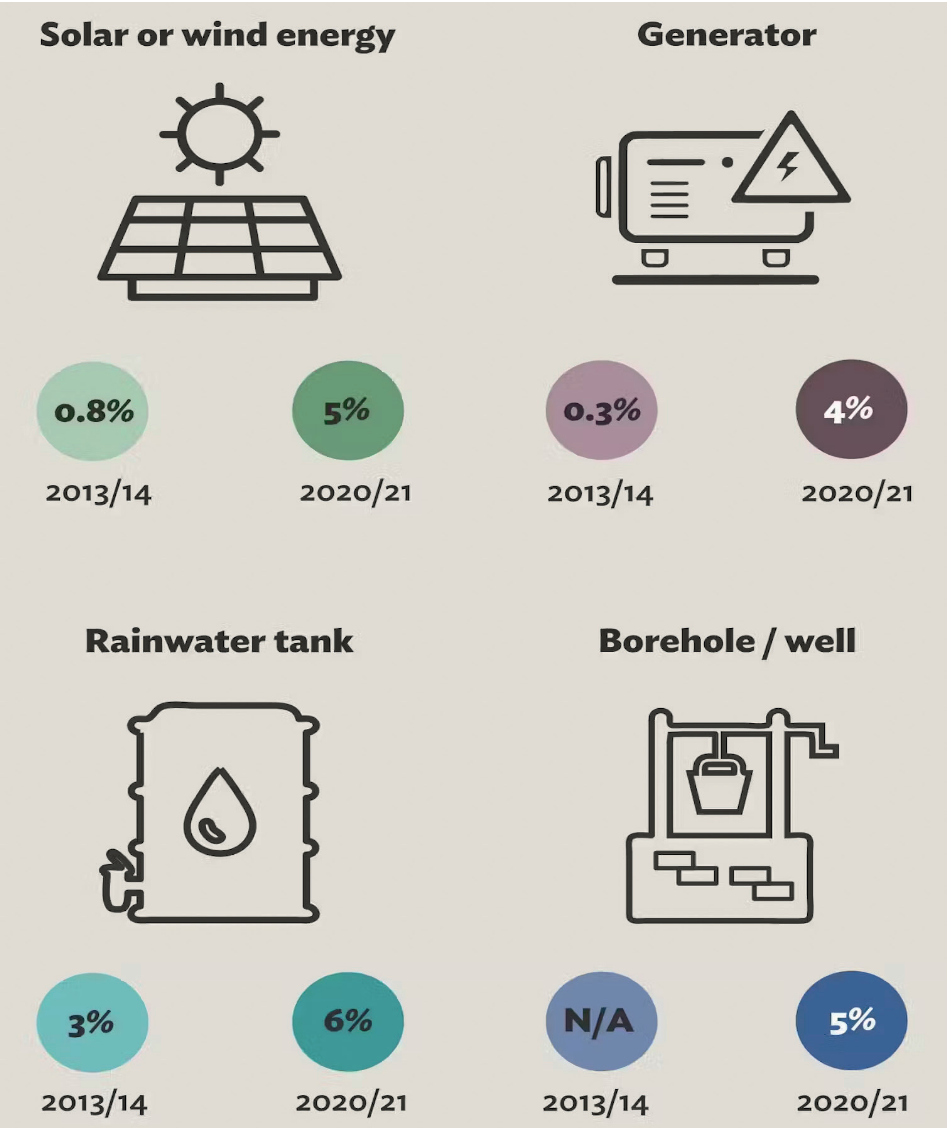
Despite the potential negative consequences of private investments in off-grid water and electricity, these

could be mobilised to help address the current crises rather than exacerbate it. However, this requires re-imagining the role of the state and citizens, reworking municipal funding models, and encouraging private investors to support the grid in various ways.

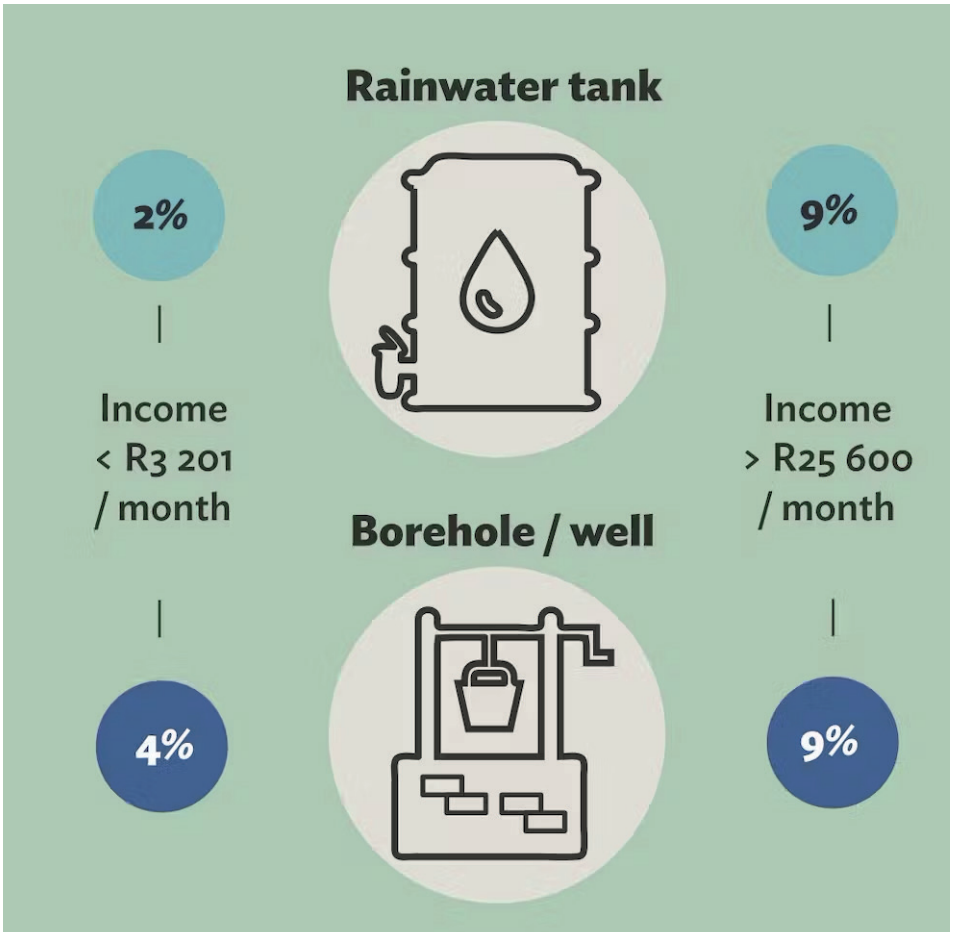
What do the Quality of Life data tell us? In early February 2023 we used survey data from 2013 to 2021 to show how Gauteng households were investing in alternative electricity and water provision. We examined who was accessing these alternative sources and who was not.

The data for this project was drawn from the Gauteng City-Region Observatory (GCRO)'s regular Quality of Life survey, which is designed to gather a representative sample of Gauteng residents. It includes questions about demographics, living conditions and socio-economic circumstances. All the datasets are freely available to download through the University of Cape Town's DataFirst platform.

The data reveal that access to alternative electricity and water sources has increased over time. In 2013/14,



Household access to alternative electricity and water sources is increasing over time.



Affluent households are more likely to have access to alternative water sources than poor households

only 0.8% of residents reported having access to solar or wind energy, while 0.3% had a generator.

By 2020/21, these figures had jumped to 5% and 4%, respectively. Despite this increase, only a small minority of Gauteng residents (about 1 in 20) have access to alternative water and electricity.

Affluent households are proportionately more likely to invest in alternative electricity and water sources than poorer households. In 2020/21, 2% of respondents with a monthly household income below R3,201 (around US$177) had a rainwater tank. Some 4% of this income group had a borehole or well.

In contrast, 9% of the respondents in the higher income groups – a monthly household income over R25,600 (about US$1,415) – had access to a rainwater tank or borehole.

The uneven increase in access to alternative electricity is particularly notable. Access to solar power grew from 0.3% in 2015/16 to 3% in 2020/21 for households earning less than R800/month. For the highest income group (monthly household income more than R51,200), access to solar increased from 4% to 12% over the same period.

IMPLICATIONS FOR A JUST TRANSITION

The gap is clearly widening between affluent households who can shield themselves from electricity and water interruptions, and poorer households who cannot afford to do so.

And this gap could widen further because of how municipal services are financed. Under the current funding model, municipalities depend on revenue from basic service provision (electricity, water and refuse) to fund their mandated activities. They use the revenue from industries, businesses and wealthy consumers to cross-subsidise services for the poor.

This model has been critiqued for being unsustainable and creating perverse incentives for municipalities to elevate tariffs and encourage high users to keep consuming electricity. But it at least ensures access to services for poor households.

The current move by residents and businesses towards self-generated electricity has potentially dire consequences for municipalities' ability to ensure fiscal stability and equitable access to services.

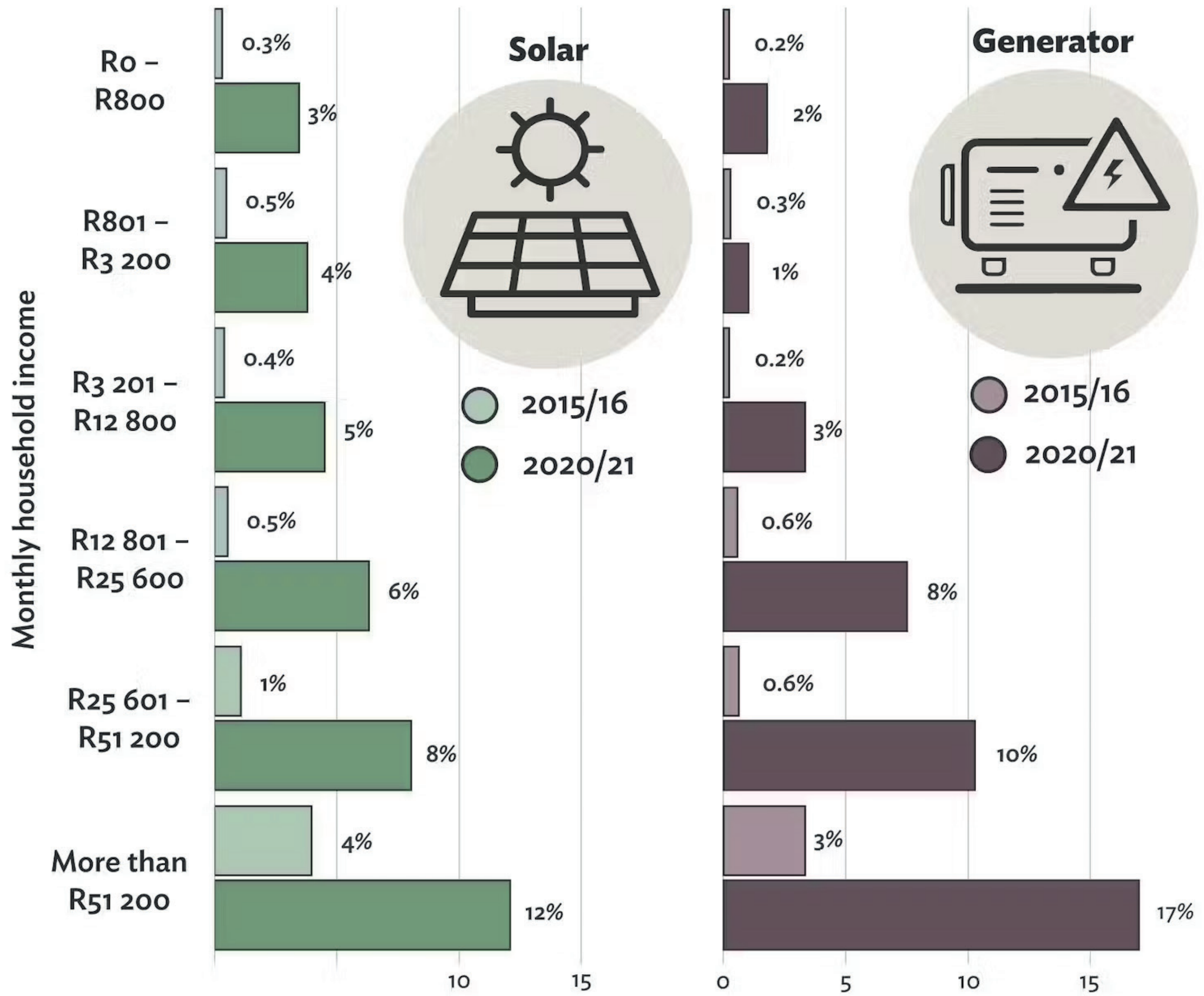
It also has some technical drawbacks. Private investments have the potential to add strain and complexity to the grid. Grid-charged battery systems increase electricity consumption and post-loadshedding peaks. Solar photovoltaic installations reduce pressure on the grid during the day. But, they leave the evening peak unchanged. Power plants must continue producing electricity in excess during the daytime demand to ensure they can meet the evening peak.

Private borehole installations could cause uneven depletion of aquifers. They could also negatively affect groundwater management and undermine the availability of these water resources for broader society.

Mobilising private investments

However, there are opportunities to harness private investments to cope with the current electricity and potential future water crises.

Municipalities are beginning to give



Over time, wealthier households have accessed alternative electricity substantially more than poorer households

households and businesses incentives to sell their excess power back to the grid. This could reduce the cost of electricity for municipalities, maximising their ability to cross-subsidise service delivery for the poor.

Where households and businesses have invested in batteries, they could store solar energy and sell it back to the grid during the evening peak. wn

Electricity Market Report 2023

Electricity is central to many parts of life in modern societies and will become even more so as its role in transport and heating expands through technologies such as electric vehicles and heat pumps.

Power generation is currently the largest source of carbon dioxide (CO_2) emissions globally, but it is also the sector that is leading the transition to net zero emissions through the rapid ramping up of renewables such as solar and wind. At the same time, the current global energy crisis has placed electricity security and affordability high on the political agenda in many countries.

The International Energy Agency's Electricity Market Report 2023 offers a deep analysis of recent policies, trends and market developments. It also provides forecasts through 2025 for electricity demand, supply and CO_2 emissions – with a detailed study of the evolving generation mix. This year's report contains a comprehensive analysis of developments in Europe, which faced a variety of energy crises in 2022. The Asia Pacific region also receives special focus, with its fast-growing electricity demand and accelerating clean energy deployment.

The IEA's Electricity Market Report has been published since 2020. Its relevance goes beyond energy and climate issues, since electricity supply impacts economies, regional development, the budgets of businesses and households, and many other areas. It is indispensable reading for anyone interested in the multifaceted importance of energy in our economies and societies today.

World electricity demand remained resilient in 2022 amid the global energy crisis triggered by Russia's invasion of Ukraine.

Demand rose by almost 2% compared with the 2.4% average growth rate seen over the period 2015-2019. The electrification of the transport and heating sectors continued to accelerate globally, with record numbers of electric vehicles and heat pumps sold in 2022 contributing to growth. Nevertheless, economies around the world, in the midst of recovering from the impacts of Covid-19, were battered by record-high energy prices. Soaring prices for energy commodities, including natural gas and coal, sharply escalated power generation costs and contributed to a rapid rise in inflation.

Economic slowdowns and high electricity prices stifled electricity demand growth in most regions around the world.

Electricity consumption in the European Union recorded a sharp 3.5% decline year-on-year (y-o-y) in 2022 as the region was particularly hard hit by high energy prices, which led to significant demand destruction among industrial consumers. Exceptionally mild winter added further downward pressure on electricity consumption. This was the EU's second largest percentage

decrease in electricity demand since the global financial crisis in 2009 – with the largest being the exceptional contraction due to the Covid-19 shock in 2020.

Electricity demand in India and the United States rose, while Covid restrictions affected China's growth. China's zero-Covid policy weighed heavily on its economic activity in 2022, and a degree of uncertainty remains over the pace of its electricity demand growth. We currently estimate it to be 2.6% in 2022, substantially below its pre-pandemic average of over 5% in the 2015-2019 period.

Further data expected in due course will provide greater clarity on trends in China in 2022, which could also have implications for the global picture. Electricity demand in India rose by a strong 8.4% in 2022, due to a combination of its robust post- pandemic economic recovery and exceptionally high summer temperatures. The United States recorded a significant 2.6% y-o-y demand increase in 2022, driven by economic activity and higher residential use to meet both heating and cooling needs amid hotter summer weather an a colder-than-normal winter.

Renewables and nuclear energy will dominate the growth of global electricity supply over the next three years, together meeting on average more than 90% of the additional demand. China accounts for more than 45% of the growth in renewable generation in the period 2023-2025, followed by the EU with 15%.

The substantial growth of renewables will need to be accompanied by accelerated investments in grids and flexibility for their successful integration into the power systems. The increase in nuclear output results from an expected recovery in French nuclear generation as more plants complete their scheduled maintenance, and from new plants starting operations, largely in Asia.

Global electricity generation from both natural gas and coal is expected to remain broadly flat between 2022 and 2025. While gas-fired generation in the European Union is forecast to decline, significant growth in the Middle East will partly offset this decrease. Similarly, drops in coal-fired generation in Europe and the Americas will be matched by a rise in Asia Pacific. However, the trends in fossil-fired generation remain subject to developments in the global economy, weather events, fuel prices and government policies.

Developments in China, where more than half of the world's coal- fired generation occurs, will remain a key factor.

China's share of global electricity consumption is forecast to rise to one-third by 2025, compared with one-quarter in 2015. Over the next three years, more than 70% of the growth in global electricity demand is set to come from China, India and Southeast Asia combined. Emerging and developing economies' growth is accompanied by a corresponding rise in demand for electricity. At the same time, advanced economies are pushing for electrification to decarbonise their transportation, heating and industrial sectors. As a result, global electricity demand is expected to grow at a much faster pace of 3% per year over the 2023-2025 period compared with the 2022 growth rate. The total increase in global electricity demand of about 2 500 terawatt-hours (TWh) out to 2025 is more than double Japan's current annual electricity consumption.

Nevertheless, uncertainties exist regarding the growth of electricity demand in China. While the country recently eased its stringent Covid restrictions in early December 2022, the full extent of the economic impacts remain unclear.

AFTER REACHING AN ALL-TIME HIGH IN 2022, POWER GENERATION EMISSIONS ARE SET TO PLATEAU THROUGH 2025

Global CO_2 emissions from electricity generation grew in 2022 at a rate similar to the 2016-2019 average. Their increase of 1.3% in 2022 is a significant slowdown from the staggering 6% rise in 2021, which was driven by the rapid economic recovery from the Covid shock. Nonetheless, electricity generation-related CO_2 emissions reached a record high in 2022.

The share of renewables in the global power generation mix is forecast to rise from 29% in 2022 to 35% in 2025. As renewables expand, the shares of coal- and gas-fired generation are set to fall. As a result, emissions of global power generation will plateau to 2025 and its CO_2 intensity will further decline in the coming years.

THE EUROPEAN UNION SAW GAS-FIRED GENERATION INCREASE DURING A TURBULENT 2022

Due to historic drought conditions, hydropower generation in Europe was particularly low in 2022. Italy saw a drop in hydropower generation of more than 30% compared with its 2017- 2021 average, followed closely by Spain. Similarly, France recorded a 20% decline in its hydro output compared with the previous five- year average.

Nuclear generation in the European Union was 17% lower in 2022 than in 2021 due to closures and unavailabilities. Plant closures in Germany and Belgium reduced the available nuclear capacity in 2022. At the same time, France faced record-low nuclear availability due to ongoing maintenance work and other challenges in its nuclear fleet. The constrained nuclear output and low hydropower supply in Europe – combined with reduced dispatchable capacity due to previous retirements of thermal generation plants – put additional pressure on remaining dispatchable capacities to meet demand. As a result, although variable renewable generation grew and record-high gas prices supported fuel-switching from gas to coal, gas-fired generation grew in 2022 by 2% in the European Union. These factors have also contributed to significant changes in the traditional import-export structure of electricity in Europe: France became a net importer and the United Kingdom a net exporter for the first time in decades.

In order to increase the security of electricity supply, reserve capacities of conventional power generation have been brought back in Europe for the 2022-2023 and 2023-2024 winters. Similarly, some plants that were previously set to be decommissioned were also extended. Germany had the highest share of such plants in Europe, having delayed the planned shutdown of its three remaining nuclear reactors, as well as delaying the closure or reactivating fossil-fired plants that make up 15% of its current fossil-fired generation capacity. An increased risk of power outages was reported in some European countries during several weeks of cold weather combined with lower-than-average hydro and nuclear output. Security of supply was achieved through successful short-term planning and management.

WHILE THE CO2 INTENSITY OF GLOBAL POWER GENERATION DECREASED IN 2022, IT INCREASED IN THE EUROPEAN UNION

After 2021, 2022 marks the highest percentage growth in CO_2 emissions of EU power generation since the oil crises of the 1970s, recording a 4.5% year-on-year growth. Excluding the 2021 post-pandemic rebound, the European Union also saw in 2022 the highest absolute growth in power generation emissions since 2003. This was mainly due to a rise in coal-fired generation of more than 6% in stark contrast to the almost 8% average annual rate of decline in coal-fired generation over the pre-pandemic period of 2015-2019.

The setback in the European Union will be temporary, however, as power generation emissions are expected to decrease on average by about 10% annually through 2025. Both coal- and gas-fired generation are expected to see sharp falls, with coal declining by 10% and gas by almost 12% annually on average over the outlook period as renewables ramp up and nuclear generation recovers.

ELECTRICITY PRICES REMAIN HIGH IN MANY REGIONS, WITH RISKS OF TIGHT SUPPLY IN EUROPE NEXT WINTER

The increase in wholesale electricity prices was most pronounced in Europe in 2022, where they were, on average, more than twice as high as in 2021. The exceptionally mild winter so far in 2022/23 in Europe has helped temper wholesale electricity prices, but they remain high compared with recent years. Elevated futures prices for winter 2023/24 reflect the uncertainties regarding gas supply in Europe over the coming year.

In the European Union, a wide range of responses to the energy crisis have been observed. In order to reduce reliance on fossil fuels and to increase resilience to price shocks, the European Commission published its REPowerEU plan in May 2022 to accelerate clean energy deployment. At the same time, discussions about electricity market design gained momentum due to soaring wholesale prices, and the Commission launched a consultation on market design reform. To dampen the effects of high electricity prices on consumers, many countries introduced measures such as the regulation of wholesale and retail prices; revenue caps on infra- marginal technologies such as renewables, nuclear and coal-plants; reductions of energy taxes and VAT; and direct subsidies.

While such market interventions can help mitigate the impacts of the energy crisis, the potential creation of uncertainty in the investment landscape needs to be minimised to ensure that responses to the crisis do not come at the expense of much-needed investment.

AFFORDABILITY WILL CONTINUE TO BE A CHALLENGE FOR EMERGING AND DEVELOPING ECONOMIES

Globally, higher electricity generation costs in 2022 were driven by surging energy commodity prices. While the cost increases were more moderate in countries with regulated tariffs and long-term fuel supply agreements (oil-indexed LNG, long-term contracts or fuel supply contracts), regions dependent on short-term markets for fuel procurement were severely affected. In particular, record-high LNG prices led to difficulties for South Asian countries trying to procure gas for the power sector, which contributed to blackouts and rationing of electricity in the region. If prices of energy commodities remain elevated, fuel procurement will continue to be a serious issue for emerging and developing economies.

NUCLEAR POWER IS GATHERING PACE IN ASIA, CURBING THE CO_2 INTENSITY OF POWER GENERATION

The energy crisis has renewed interest in the role of nuclear power in contributing to energy security and reducing the CO_2 intensity of power generation. In Europe and the United States, discussions on the future role of nuclear in the energy mix have resurfaced. At the same time, other parts of the world are already seeing an accelerated deployment of nuclear plants. As a result, global nuclear power generation is set to grow on average by almost 4% over 2023-2025, a significantly higher growth rate than the 2% over 2015-2019. This means that in every year to 2025, about 100 TWh of additional electricity is set to be produced by nuclear power, the equivalent of about one-eighth of US nuclear power generation today.

More than half of the growth in global nuclear generation to 2025 comes from just four countries: China, India, Japan and Korea. Among these countries, while China leads in terms of absolute growth from 2022 to 2025 (+58 TWh), India is set to have the highest percentage growth (+81%), followed by Japan. This results from the Japanese government's push to ramp up nuclear generation in order to reduce reliance on gas imports and strengthen energy security. Outside Asia, the French nuclear fleet provides more than one-third of the absolute growth in global nuclear generation to 2025 as it gradually recovers.

EXTREME WEATHER EVENTS HIGHLIGHT THE NEED FOR INCREASED SECURITY OF SUPPLY AND RESILIENCE

In a world where both the demand and supply of electricity are becoming increasingly weather-dependent, electricity security requires increased attention. Along with the high cost of electricity generation, the world's power systems also faced challenges from extreme weather events in 2022. In addition to the drought in Europe, there were heatwaves in India, where the hottest March in over a century was recorded, resulting in the country's highest ever peak in power demand. Similarly, central and eastern China were hit by heatwaves and drought, which caused demand for air conditioning to surge amid reduced hydropower generation in Sichuan. The United States saw severe winter storms in December, triggering massive power outages. Mitigating the impacts of climate change requires faster decarbonisation and accelerated deployment of clean energy technologies. At the same time, as the clean energy transition gathers pace, the impact of weather events on electricity demand will intensify due to the increased electrification of heating, while the share of weather-dependent renewables will continue to grow in the generation mix. In such a world, increasing the flexibility of the power systems while ensuring security of supply and resilience will be crucial.

GLOBAL OVERVIEW - DEMAND

The energy crisis sparked by the Russian Federation's (hereafter "Russia") invasion of Ukraine has been characterised by record-high commodity prices, weaker economic growth and high inflation.

Higher fuel prices increased the cost of electricity generation around the world, putting downward pressure on consumption in many regions. Despite the worsening crisis, global electricity demand remained relatively resilient, growing by almost 2% in 2022.

By 2025, for the first time in history, Asia will account for half of the world's electricity consumption and one-third of global electricity will be consumed in China. Over the outlook period, global electricity demand is set to grow at an accelerated pace, by an annualised 3%, as electricity consumption increases in emerging markets and developing economies (EMDEs), led by the People's Republic of China (hereafter "China"), India and Southeast Asia.

As the energy crisis abates, global electricity demand growth is set to rise from 2.6% in 2023 to an average 3.2% in 2024-2025. This stronger growth is well above the pre-pandemic rate of 2.4% observed in the 2015-2019 period. Indeed, by 2025 demand will increase by 2 500 TWh from 2022 levels, which means that over the next three years the electricity consumption added each year is roughly equivalent to that of the United Kingdom and Germany combined. More than half of the increase will come from China. The remaining growth will largely take place in India and Southeast Asia.

In China, electricity demand growth was subdued on weaker economic activity in 2022, rising at an estimated 2.6%, and significantly below its trend of 5.4% in 2015-2019. China is by far the world's largest electricity consumer at 31% of global demand in 2022. For 2023-2025 we expect an average annual growth of 5.2%.

In India, the robust post-pandemic recovery continued to support strong electricity demand of over 8.4% in 2022, which was substantially higher than the average annual growth rate of 5.3% seen in the 2015-2019 period.

The peak summer season also arrived early in 2022, resulting in the hottest March in over a century. Electricity demand from March to July was 12% higher than the same period in 2021. For the 2023-2025 period, we expect slightly slower growth, averaging 5.6% per year.

Electricity demand in the European Union (EU) fell 3.5% in 2022, with spiking electricity prices, demand destruction in electricity- intensive industries, energy saving measures and a mild winter all contributing to the decline. We expect EU demand to grow by around 1.4% on average in 2023-2025.

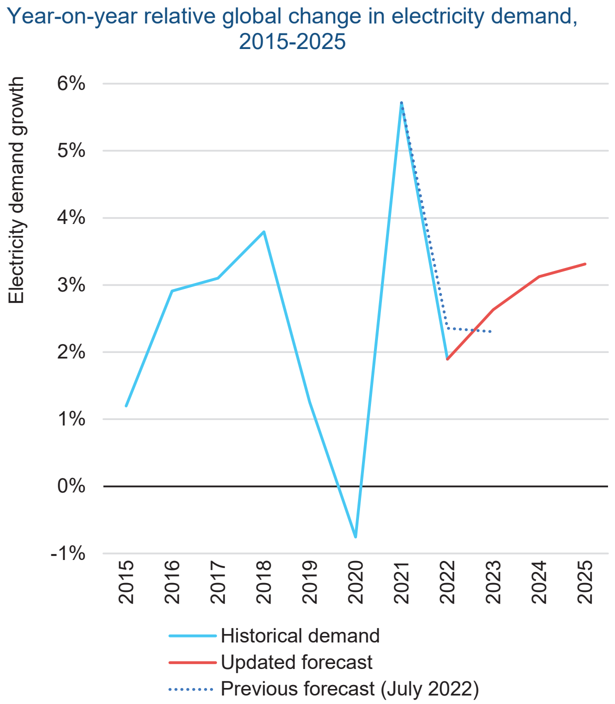
In the United States, electricity demand rose by 2.6% in 2022, surpassing pre-Covid levels. But an expected economic slowdown in 2023 is expected to lead to a decline of about 0.6%, before returning to growth of 1.2% in 2024 and 1.3% in 2025.

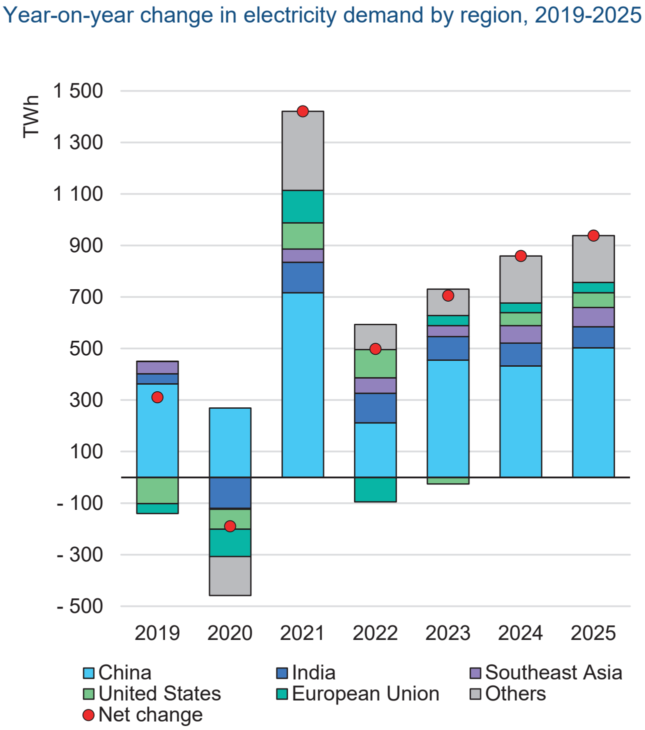
In Africa, electricity demand rose by 1.5% in 2022, with growth tempered by both lofty energy prices and high inflation rates. Our 2023-2025 outlook for the region shows much stronger growth of an average 4.1%, led by a post-crisis economic recovery.

GLOBAL ECONOMIC GROWTH SHOWS SIGNS OF RESILIENCE BUT CONTINUES TO FACE CHALLENGES

The global economy continues to face myriad challenges in the wake of Russia's war in Ukraine and the rise in central bank rates aimed at combating persistent inflation. The International Monetary Fund's (IMF) January 2023 World Economic Outlook provides forecasts up to 2024 and shows global GDP growth of 6.2% in 2021 contracting

Out to 2025, more than 70% of the growth in global electricity demand is set to come from China, India and Southeast Asia combined





to 3.4% in 2022 and easing to 2.9% in 2023. By 2024, growth inches higher again, to 3.1%. The latest forecast represents downward revisions of 0.2%, 0.7% and 0.3%, respectively, compared with the April 2022 forecast, which underpinned our July update. The January 2023 outlook, however, was slightly more optimistic than the previous October 2022 forecast for the short term, with global GDP growth for both 2022 and 2023 raised by 0.2 percent points. The October outlook, which provided projections up to 2027, forecast a global GDP growth rate of 3.4% in 2025.

For the United States, the IMF revised its latest GDP estimate to 2% for 2022 from 3.7% in April and its outlook to 1.4% from 2.3% for 2023. Growth is forecast at a slower 1% in 2024. The contracting trend reflects persistent and broadening inflation pressures and higher interest rates that will continue to temper purchasing power. 2025 growth from the October outlook is 1.8%.

For the Euro area, GDP growth is estimated in the January outlook at 3.5% for 2022 before plummeting to just 0.7% in 2023 and then recovering to 1.6% in 2024. The latest forecast shows a sharp downward revision from the April estimate of 2.3% for 2023. The weaker outlook largely reflects the spillover effects from the war in Ukraine and rate hikes from the European Central Bank, which are partially offset by lower wholesale energy prices and support from energy price controls. For 2025, a growth of 1.9% was forecast in the October outlook.

Under pressure from its zero-Covid policy, China's economy slowed from the pre-pandemic average growth of 6.7% between 2015-2019 to 3% in 2022. However, the country's sudden easing of its stringent pandemic restrictions prompted an upward revision to 5.2% for 2023, up three percentage points from the October projections but similar to its 5.1% estimate in April. Growth is forecast to slow to 4.5% in 2024. The October forecast estimated growth of 4.6% for 2025.

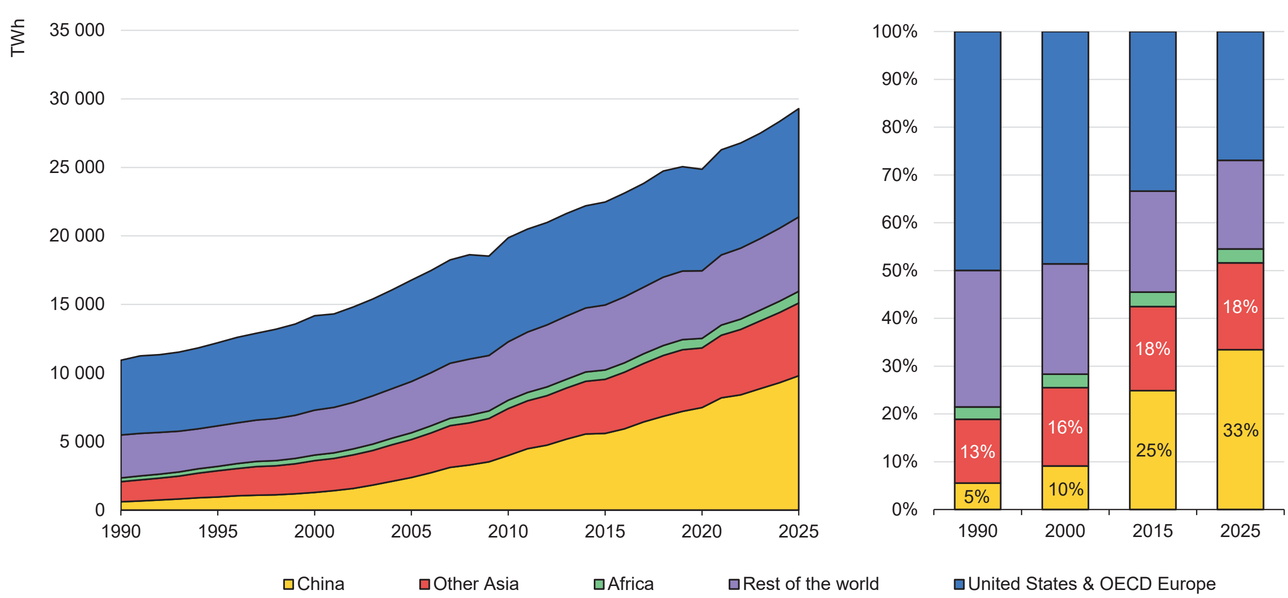
The GDP growth for India is estimated at 6.8% for 2022.The outlook was revised downward in January to 6.1% from 6.9% for 2023, largely due to slow economic growth in its trading partner countries. GDP growth for 2024 was unchanged at 6.8%. The 2025 forecast from the previous October outlook is 6.8%.

Sub-Saharan Africa's GDP growth is estimated to ease from 4.7% in 2021 to 3.8% in 2022, due to higher inflation and slower-than- expected progress on poverty reduction. However, economic growth will speed up from 3.8% in 2023 to above 4% in 2024 and 2025.

The IMF expects Latin America and the Caribbean's GDP to grow by 3.9% in 2022, 1.8% in 2023 and 2.1% in 2024. October forecast for 2025 was 2.5%.

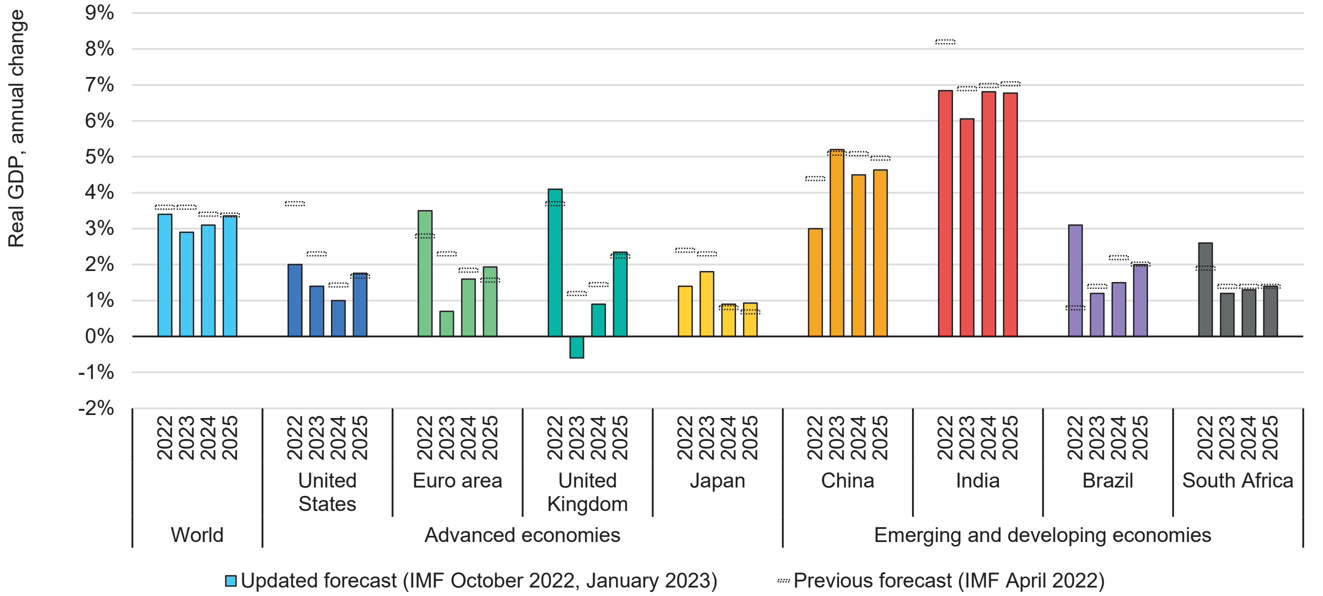
By 2025, Asia will account for half of the world's electricity consumption and one-third of global electricity will be consumed in China

Evolution of global electricity demand by region (left) and regional shares (right), 1990-2025



The war in Ukraine, energy crisis and persistent inflation suppress the economic outlook

Gross domestic product growth assumptions by country and region, 2022-2025



Notes: The bars represent annual changes in GDP relative to the previous year. The hollow lines show the previous April 2022 forecast. 2022-2024 values are from the January 2023 World Economic Outlook Update of International Monetary Fund (IMF). 2025 values are from IMF's October 2022 outlook.
Sources: Based on International Monetary Fund (2023), World Economic Outlook October 2022 Database, World Economic Outlook Update January 2023, 1 February 2023.

INDUSTRIAL ELECTRICITY DEMAND PLUMMETED TO HISTORIC LOWS IN MULTIPLE COUNTRIES IN 2022

In 2021, many countries started to gradually phase out Covid-19 public policy measures and return to more normal economic activity. However, some economies (e.g. China) still imposed lockdowns in 2022, which had an impact on both residential and industrial electricity consumption. Equally, persistently high electricity prices continued to add downward pressure on consumption, particularly in the residential and industrial sectors.

Comparing the first three quarters of the years, both the United Kingdom and Spain experienced the lowest industrial electricity consumption in over 20 years in 2022. Spain saw a decrease of more than 10% compared to 2019, while the United Kingdom posted a drop of almost 15% in 2022 versus 2019. Spain's electricity-intensive manufacturing activity was especially hard hit by the rise in prices. The country's industrial electricity consumption posted a similar y-o-y decline in 2022 as it did in 2020 when severe Covid-related lockdowns led to substantial demand destruction. Of the countries surveyed, the United Kingdom saw the sharpest rise in average wholesale electricity prices. Spain followed with the second highest level, despite the June 2022 implementation of the Iberian exception, a cap on wholesale gas prices adopted to reduce the cost of electricity.

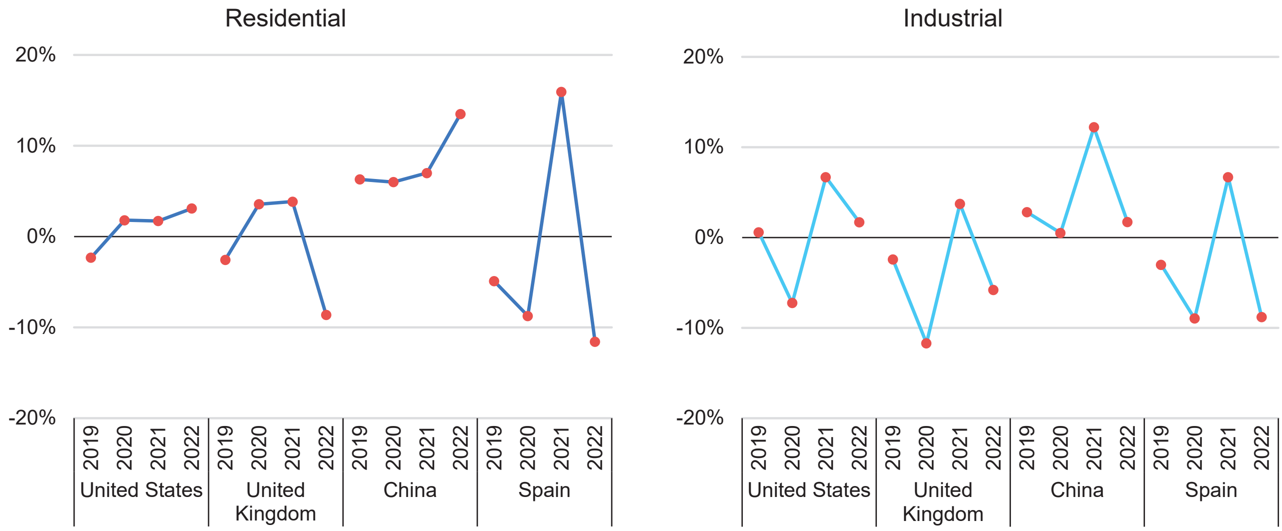
In the United Kingdom and Spain, as elsewhere, residents spent more time at home during widespread Covid-19 lockdowns in 2021, which led to higher residential electricity consumption that was well above the subsequent 2022 levels when pandemic restrictions were eased. Although formal Covid restrictions were lifted in the United Kingdom in July 2021, many employees continued to telework through the end of the year, which was less the case in 2022. In addition to the surge in prices amid the energy crisis, a return to more normal work patterns and warmer temperatures weighed heavily on UK residential consumption in 2022.

China's zero-Covid policy in 2022 boosted residential electricity demand while growth in the industrial sector was tempered by weaker economic activity. Residential power consumption has been steadily increasing as the electrification of homes rapidly expands, with a growing share of electricity used in cooling, heating, cooking and appliances. The country's house-bound population propelled residential electricity demand up by a sharp 13.5% in 2022.

By contrast, China's strict pandemic restrictions and lockdowns disrupted the country's economic activity. As a result, electricity demand in the industrial sector was up a modest 1.7%. Coal supply shortages also caused power

The United Kingdom and Spain saw a decline in industrial electricity consumption in 2022

Year-on-year change in sectoral electricity consumption in selected large economies, 2019-2022



Note: The analysis is based on data for the first three quarters of 2019-2022.

Sources: IEA analysis using data from the China Electricity Council (China) (2023), U.S. Energy Information Administration (United States) (2023), GOV.UK (United Kingdom) (2023), Red Eléctrica (Spain) (2023), 31 January 2023.

restrictions and outages in industrial hubs such as in Northeast China and the provinces of Guangdong and Hunan, further contributing to the slowdown.

In the United States, residential electricity consumption saw a similar y-o-y growth in 2022 as in the previous two years. Weaker industrial electricity demand growth mainly reflected the slowdown in the economy.

SUPPLY

LOW-CARBON SOURCES SET TO COVER ALMOST ALL THE GROWTH IN GLOBAL ELECTRICITY DEMAND BY 2025

Power systems faced challenges in multiple regions in 2022 due to extreme weather events. Heatwaves and droughts strained the supply situation in both China and India. A historic drought in Europe resulted in low hydropower output, putting increased pressure on dispatchable capacities amid record-low nuclear generation in France. In the United States, winter storms caused widespread power outages. These extreme events reinforce the urgent need to increase the flexibility of the power system and enhance security of electricity supply to better cope with weather- related contingencies.

In 2022, the surge in fossil fuel prices following Russia's invasion of Ukraine also compounded the supply situation, especially for gas. The relatively higher increase in natural gas and LNG prices prompted a wave of fuel switching in the world to coal for use in power generation. Global coal-fired generation rose by 1.5% in 2022, with the largest absolute increases in the Asia Pacific region. Coal-fired generation also rose significantly in the European Union amid low hydro and nuclear output. However, 2022 is likely to be an exception and global coal-fired generation is forecast to plateau in 2023-2025, as higher output in the Asia Pacific region is offset by declines in Europe and the Americas. Global gas-fired generation remained relatively unchanged in 2022 compared to 2021, as declines in China, India and other regions were largely offset by a rise in gas-fired output in the United States.

We expect global gas-fired generation to stagnate to 2025 on average, after declining by 3% in 2023, then growing by 1.4% in 2024 and 2% in 2025. Substantial declines in the EU will partly be offset by significant growth in the Middle East. Low-carbon generation from renewables and nuclear had diverging trends in 2022. Renewables saw a year-on-year rise of 5.7%, making up almost 30% of the generation mix. A surge in renewable generation in the Asia Pacific region accounted for more than half of the increase, followed by Americas.

By contrast, nuclear output fell 4.3%. This was due to maintenance outages at a large number of French plants, decommissioning of units in Germany and Belgium, and reduced Ukrainian output.

Our outlook for 2023 to 2025 shows that renewable power generation is set to increase more than all other sources combined, with an annualised growth of over 9%. Renewables will make up over one-third of the global generation mix by 2025. This trend is supported by government pledges to increase spending on renewables as part of economic recovery plans such as the Inflation Reduction Act in the United States. Nuclear output is expected to grow by 3.6% per year on average, mainly due to the increase in Asia Pacific, plus French generation returning to normal. As a result, low-carbon generation sources – renewables and nuclear together – are expected to meet on average more than 90% of the additional electricity demand over the next three years, unless developments in the global economy and weather events change the trends in electricity demand and fossil-fired generation.

HYDROPOWER GENERATION EXCEPTIONALLY LOW IN EUROPE IN 2022 DUE TO THE HISTORIC DROUGHT

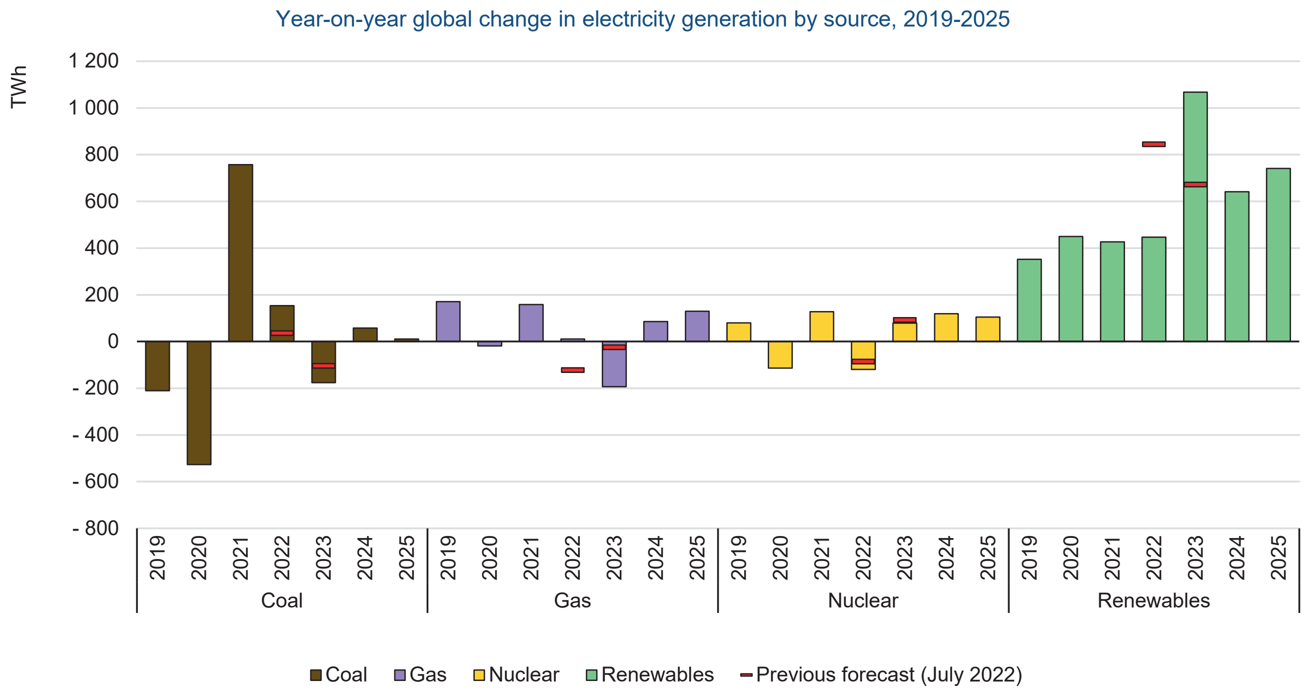
The year 2022 was characterised by heatwaves and droughts in many regions, causing significant declines in hydropower output.

This has underscored the potential impacts of changing climate patterns on power systems as low hydropower generation puts additional strain on the remaining dispatchable conventional fleet and increases the cost of electricity supply. Despite these uncertainties, our current outlook sees global hydropower supply grow in 2023 to 2025 on planned capacity expansions.

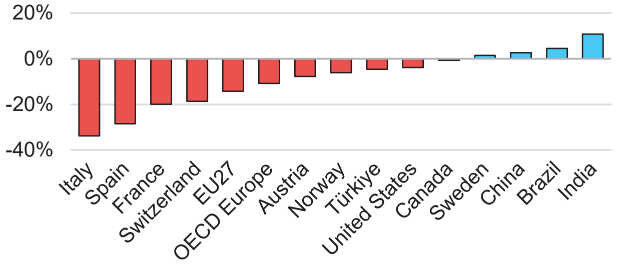
Europe saw its worst drought in 500 years in 2022. Italy had a record drop in hydropower output, posting its lowest hydropower generation in the last two decades in the February-April 2022 period. Italy's hydro use was down more than 30% compared to 2017-2021 averages, followed closely by Spain at 29% and France at 20%. Norway had the driest 12-month period in 26 years, with hydro reservoir levels in September declining to the lowest monthly output in the last decade. Republic of Türkiye (hereafter "Türkiye"), which saw its lowest hydro output in 2021 since 2014, had a strong 20% year-on-year rebound in 2022 but remained 5% below its 2017-2021 average.

In China, drought conditions in Sichuan caused a significant drop in hydropower output during August and September, depressing annual growth to just below 1% in 2022. In India, despite a record heatwave in 2022, hydropower generation increased more than 10% above its 2017-2021 average.

Renewables growth dampens fossil fuel-fired generation from 2023 to 2025

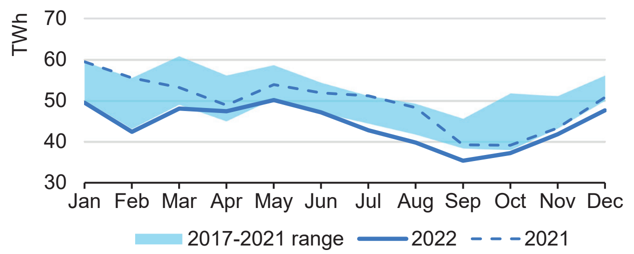


Percentage change in hydropower generation in 2022 compared to the 2017-2021 average in selected countries and regions



Source: IEA (2023), Monthly Electricity Statistics, 31 January 2023.

Monthly hydropower generation in OECD Europe, 2017-2022



Source: IEA (2023), Monthly Electricity Statistics, 31 January 2023.

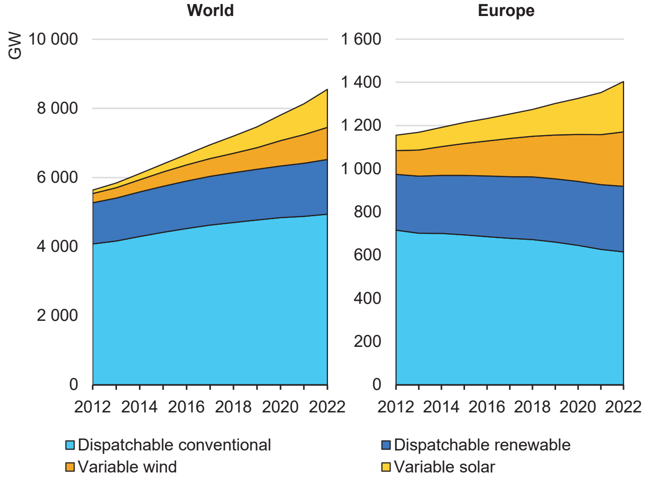
SIGNIFICANT POTENTIAL TO INTEGRATE MORE RENEWABLES IN THE WORLD'S ELECTRICITY GENERATION FLEET

Global installed capacity of renewables is estimated to have increased at a faster year-on-year rate of almost 11% in 2022 compared to the average 9% growth seen in the 2017-2021 period. Variable renewables – wind and solar PV – continued to see strong growth in combined capacity, up nearly 18%. This corresponds to about 300 GW in additional installed capacity of variable renewables, which is greater than the current combined wind and solar PV cumulative capacity in the United States (approximately 280 GW).

Despite continued growth in 2022, the share of variable renewable capacity in the total generation fleet remains below 25% in the world, whereas in Europe it is 35%. In countries with high variable renewables penetration, variable wind and solar PV can make up more than 60% of the total generation capacity (e.g. Denmark, Germany). From a global perspective, there is enough potential for further capacity expansions of variable renewables in many regions of the world without facing major system integration bottlenecks.

As the share of variable renewables increases in the generation fleet, their successful integration into the power system will increasingly become more challenging. For the balancing of variable generation, apart from expanding storage capacities and increasing demand-side flexibility, having sufficient

Evolution of dispatchable and variable generation capacities in the world and in Europe, 2012-2022



Note: Dispatchable renewable capacity in the figure also includes run-of-river hydropower plants.
Sources: IEA (2022), World Energy Outlook 2022; IEA (2022), Renewables 2022.

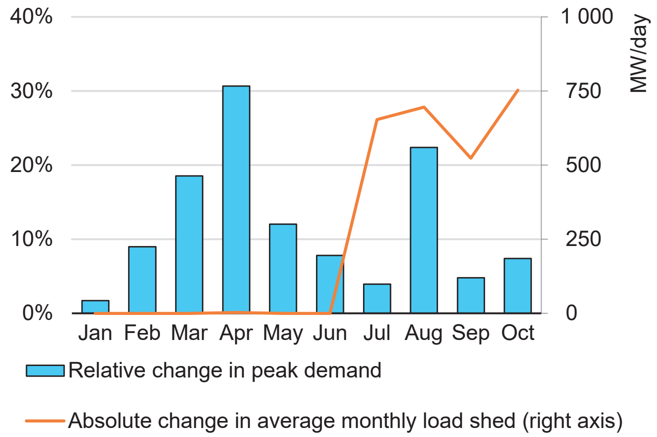
dispatchable capacity will be crucial. In a decarbonised electricity sector, dispatchable renewables such as hydro reservoir, geothermal and biomass plants will be essential for complementing the variable renewables.

The cost of electricity generation in 2022 increased in many parts of the world, led by surging energy commodity prices. The rise in generation costs has been more moderate in places with regulated tariffs and long-term fuel supply agreements. However, regions depending on short-term markets for fuel procurement were severely affected by the steep rise in prices. In particular, record- high LNG prices created financial hardships for South Asian countries – most notably Bangladesh and Pakistan – trying to procure gas for the electricity sector, and significantly contributed to power outages and rationing.

In Bangladesh, natural gas plays a prominent role in electricity supply, making up about 80% (2018-2022 average) of the generation mix. At the same time, Bangladesh relies on LNG imports to meet fuel demand for power generation and was therefore hit hard by high LNG prices in 2022. LNG accounts for approximately 20% of the total natural gas consumption of Bangladesh. Because of a notable decrease in its foreign exchange reserves, the government stopped buying LNG from the spot market during the period of July-November 2022, which resulted in fuel shortages for the power sector.

Following the LNG shortage, Bangladesh faced harsh power disruptions due to load shedding, where forced supply interventions were carried out to resolve the imbalance between electricity demand and supply. During these outages, electricity supply to areas with industrial production activities were given priority to minimise the impact on the industrial sector. Nevertheless, industries as well as households faced electricity scarcity and outages.

Year-on-year monthly change in electricity peak demand and load shedding, Bangladesh, January-October 2022 vs. 2021



Note: Average load shed is calculated as an average of day peak and evening peak load shed.

Source: IEA analysis based on Ministry of Information and Broadcasting (Bangladesh) (2023), Monthly Management Report, 10 January 2023.

Pakistan was also severely affected by the high prices of fossil fuels due to its strong reliance on fossil fuel imports, as gas (20%) and coal (30%) play a significant role in its power generation mix. In 2022, electricity production from imported LNG fell by approximately 13% compared to 2021. The reduced LNG imports were attributed to the country's inability to afford the supplies at the sharply elevated price levels.

Similarly, in the face of a tight coal market, imports of high calorific- value coal declined in 2022, leading to closures of coal-fired power plants. By contrast, lignite-fired plants experienced a surge in output during 2022, attributed to an increase in domestic lignite production coupled with a fourfold expansion in imports from Afghanistan, payable in Pakistani rupees, in H1 2022.

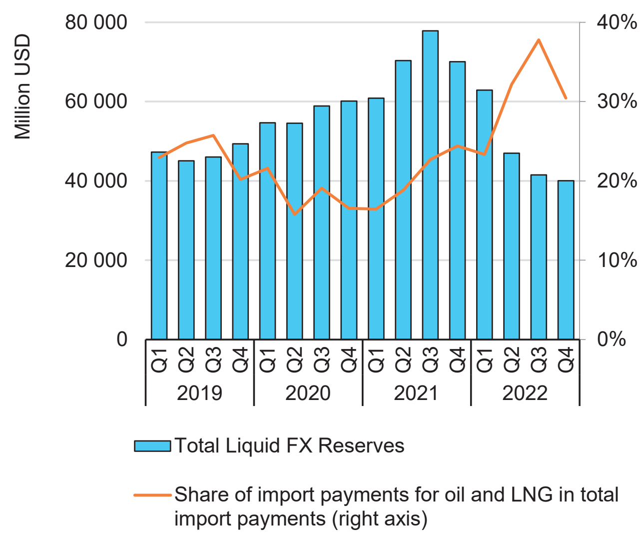
Fuel shortages for the power sector were further exacerbated by the country's severe flooding between July and September.

Consequently, a quarter of the total operational power generation capacity had to be shut down. This contributed to scarcity of electricity supply and subsequent power outages.

In 2022, Pakistan's liquid foreign exchange reserves reached their lowest level since 2014, leading to the prioritisation of energy imports to the detriment of other imports. This caused the shutdown of some industrial facilities due to a lack of imported raw materials.

For emerging markets and developing economies, fuel procurement will continue to be an important issue if energy commodity prices remain high in the coming years. Increased integration of renewable energy sources will not only serve to decarbonise the energy sector but would also reduce reliance on fossil fuel imports and help shield the economies from external fuel price shocks.

Quarterly evolution of liquid foreign exchange reserves and the share of payments for oil and LNG imports in the payments for total imports, Pakistan, 2019-2022



Note: Oil refers to petroleum products and crude oil.
Sources: IEA analysis based on State Bank of Pakistan (2023), Import Payments by Commodities and Groups, Gold and Foreign Exchange Reserves of Pakistan, 10 January 2023

STATIONARY BATTERY STORAGE CAPACITY ADDITIONS ARE SPEEDING UP IN EMERGING ECONOMIES

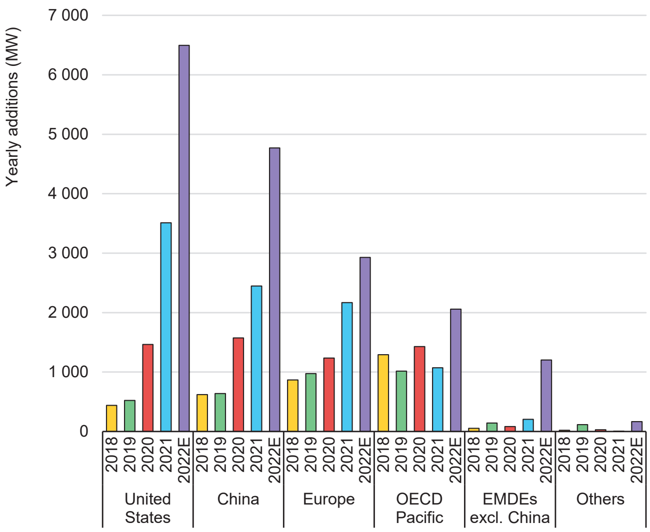
As the share of variable renewable sources in electricity systems further increase globally, battery systems are expected to play a growing role by providing frequency control and operational reserves as well as for wholesale arbitrage, while helping reduce grid integration costs. The deployment of stationary battery systems is speeding up. In absolute magnitude, the United States, Europe and China are leading the latest annual capacity additions.

However, based on our 2022 estimates, emerging markets and developing economies are on the way to catching up.

Compared with 2021, capacity additions in 2022 rose by over 80% in the United States, almost 100% in China, roughly 35% in Europe, 90% in OECD Pacific (i.e. Japan, Korea, Australia and New Zealand) and about sixfold in EMDEs, excluding China. In 2022, the largest fleet of cumulative battery systems installed remains in the United States while China surpassed Europe in cumulative capacity, reaching a total of 10 500 MW compared to Europe's 9 400 MW.

The deployment rate in EMDEs gathered pace in 2022, with capacity additions more than twice as high as the total cumulative additions in 2015-2021. In China and the United States, over 45% of the installed cumulative capacity was deployed in 2022. By contrast, in EMDEs (excluding China), capacity additions in 2022 had a relatively much higher impact, accounting for almost 70% of the total cumulative capacity in these regions.

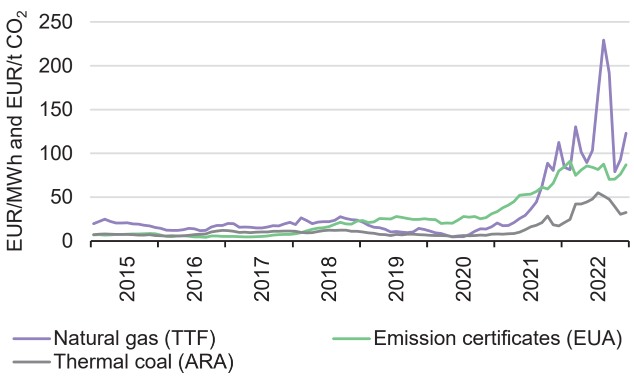
Yearly stationary battery system additions by country and region, 2018-2022



Note: 2022 values are estimates.
Sources: IEA calculations based on Clean Horizon (2022), BNEF (2022), China Energy Storage Alliance (2022).

In the European Union, estimated gas-based thermal generation cost more than doubled in 2022 compared to the previous year, to an average of USD 350/MWh. Coal-based thermal generation costs almost doubled to an average of USD 190/MWh. This has been primarily driven by the rapidly tightening gas and coal market fundamentals. Russia more than halved its pipeline gas supplies to the European Union in 2022 – a year-on-year drop of 80 bcm in absolute terms. Consequently, European gas prices soared to record highs. Gas prices on the Title Transfer Facility (TTF) in the Netherlands, the region's leading hub, averaged USD 37/MBtu (EUR 123/MWh) in 2022 – more than five times their 2016-2021 average. The strong increase in gas prices provided upward pressure on thermal coal prices through fuel-switching dynamics in the power sector. Rotterdam thermal coal prices averaged at an all- time high of USD 290/t (EUR 40/MWh) in 2022. Despite record-high prices for coal and gas, gas- and coal-fired generation rose in the European Union by about 2% and 6% y-o-y, respectively, as low hydro and nuclear power output increased the call on thermal power plants.

Monthly average prices of natural gas, thermal coal and emission certificates, Europe, 2015-2022



Sources: Natural gas prices from TTF; coal prices are CIF ARA; emission certificate prices are EUA prices from EU ETS.

THE SURGE IN COAL AND GAS PRICES RAISED THERMAL GENERATION COSTS TO DECADE HIGHS IN 2022

Russia's invasion of Ukraine put unprecedented pressure on European and global energy markets. Natural gas and thermal coal prices in Asian and European spot markets rose to all-time highs throughout 2022, sharply increasing the cost of thermal generation in those markets.

In the United States, tight supply and demand fundamentals drove both coal and natural gas prices to decade highs. Thermal generation costs are expected to remain well above historical averages out to 2025, further eroding their competitiveness compared to low-emission alternatives.

The price of the emissions allowances (EUA) on the EU Emissions Trading System (EU ETS) saw record highs, reaching almost EUR 100/t CO_2 in August 2022. The surge in emission prices was mainly driven by the increase in coal-fired generation, which then resulted in stronger demand for the allowances. Later in 2022, carbon prices fell, as lower gas prices reduced gas-to-coal switching in power generation. Despite this, in 2022 EU ETS prices at an average EUR 81/t CO_2 were 50% more expensive than in 2021. Even with the rising costs of CO_2 emissions in 2022 – which weigh proportionally on coal power much more due to higher CO_2 emission factors – the generation cost of coal-fired power plants in Europe remained substantially below that of gas-fired plants.

Forward curves as of late January 2023 indicate that, despite declining, both natural gas and coal prices remain well above their pre-2021 historical averages through to 2025, at USD 15-20/MBtu and USD 130-170/t, respectively. By 2025 generation costs from gas are expected to decline and approach coal-fired generation cost levels.

In Asia, estimated gas-based thermal generation costs in Japan and Korea rose by 65% in 2022, to an average of USD 135/MWh. Coal-based thermal generation costs increased by more than 70% to over USD 100/MWh. The steep drop in Russian piped gas supply to the European Union was largely offset by LNG, driving up competition between Asian and European buyers. This put strong upward pressure on Asian spot LNG prices, which averaged an all-time high of USD 30/MBtu in 2022. Oil-indexed LNG prices displayed less volatility, averaging about USD 15/MBtu. High spot LNG prices and flood-induced supply outages in Australia also drove Newcastle coal prices to peak levels, to an average of USD 360/t.

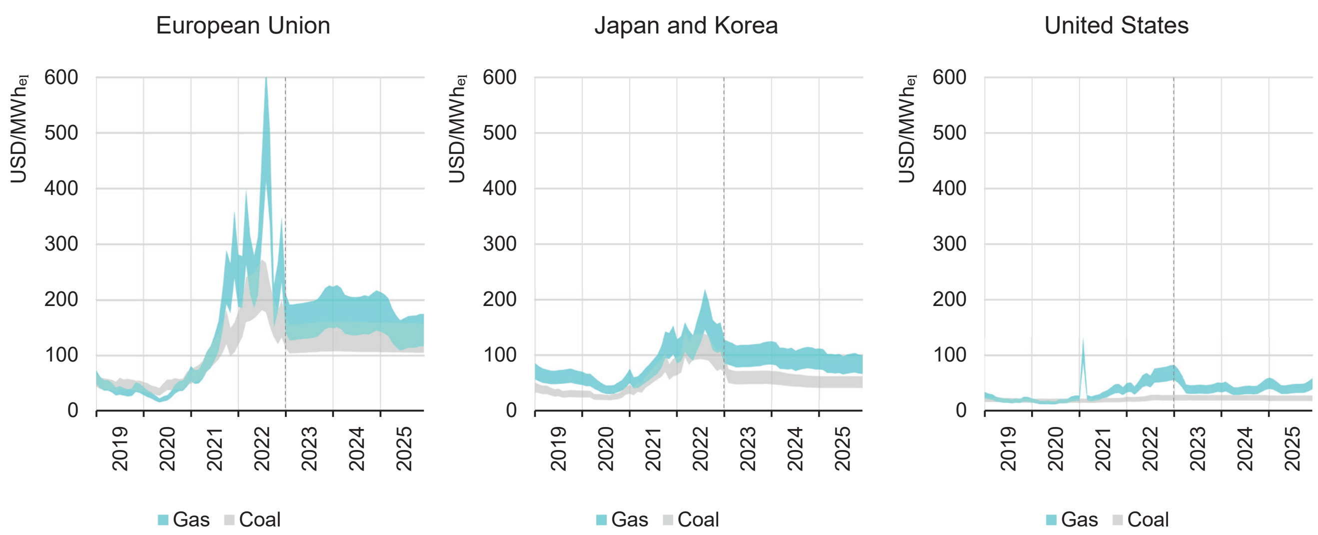
Forward curves as of late January 2023 indicate that spot LNG and thermal coal prices are expected to remain elevated, putting upwards pressure on thermal generation costs out to 2025. Despite this, the thermal generation costs in Korea and Japan would be roughly half that of Europe in 2025 according to the forward prices.

In the United States, the cost of gas supplied to power plants increased substantially, by more than 50% y-o-y, driving up the cost of gas-fired generation by a similar magnitude in 2022. This was driven by a number of factors: supply constraints and low inventory levels elevated thermal coal prices; the Central Appalachia benchmark averaged USD 170/t – its highest level since 2010; reduced availability of thermal coal increased the call on gas-fired power plants; and higher gas burn in the power sector, together with below-average gas storage levels and rising LNG exports, tightened gas market fundamentals. As a result, Henry Hub prices rose by more than 60% y-o-y, to an average of USD 6.50/MBtu in 2022.

Tight market conditions are expected to linger into the medium term based on forward curves at the start of January 2023 that show natural gas and coal prices remaining above their historical averages, at USD 3-5/MBtu and USD 110-150/t, respectively, in 2023-2025. The generation cost gap between electricity generation from coal and gas narrows based on the forward prices.

Large regional differences in thermal generation costs by 2025, with Europe about twice as high as Asia

Generation costs of coal- and gas-fired power plants including emission costs, 2019-2025



Notes: Coal range reflects 33-45% efficiency; gas range reflects 43-55% efficiency. Due to the large geographic areas covered in each region, costs can differ between and within countries and should therefore be interpreted as general trends. In the United States, natural gas prices increased significantly (exceeding USD 15/MBtu) in February 2021 due to supply constraints. 2023-2025 costs for the regions are based on forward prices of fuels as of end of January 2023 and should not be interpreted as forecasts, rather as costs reflecting the current market expectations. Fuel price assumptions for the model forecasts presented in this report are based on average forward prices.

Sources: United States: based on EIA (2023), STEO January 2023. European Union: natural gas prices TTF; coal prices CIF ARA; emission costs EU ETS. Japan and Korea: natural gas prices reflect estimated LNG import prices, including via oil-indexed LNG contracts and spot procurements; coal prices are Japan marker prices. Latest update: 31 January 2023.

EMMISSIONS

LARGE REGIONAL DIFFERENCES IN THERMAL GENERATION COSTS BY 2025, WITH EUROPE ABOUT TWICE AS HIGH AS ASIA

We estimate that the world reached a new all-time high of about 13.2 Gt CO_2 in power sector emissions in 2022, a year-on-year increase of 1.3%. Record-level emissions in 2022 were mainly due to growth in fossil-fired generation in Asia Pacific.

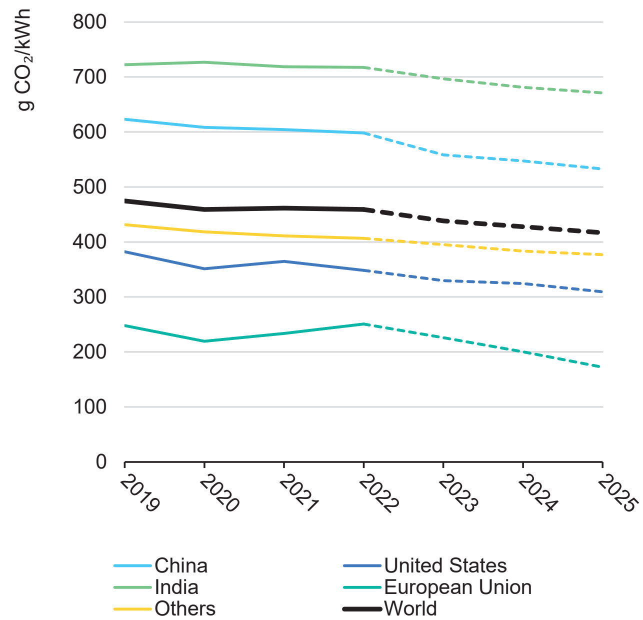
Europe and Eurasia also contributed to this increase. Similar to what was highlighted in the IEA's World Energy Outlook 2022 for the overall energy sector, the rise in power sector emissions in 2022 was still less than the y-o-y change in 2021 related to the post-pandemic rebound.

After a projected decline in global electricity generation CO_2 emissions in 2023 due to lower gas- and oil-fired generation, we forecast that emissions will plateau out to 2025.

In the 2023-2025 period, lower emissions in regions such as Europe and the Americas (each down roughly 70 Mt/yr on average) partly offset the significant increases in Asia Pacific (up 100 Mt/yr on average), mostly attributed to China and India. By 2025, the Asia Pacific region will account for 67% of global power sector emissions (up from 64% in 2022). Trends from other regions show mild growth or remain flat.

In 2025, CO_2 intensity of global power generation would reach

Regional evolution of power system CO_2 intensity, 2019-2025

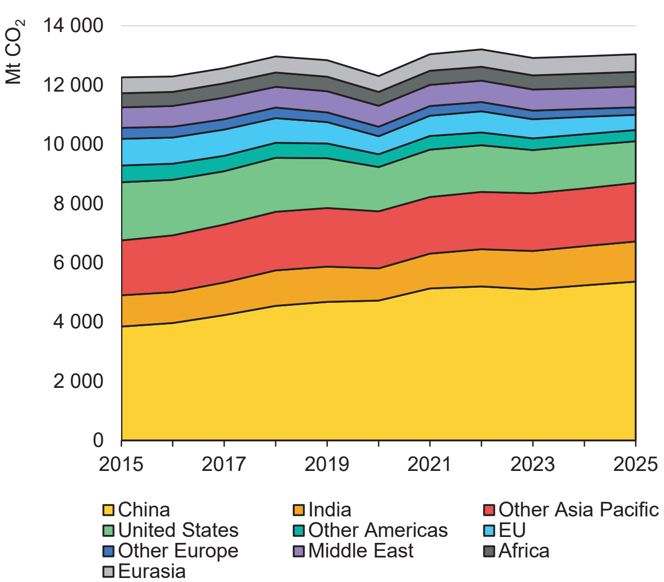


Note: The CO_2 intensity is calculated as total CO_2 emissions divided by total generation.

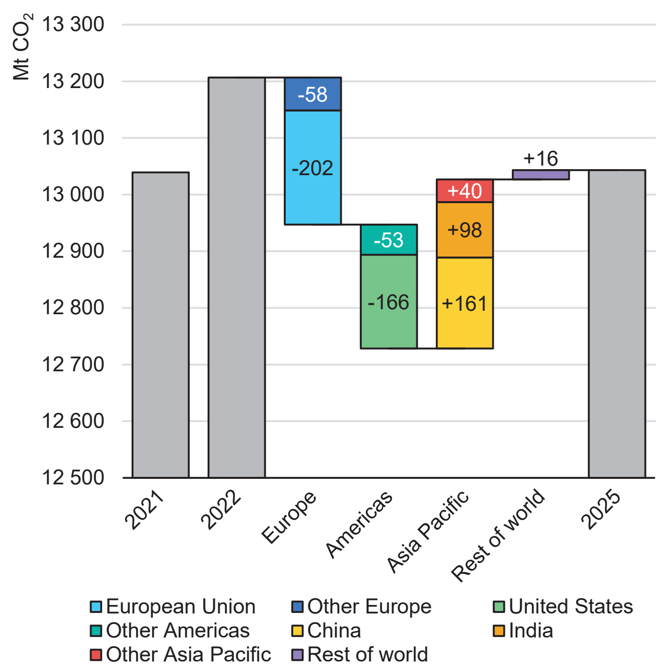
417 g CO_2/kWh, a decline of 3% on average each year to 2025. The average annual rate of decline from 2023 to 2025 is markedly steeper in Europe (-12%) and the United States (-4%).

Global emissions of power generation are expected to plateau from 2023 through 2025

Global emissions of power generation, 2015-2025



Changes in global emissions of power generation, 2021-2025



WHOLESALE PRICES

ELECTRICITY PRICES REMAIN ELEVATED IN MANY REGIONS, LED BY THE HIGH COST OF ENERGY COMMODITIES

The global energy crisis, with soaring prices of energy commodities combined with the pandemic rebound and supply chain issues, has resulted in substantially higher wholesale electricity prices in many regions of the world in 2022 over year-ago levels.

In a large number of European countries, wholesale electricity prices (i.e. day-ahead spot prices) in H2 2022 exceeded the second-half average prices between 2019 and 2021, e.g. fourfold in France.

In H2 2022, the average wholesale price reached almost EUR 330/MWh in Germany and surpassed EUR 320/MWh in France, exacerbated by nuclear unavailabilities. By contrast, in Spain, average prices were much lower for the same time period at about EUR 130/MWh due to the Iberian price cap. The demand- weighted average price for Germany, France, Spain and the United Kingdom in H2 2022 was almost four times as high as the H2 2019-2021 average.

The elevated futures prices in Europe for winter 2023/24 reflect the continued uncertainties associated with gas supply for Europe.

Futures with delivery in Q4 2023 are EUR 227/MWh in France and EUR 184/MWh in Germany while those for Q1 2024 are EUR 258/MWh in France and EUR 186/MWh in Germany.

On the Nord Pool power exchange, average wholesale electricity prices remained at unprecedented high levels in H2 2022, exceeding EUR 150/MWh. Low hydro availability in the Nordics and increased cross-zonal demand pushed prices up by almost 90% year-on-year, yet they remained below European averages.

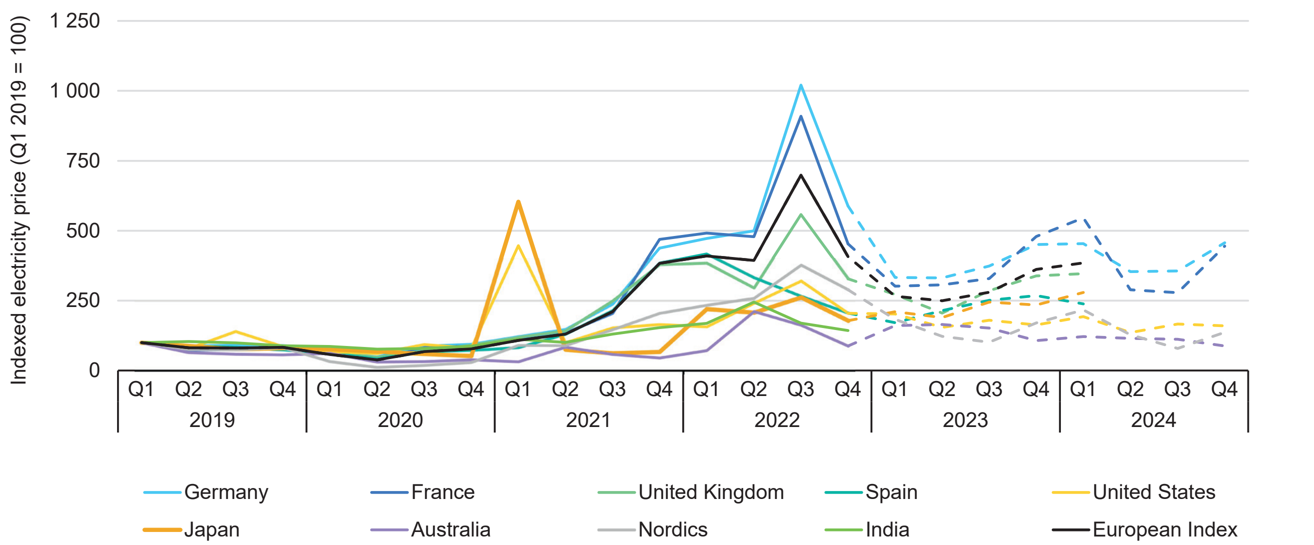
In the United States, the average wholesale price in H2 2022 stood at about USD 91/MWh, more than twice the 2019-2021 second-half average, and 65% higher than the price in H2 2021. This increase was driven by exceptionally high gas prices.

Japanese wholesale prices in H2 2022 averaged almost YEN 22 000/MWh (EUR 155/MWh), three times higher compared to H2 2021 because of the tight supply situation. The increased prices of fossil fuels also affected Japan because of its low energy self- sufficiency ratio.

However, the majority of the imported LNG volumes is contracted under oil-indexed long-term contracts which alleviated some of the effects of soaring spot prices.

Elevated futures prices in Europe reflect risks of tight supply in the winter of 2023/24

Indexed quarterly average wholesale prices for selected regions, 2019-2024

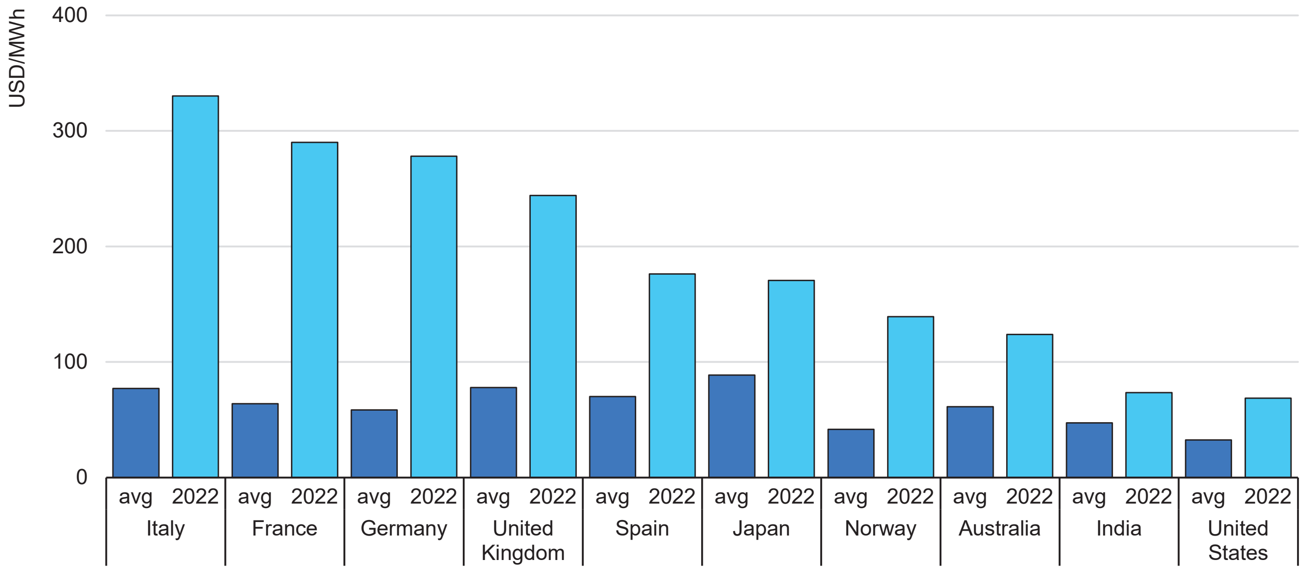


Notes: The European Index is calculated as the demand-weighted average of the prices for the European countries included in the analysis. For the Nordics region, the Nord Pool system price is used for the historical prices and EEX Nordics futures are used for forward prices. The prices for Australia and the United States are calculated as the demand-weighted average of the available prices of their regional markets. Continuous lines show historical data and dashed lines refer to forward prices. Price estimates for Q1 2023 and beyond are based on the historical prices and the latest forward baseload electricity prices, except for the United States, where we use EIA (2023) values. The forward prices for Japan are volume-weighted estimates of the latest JPX settlement prices, considering the baseload contracts (areas B1 and B3).

Sources: IEA analysis using data from RTE (France) and Red Eléctrica (Spain) – both accessed via the ENTSO-E Transparency Platform; Bundesnetzagentur (2023), SMARD.de; Elexon (2023), Electricity data summary; AEMO (2023), Aggregated price and demand data; EIA (2023), Short-Term Energy Outlook January 2023; Nord Pool (2023), Market Data; IEX (2023), Area Prices; EEX (2023), Power Futures; JPX (2023), Daily Data (Electricity Futures); ASX (2023), Electricity Futures © ASX Limited ABN 98 008 624 691 (ASX) 2020. All rights reserved. This material is reproduced with the permission of ASX. This material should not be reproduced, stored in a retrieval system or transmitted in any form whether in whole or in part without the prior written permission of ASX. Latest update: 31 January 2023.

Electricity markets were impacted differently across the world – Europe being hit the hardest

Annual wholesale prices in selected countries, 2022 and 2017-2021 average



Notes: Avg refers to an average of the years from 2017 to 2021. The annual averages are calculated from the daily wholesale electricity prices.
Source: IEA analysis using data from RTE (France) and Red Eléctrica (Spain) – both accessed via the ENTSO-E Transparency Platform; Bundesnetzagentur (2023), SMARD.de; Elexon (2023), Electricity data summary; AEMO (2023), Aggregated price and demand data; EIA (2023), Short-Term Energy Outlook January 2023; Nord Pool (2023), Market Data; IEX (2023), Area Prices. Latest update: 31 January 2023.

In 2022, Australian wholesale prices averaged AUD 170/MWh (Australian dollars; EUR 110/MWh), more than double the H2 2021 levels. This was due to surging electricity demand and gas prices.

In India, despite increased coal stocks, higher electricity consumption resulted in a 10% price rise in H2 2022 over the H2 2021 level. The average wholesale price in H2 2022 was INR 5 000/MWh (Indian rupees; EUR 55/MWh). Strong growth of solar PV helped to meet peak loads driven by higher refrigeration and space cooling.

CARBON PRICING TRENDS

STATUS AND TRENDS OF CARBON PRICING MECHANISMS IN 2022

Carbon pricing is a key instrument to mitigate emissions, incentivise investments in low-carbon technologies and reduce demand for greenhouse gas (GHG)-intensive activities. Such policy instruments usually take the form of a carbon tax, an Emission Trading System (ETS) or a hybrid of the two. Due to the ongoing energy crisis, carbon pricing policies have entered uncharted territory, and are facing new challenges hindering their effectiveness. While the EU's carbon price influences the variable generation cost, and hence the merit-order of the power plants, carbon pricing is currently unable to perform its traditional role of incentivising a coal-to-gas switch in electricity production given exceptionally high gas prices. Nevertheless, carbon pricing still has a crucial role to play in maintaining a long-term investment signal and making carbon-intensive fossil generation such as coal-fired electricity an economically unattractive solution. In addition, it can be a useful instrument to generate additional revenue for governments to support faster clean energy transitions, and mitigate social and competitiveness impacts.

As of April 2022, 68 carbon pricing initiatives were in place worldwide, covering over 23% of GHG emissions, with the majority in the form of an ETS. Many of them saw carbon price increases compared to 2021. The price of allowances in the EU ETS, the most established ETS globally, rose from an average of USD 50/t CO_2-eq to more than USD 90/t CO_2-eq for January to April 2022. Prices in the UK ETS rose to more than USD 100/t CO_2-eq, and doubled in the New Zealand ETS (USD 50/t CO_2-eq) and in state-level systems in the United States. Allowance prices in Korea (USD 19/t CO_2-eq) and China's national ETS (USD 9/t CO_2-eq) increased only slightly.

Despite these increases, less than 10% of global emissions are covered by a carbon price that is higher than USD 10/t CO_2-eq. In some jurisdictions in 2022, carbon pricing instruments have had difficulty incentivising a fuel switch

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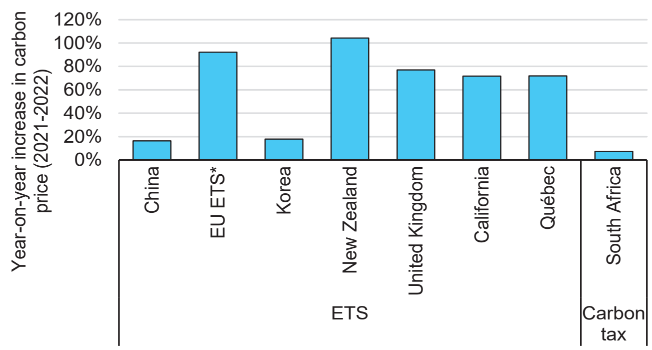
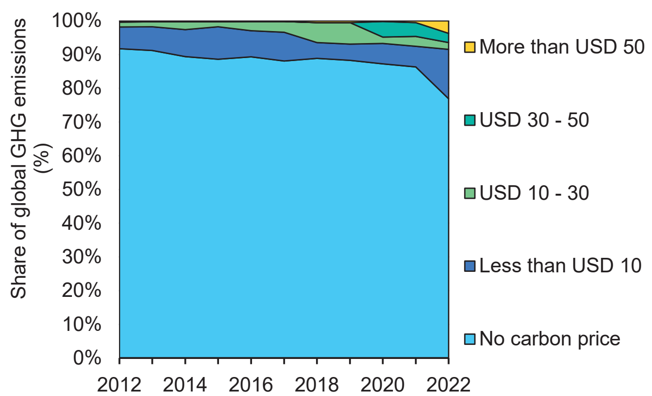
to lower-carbon sources due to high natural gas prices. For example, EU coal-fired generation rose by 6% in 2022.

Price evolution of selected carbon pricing instruments (as of April 2022, annual average levels)



*The EU ETS operates in all EU countries, Iceland, Liechtenstein and Norway.
Notes: The year-on-year increase compares the 2021 full-year averages versus the 2022 January-April averages.
Sources: World Bank Carbon Pricing Dashboard, ICAP, and Ember.

Share of global GHG emissions covered by a carbon price, by price level, 2012-2022



Source: World Bank (2022), Carbon Pricing Dashboard, 15 November 2022.

Increases in carbon prices and coverage have led to a new record of revenues raised by these instruments, reaching USD 140 billion in 2021, with ETS revenues more than doubling within a year (USD 26 billion to USD 56 billion). Schemes differ in the use of their revenues. California's Cap-and-Trade, for example, returns the majority of revenues to power companies and, ultimately, electricity consumers, while another part is used for carbon mitigation

Increases in carbon prices and coverage have led to a new record of revenues raised by these instruments, reaching USD 140 billion in 2021, with ETS revenues more than doubling within a year (USD 26 billion to USD 56 billion). Schemes differ in the use of their revenues. California's Cap-and-Trade, for example, returns the majority of revenues to power companies and, ultimately, electricity consumers, while another part is used for carbon mitigation programmes through its Greenhouse Gas Reduction Fund. This notably includes programmes on renewable energy integration towards low-income households.

China's national ETS, introduced in 2021 and covering the power sector only, is the biggest carbon market, and accounts for about 9% of global GHG emissions. The introduction of partial auctioning of allowances – instead of free allowance allocation – in the power sector as well as expansion to industry are currently being considered. Japan's GX League, composed of over 500 companies, has started pilot trading in its voluntary carbon market, with official trading starting in April 2023. This includes major participants in the electricity, gas and heat and water sectors, such as TEPCO, Kanden and Chuden. India also recently adopted a carbon market framework legislation, envisioning the construction of a national carbon market.

Electricity projects are also being affected by rules decided in voluntary carbon markets. Most notably, since 2020 the two biggest carbon credits standards issuers, Gold Standard and Verra, decided to no longer register new renewable projects, except for those located in Least Developed Countries. This is because large-scale renewable electricity projects are already cost-effective, not requiring further support from carbon markets.

REGIONAL PERSPECTIVES

AFRICA

AFRICA'S ELECTRICITY CONSUMPTION GROWTH IS SET TO ACCELERATE TO 2025.

Electricity demand in Africa increased by an estimated 5.7% in 2021, rebounding from a 3.3% decline in 2020 due to the Covid-19 pandemic impact on the economy. We estimate that electricity demand in the region grew by 1.5% in 2022, down from our previous forecast of 4%. Russia's invasion of Ukraine triggered a downward revision in economic growth prospects in Africa due to a combination of record-level energy prices and high inflation rates, which weighed heavily on our forecast for electricity demand across the region. In addition, electricity consumption in South Africa was revised lower – the continent's largest electricity consumer – because of production capacity constraints that turned out to be worse than previously expected.

Natural gas-fired output, which accounted for an estimated 42% of Africa's electricity generation in 2022, remained stable in volume compared to 2021. However, coal and nuclear (accounting for a respective 27% and 1% share of Africa's generation mix) both saw their output decline in relation with supply shortages, while oil-fired generation (5% of the mix) jumped by an estimated 24% year-on- year. Supply from renewables (24% of the generation mix) increased by 2% in 2022.

Electricity demand growth on the continent is expected to rebound in 2023 to over 3%, thanks to an improvement in South African production capacity as well as slightly enhanced macroeconomic conditions, followed by an average 4.5% regional growth for 2024 and 2025.

The large majority of incremental generation to 2025 will come from renewable sources, followed by natural gas. We expect electricity delivered from renewable sources to increase by over 60 TWh in 2023-2025, to reach almost a 30% share of total generation by the end of the forecast period (from 24% in 2021), replacing coal as the second largest source of electricity in Africa.

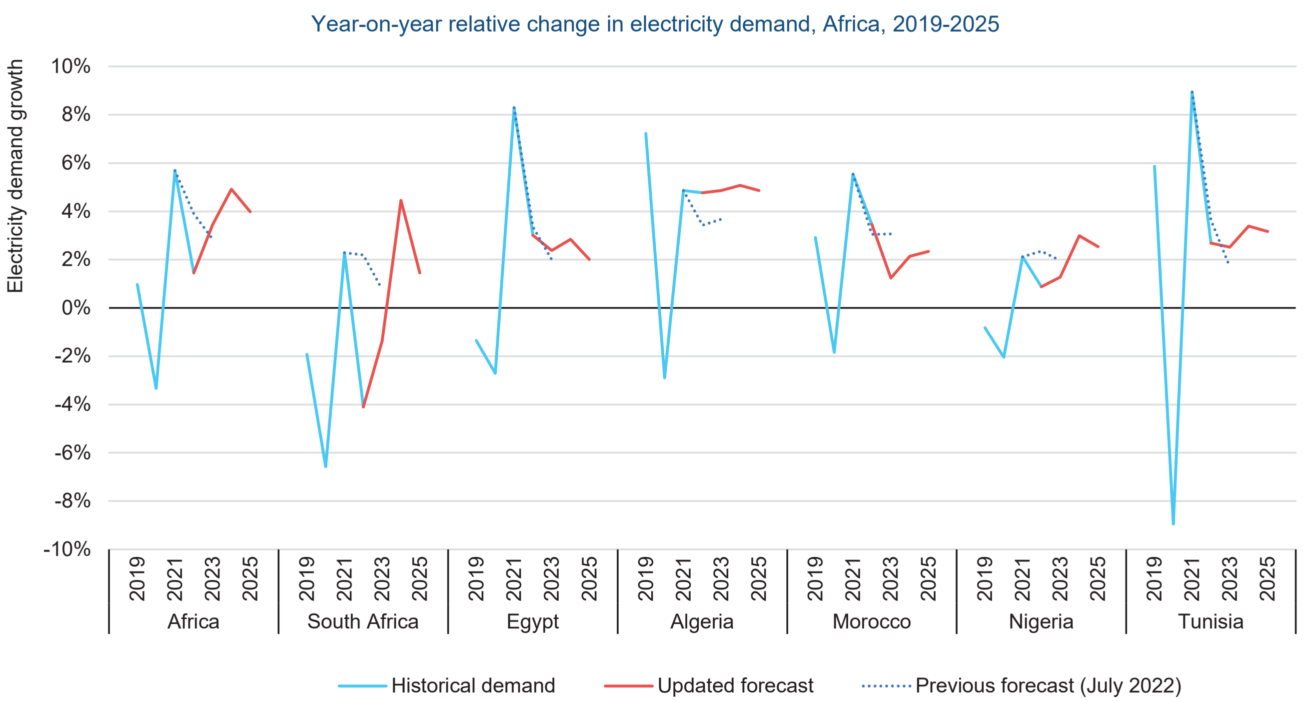
Natural gas is expected to remain the largest source of electricity in Africa through 2025, rising by around 30 TWh from 2022 to 2025, to close to 400 TWh. However, despite this increase, gas sees its share in the power generation mix decline slightly from 42% to 41% over the same period as renewables expand. Coal-fired electricity generation is expected to remain stable in output at around 240 TWh, declining in terms of share from 28% in 2021 to 24% in 2025. The declining share of fossil-fuelled generation to 2025 results in lower power generation CO_2 intensity in the region by the end of our forecast period. We expect CO_2 intensity to decrease from about 540 g CO_2/kWh in 2021 to around 500 g CO_2/kWh in 2025. In the same period, electricity generation CO_2 emissions would increase slightly (+18 Mt CO_2), reaching almost 490 Mt CO2, mainly due to higher gas-fired generation than in 2021.

SOUTH AFRICA

Electricity consumption in South Africa fell by less than 4% y-o-y in 2022, due to declining availability of its ageing coal fleet and delays in construction and commissioning of new generation projects. This has resulted in unprecedented amounts of load shedding, with over 8 TWh (or 5% of forecasted annual demand) being reduced through load shedding during 2022. This represents a fourfold increase in unmet demand compared to 2021. In addition, load shedding was implemented 205 days during 2022, approaching almost a threefold increase on the 75 days in 2021.

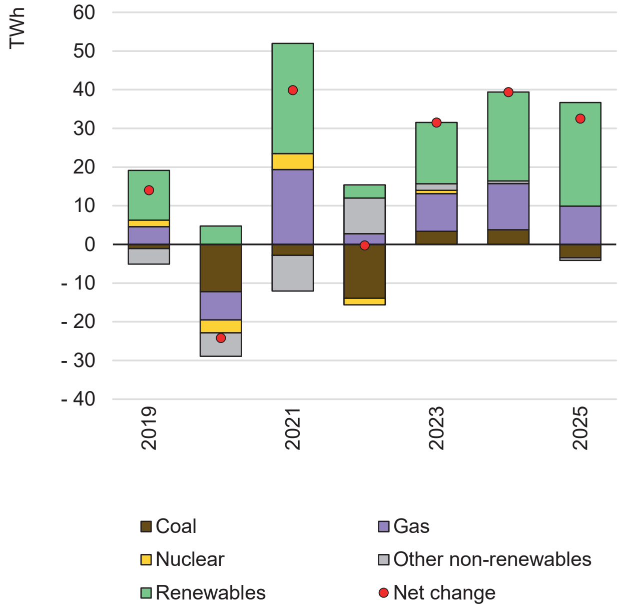
At the end of August 2022, Eskom, the state-owned utility, released their System Status and Outlook for 2022/23, where its base case scenario for the period September 2022 to August 2023 would see a reduction in load shedding to only 24 days. However, due to ongoing issues with the commissioning of its new-build coal generation, it has already seen 46 days of load shedding across September and October 2022 alone. This aligns with the middle of its most pessimistic scenarios, which forecasts between 203 and 326 days of load shedding over the September 2022 to August 2023 period, painting a potentially sombre picture for

South Africa deviates in its demand growth trend from other countries in Africa

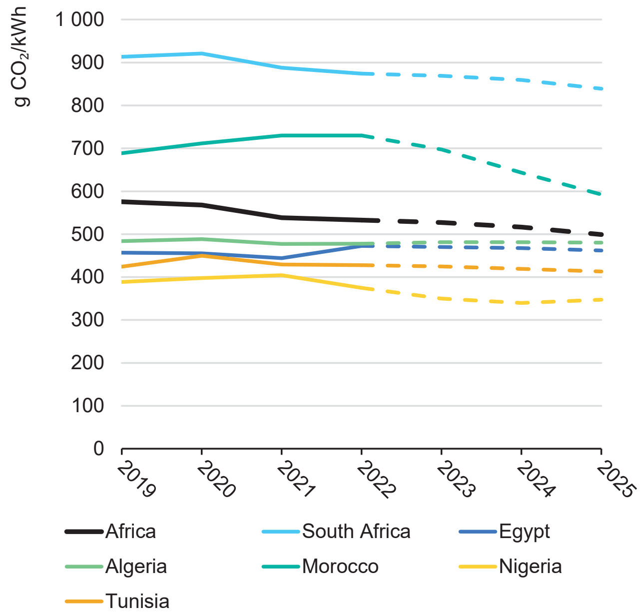


Renewables lead the race in terms of generation increases, followed by natural gas

Year-on-year change in electricity generation, Africa, 2019-2025

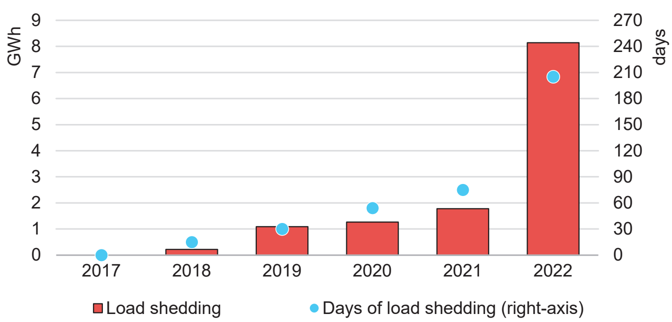


Development of average CO_2 intensity, Africa, 2019-2025



Notes: *Other non-renewables* includes oil, waste and other non-renewable energy sources. The CO_2 intensity is calculated as total CO_2 emissions divided by total generation.

Volume and number of days of load shedding, South Africa, 2017-2022



Source: IEA analysis based on hourly data from Eskom (2023), Data Portal, 18 January 2023.

the South African power sector in 2023, with new sources of generation needed to lift the country out of this crisis. This is not aided by the fact that one of the units of its only nuclear plant is also due to be taken out of service for most of the first half of 2023, which will result in an even tighter system. The outlook could be even more dire after reports that Eskom had spent its entire budget for the financial year (April 2022-March 2023) for diesel used in its 3 GW of gas peaking plants, and therefore this capacity will not be available until the start of the next financial year in April 2023.

In July 2022, President Cyril Ramaphosa announced a 10-point plan to address the ongoing power crisis in South Africa. Measures included the removal of licensing requirements for private energy projects, although still retaining the requirement for registration with the regulator. This builds upon the earlier relaxation of licensing requirements, which raised the licence exemption threshold from 1 MW to 100 MW in June 2021. In coming years this should accelerate Eskom's and the municipalities' ability to procure clean power directly. Already, the change in the licence exemption threshold in 2021 led to a number of announcements from major industrial consumers, including many large mining companies, to power their own operations using a combination of renewable technologies.

Another measure announced was the almost doubling of the allocated capacity for procurement in the latest renewable energy auction (i.e. Bid Window 6 of the REIPP Procurement Programme) from 2 600 MW to 4 200 MW. This sixth auction round was concluded in December 2022, with South Africa selecting five solar PV projects for a total capacity of 860 MW, significantly lower capacity compared to the originally planned allocation. The auction also saw no wind power project selected, due to a lack of grid capacity for connection.

This is the second auction of this kind after a seven-year disruption following the refusal of Eskom to sign power purchase agreements (PPAs) with the preferred bidders of the fourth bid window. While the preferred bidders for Bid Window 5 have been announced, only three of the bidders have signed a PPA as the others have struggled to reach financial close due to delays in receiving quotations on connection infrastructure from Eskom. An initial deadline at the end of April 2022 was continuously delayed, then extended until the end of October 2022 and has been extended beyond this date in November. There are also ongoing delays with the Risk Management IPP Procurement Programme (RMIPPPP) that aimed to procure 2 GW of firm capacity and was concluded in 2021, but which has been continuously delayed since.

It is expected that capacity from these auctions, along with the coming online of the two coal megaprojects Kusile and Medupi and improvements to performance of the existing coal fleet, will lead to an increase in available capacity and a recovery of demand. Given the uncertainty due to the tight supply situation, we estimate South African demand and generation could recover to 2021 levels in 2024-2025. While we expect coal to continue making up the majority of the South African generation mix (82% in 2025), our forecast sees the share of renewables increasing to 12% in 2025, from 9% in 2022.

EGYPT

Electricity consumption in Egypt increased by 8% in 2021 after a 2.7% decline in 2020. Growth slowed down in the first seven months of 2022 to an estimated 3% y-o-y increase, against the backdrop of domestic economic pressures and the global energy crisis. The continuous weakening of the Egyptian pound and spiralling inflation (24.5% core inflation annualised rate in 2022) since the beginning of the year puts the country's economy under pressure and resulted in a record USD 7.3 billion deficit in the balance of payments in the first nine months of 2022. For the third time since 2020, the Egyptian government decided in June to postpone its planned increase in electricity tariffs until early 2023 in order not to add new burdens on citizens. The country took measures to reduce its natural gas consumption in power generation (which provides up to 90% of total generation) in order to maximise its LNG export volumes and generate revenue in foreign currencies. This included substantial switching back to oil-fired generation, with fuel oil burn averaging above 100 kb/d in the first nine months of 2022, its highest level in four years.

Demand-side measures were also adopted in order to reduce electricity consumption. In August 2022, the government implemented electricity rationing measures targeting reductions in lighting and air conditioning in administrative buildings, commercial and leisure facilities, as well as for street lighting.

We estimate a 3% y-o-y growth in electricity demand in Egypt for 2022, and an average annual 2.4% growth rate in 2023-2025 based on the combination of an expected prolonged preference for gas exports against domestic use and planned continuation of electricity tariff rises as part of a government programme to lift subsidies by 2025.

Egypt has shifted its priority for new capacity from conventional thermal to low-carbon sources of power generation over recent years, after strong development of its gas-fired generation fleet in the mid-2010s. The country currently has 3.1 GW of installed wind and solar capacity on top of 2.8 GW of hydropower, and an additional 2.8 GW of planned renewable capacity to be commissioned by the end of 2023.

Diversification and decarbonisation of the generation mix also includes nuclear, with the start of construction work for the 4.8 GW El Dabaa plant in July 2022, which is scheduled for commissioning in 2026. Egypt aims at using its rising electricity surplus to become a regional hub for the east Mediterranean, with several transmission projects under way, including a 3 GW interconnection with Saudi Arabia under construction and scheduled for 2026, and plans to develop a 3 GW interconnection with Europe via Greece.

ALGERIA

Algeria's installed production capacity grew by 3.2 GW, or about 13%, between September 2021 and August 2022, according to the government's policy statement to the parliament in September 2022. State-owned utility Sonelgaz indicated in September that a new consumption peak record was reached in August 2022 at 16 822 MW. Algeria's domestic electricity consumption increased by an estimated 5% in 2021, after a 3% decline in 2020 and an average 6% growth rate during 2015-2019. The country's continuous rise in electricity consumption is supported by substantial subsidies. In spite of its growing deficit and a quadrupling of its debt in two years, Sonelgaz' confirmed in August that tariffs would not be revised. This forecast expects Algeria's electricity demand to increase at an average rate of about 5% per year in 2022-2025.

Algeria seeks to expand its electricity exports to neighbouring countries in North Africa and Southern Europe, thanks to planned development of its renewable generation capacity over the next decade. The country's energy strategy has set a target of developing 15 GW of renewable capacity by 2035. Renewable development operator Shaems announced in July that first production of 50 MW from solar should be expected by end 2023 from the 1000 MW solar project currently underway. A potential project of a subsea interconnection with Italy was announced in July and is currently being studied.

MOROCCO

Electricity consumption increased by 5.5% in 2021 in Morocco, recovering from a 1.8% decline in 2020. This was supported by a 16% rebound from high-voltage customers, while residential consumption increased by 2%. Domestic generation grew by 6.7% year-on-year, principally driven by thermal generation from state- owned ONEE (up 11.9%), while electricity supplied by independent power producers (which account for about 60% of total domestic generation) and from renewable sources both increased by close to 5%.

According to statistics from the Ministry of Economy and Finance, electricity demand rose by 4.8% y-o-y in the first eight months of 2022, down from 6.5% over the same period in 2021, principally driven by medium- and low-voltage electricity customers (up by 7% and 3.8% y-o-y, respectively) while demand from high- voltage users rose 1.5%. Domestic production was up by 3% y-o-y in the first eight months of 2022, with renewable generation growing by 8.6% and thermal from ONEE up by 22.6%.

Output declined 3.2% from independent producers. The balance of trade, which had shifted to net electricity exports in 2021, returned to net imports, with a more than doubling of imports while exports declined by 29%.

Morocco has experienced strong growth in renewables over the past several years. As of end 2021, renewable capacity accounted for 3 950 MW, or 37% of the country's installed electricity generation capacity – with 1 770 MW of hydro, 1 430 MW of wind, and 750 MW of solar. The country aims to increase the share of renewable capacity to 52% by 2030, 70% by 2040 and 80% by 2050, and to gradually expand its exports to Europe over the period. The European Union signed in October 2022 a Green Partnership on energy, climate and the environment with Morocco, the first of its kind with a partner country, which will contribute to scale up cooperation on energy transition and decarbonisation.

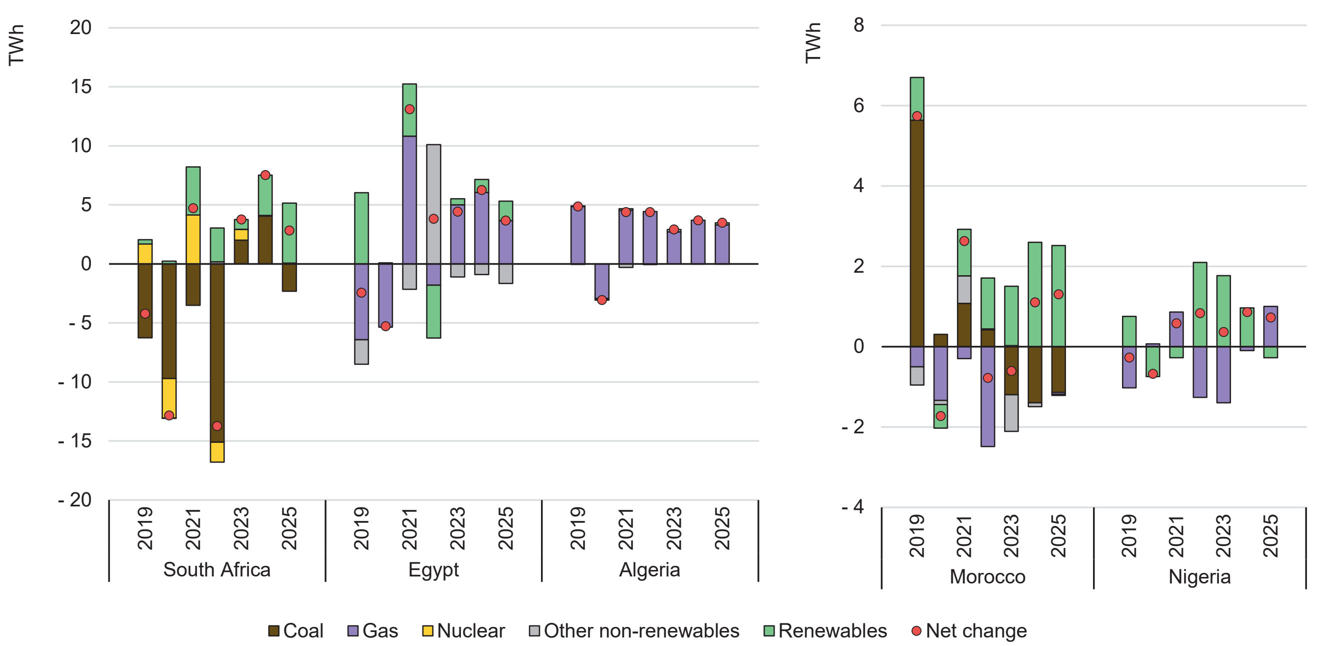
We forecast Morocco's electricity demand to grow at an average annual rate of 2% between 2023 and 2025, similar to generation – with renewables growing at an average 19% per year while thermal declines by an annual average of 5% over the same period.

TUNISIA

Tunisia's final consumption of electricity increased by 9% y-o-y in 2021, driven by all types of consumers – the residential sector is the largest and accounted for 38% of total electricity consumption, followed by industry with 30%, commercial at 20%, and other sectors for the remaining 12%. In 2022, total electricity demand (including the

Morocco set to see the highest relative growth in renewables in Africa, followed by South Africa

Year-on-year change in electricity generation in selected countries in Africa, 2019-2025



Note: *Other non-renewables* includes oil, waste and other non-renewable energy sources.

sector's own consumption and exports) increased by 10%. In comparison, electricity generation grew by 2% to 22 TWh, principally from gas-fired generation which accounted for close to 94% of total generation. The remaining supply requirements were met by 1 TWh of renewable electricity generation and by a strong increase in electricity imports from Algeria (up by close to 1 TWh) and reduced exports to Libya (down by close to 0.6 TWh).

Statistics from the Ministry of Industry, Energy and Mines indicate that Tunisia's reliance on electricity imports further increased in the first ten months of 2022 due to higher gas import prices, up by a sharp 150%, from 864 GWh to 2 169 GWh, a jump from less than 5% of total supply to over 11%. This stems from a 2% decline in domestic generation from gas-fired plants from independent power producers (down 74% from 2 725 GWh to 706 GWh over January to October) while generation from state-owned STEG (also primarily gas-driven) increased by 12% to 16 024 GWh to bridge the gap. Electricity consumption increased by 6% y-o-y in January through October, driven by low- and medium-voltage customers (up by 9% and 6%, respectively) while demand from high-voltage customers declined 7%.

We forecast an average 3% growth per year in Tunisia's electricity consumption in the 2023-2025 period, principally met by growing domestic renewable generation. Generation from renewable sources is expected to increase by 80% between 2022 and 2025 and reach around 2 TWh by the end of the period – or the equivalent of close to 8% of Tunisia's electricity consumption, against less around 5% in 2022. Tunisia's energy strategy plan to 2030 targets a 30% share of renewables by the end of the decade.

NIGERIA

Access to electricity in Nigeria is hampered by insufficient available power generation and transmission capacity, and is further constrained by grid collapses. According to industry data, Nigeria's power grid collapsed seven times in January through to September 2022. This is higher than in 2020 and 2021, when there were four grid collapses each year according to the Nigerian Electricity

Regulatory Commission, but still shows some improvement compared to the average rate of default observed since 2015, which averaged 13 collapses per year (with a peak of 28 in 2016).

Earlier this year, President Buhari announced that electricity availability issues were mainly caused by low gas-fired generation (which represents 73% of the electricity mix in 2022) resulting from sabotage of gas pipelines.

A report from Nigeria's Association of Power Generation Companies showed that the country's average available generation capacity fell to its lowest level in seven years in 2022 (January to August) with 5 634 MW available, 20% below an annual average of 7 078 MW over the reported period, and 28% below the highest capacity – recorded in 2020 (7 792 MW).

New capacity is expected to be commissioned in early 2023, with the start-up of the 700 MW Zungeru hydroelectric power plant scheduled for the first quarter. President Buhari reaffirmed in October 2022 the country's dedication to the Presidential Power Initiative, an ambitious electricity development plan launched in 2019 with Siemens and with the support of the German government, which would raise the country's total available generation capacity to 25 GW by 2025. The Senate passed a constitutional amendment bill in July 2022 that would allow states to own and develop electricity generation, transmission and distribution capacity. This proposed removal of the federal state's monopoly on the electricity system would contribute to foster investment in new capacity through public-private partnerships.

A Review of Solid-State Transformer for Smart Energy

The next generation distributed transmission grid, called the smart grid, is the backbone of modern electrical power infrastructure, mimicking neural networks, and the design to solve the problem of integration of energy sources is crucial. These energy sources generate and transmit Electrical power at multiple frequencies and voltages. The power quality problems like voltage sags, voltage and current spikes from lightning, power factor issues, downtime, reliability issues and efficiency of the power system (because of losses and waste of electrical energy) cannot be mitigated by the current grid but by a smart grid and a solid-state transformer.

By | Adimchinobi D Asiegbu & Dr. Ali Alimaktoof DEECE FEBE, CPUT

Modernisation and advances in technology demand more energy in a purer form. The current decarbonisation policy and various policies to improve efficiency and reduce energy consumption from biomass and fossil fuel energy sources, coupled with the decrease in the cost of renewable energy sources like photo-voltaic (PV) cells and concentrated solar power (CSP), results in high penetration of renewable energy technologies and generation, and the development of electric vehicles, directly put stress on the current grid infrastructure, especially in withstanding the electrical power factor, frequency, voltage and current variations.

A Solid-State Transformer (SST) with bidirectional transmission capability, artificial intelligence, and multilayer applications is needed to mitigate the problems associated with current line or low-frequency transformers. The SST can be designed to function in the medium and low voltage region of 10KV and above by combining different SST topologies and control strategies. Hence SST can also be referred to as a high-frequency transformer (HFT), Intelligent Universal Transformer (IUT), or Electronic Power Transformer (EPT) due to its unique and indispensable features and characteristics.

STATEMENT OF THE RESEARCH PROBLEM

The need for a smart energy system which includes a smart grid that is reliable and sustainable means that a modern Solid-State Transformer (SST) which allows bi-directional transmission of energy at high efficiency, reduce electrical disturbances like harmonics from non-linear loads and provides different conversion topologies is needed to replace the current transformer. William McMurray proposed the solid-state transformer concept as a high-frequency AC/AC power converter link in 1970 (Shamshuddin et al., 2020).

BACKGROUND TO THE RESEARCH PROBLEM

Electricity is an important clean energy source and smart energy. Access to electrical energy is a major indicator of energy poverty and quality of life in general. Energy consumption is not unconnected with socio-economic growth. An increase in electrical energy consumption indicates growth in economic activities and an improved standard of living.

Economic and sustainability factors favour the generation of electricity from renewable sources. These sources can be influenced by the weather, climate, season of the year and other natural effects, leading to variable rates of generated electrical energy output from these sources.

These present problems with coordinating and integrating different variations in generating electricity from

diverse sources. Some of the sources, like wind turbines, generate alternating current (ac) electrical energy, which has sinusoidal or semi-sinusoidal waveform, while others, like photo-voltaic cells (PVC), generate direct current (dc) electrical energy, which is horizontally linear in shape. The problem is that due to unavoidable variations in the input effects/energy, the electrical energy output is not steady, and this output of electrical energy varies.

On the load side or electrical energy demand side, non-linear loads like Resistive-Inductive-Capacitive Loads introduce harmonics and distortion to the energy system. The problem is that these undesirable harmonic currents flow to other sources and loads in the distributed generation system.

The problem on the grid side is that some effects like thunderstorms and lightening can discharge or inject current of high magnitude for a short period into the grid system, causing voltage spikes, swell, or swag capable of introducing harmonics into the energy system and destroying insulation or important parts of the energy system.

Energy resources are not located in the same place on Earth. Weather changes are different in different places, and storage systems can be maintained at the source or load side. The problem of integration needs to be mitigated.

SIGNIFICANCE OF PROBLEM

To address these problems and improve the reliability/efficiency of the distributed generation, a solid-state transformer is designed based on the power system, control system, power electronics and high voltage engineering. The current low-frequency power system transformers cannot solve the problems mentioned above.

MERITS OF SST

- SST allows a bi-directional flow of electrical energy between source and load.
- SST reduces/eliminates harmonic currents and distortions from flowing in the smart energy system.
- SST minimises voltage flicker and does not need dielectrics and mineral oil.
- SST incorporates different voltage (ac to dc, dc to dc, dc to ac, ac to ac) conversion topologies, can receive ac/dc input and output dc/ac, mitigate voltage swag, swell, and spike, can be operated at different frequencies. It can produce different voltage levels (voltage regulation) (Banaei, Salary: 2014a).
- The solid-state transformer performs VAR compensation, smart protection, active filtering, power factor correction and disturbance isolation. There is increasing attention to the matrix converters as a variable frequency and variable voltage AC to AC power system that can be applied to areas that demand easier maintenance, smaller size, and higher power density (Lee, Nguyen, Chun: 2008) (Hooshmand, Ataei, Rezaei: 2012).
- SST can make decisions to improve performance/efficiency and can be digitally/remotely operated by a computer for solving complex smart energy problems.

LIMITATIONS OF SOLID-STATE TRANSFORMERS (SST)

SST has its drawbacks as follows:

- Many conversion stages can reduce the total efficiency
- Due to the DC link, coupling Capacitors are required
- Transformer life span can drop because of the storage devices

SOLID STATE TRANSFORMER MODELLING

- A MATLAB program is built to investigate and study the different parameters of the solid-state transformers, like evaluating some core materials through their magnetic classifications and characterisations (Gupta, Sinha, Vates, Chavan: 2021) and the SST design. To confirm the proposed performance of the SST, computer-aided simulations are done using SIMULINK /MATLAB (Banaei, Salary: 2014b).

THE LITERATURE REVIEW

- The electrical power system is the cleanest form of energy for easy transmission, distribution and utilisation by the end-user or demand side. It can be efficiently stored and converted to other forms of energy.
- Central to the modern power system (smart grid, artificial intelligence (AI) controlled industrial production (smart industry 4.0) and a modern energised house called smart house (SM)) is the Solid-State Transformer.
- The solid-state transformer is a multifunctional equipment that uses power electronics components and a transformer operating at a high frequency to perform isolation and conversion of voltage.

LINE FREQUENCY TRANSFORMER AND SOLID-STATE TRANSFORMER CHARACTERISTICS

- The traditional transformer, also known as frequency line transformer (FLT), has been an important component in power systems starting from 1885, the time Zipenowsky et al. showed the operation of the first commercial transformer (Krause: 2012) (Orosz:2019). In 1888 Tesla made a case for using transformers for an electrical distribution system (Tesla: 1888).
- The current transformer, also known as Line Frequency Transformer (LFT), is an important electrical device for transforming electrical energy from high to low or low to high in alternating current systems. This LFT is also used as an isolating transformer. Since the invention of this LFT, electrical energy has become affordable, more efficient, more reliable, and modern technology with increased performance at a marginal cost (Hopkins and Safiuddin: 2010).

DRAWBACKS OF LFT

1. Total large size and big weight
2. The oil used in transformers can be a contaminant and hazardous to the environment and humans
3. The magnetic material used in the core is not very efficient, resulting in the core being saturated and a large inrush magnetising current, increasing the losses of the LFT and current drawn from the supply, resulting in more losses in the transmission lines and emission of more greenhouse gases (GHG).
4. Undesirable effects on the input are carried over to the output
5. The harmonics in the load side can affect the input side causing more core losses and system disturbances.
6. If LFT is not operated in the full load mode, the efficiency of the LFT decreases, which means more losses—relatively high losses at their average operation load. Transformers are usually designed with their maximum efficiency at near full load.
7. Most LFTs have voltage regulation problems. Since the voltage regulation is inversely proportional to the FLT rating, Transformers used for electricity distribution are of low rating, resulting in poor voltage regulation.

THE BENEFIT OF SOLID-STATE TRANSFORMER

1. SST produces voltage regulation better than FLT, which uses tap changers.
2. SST can compensate voltage sags, interconnecting networks with different frequencies, and harmonic problems, serving as an interface between DC and AC port(s) respectively,
3. Compensation of reactive power, voltage magnitude resolution, disturbances isolation from the load and source or from source to load.
4. Tap changers and mechanical actuators are not required

THE COMPARISONS BETWEEN LFT AND SST

- The cost of LFT is less than SST. However, with advances in semi-conductor technology and decreased prices of modern power electronics components, SST will become cost-effective and affordable compared to LFT cost.
- Because of the complexities of the SST configurations, it may not be reliably compared to LFT. But the SST modular design allows for faults detection, bypassing and isolation. This means that the reliability of the SST will increase as technological advances are made.
- The efficiency of the SST is less than the LFT because of the losses in the power electronics components. The efficiency of SST is between 90 - 98 % against that of the LFT, which is greater than 97%. However, harmonic reduction and power factors close to unity in SST can give SST better performance than the LFT.

SST ARCHITECTURE

The SST structure is classified based on three important properties or characteristics of the SST, like connection to High Voltage or Medium Voltage to at least one port, MF isolation stage, and control of input or output electrical variables, being universal to incorporate any SST. Thus, the classifications of SST are as follows:

- Single stage Solid State Transformer
- Two-stage Solid State Transformer with Medium Voltage Direct Current-link
- Two-stage Solid State Transformer with Low Voltage Direct Current-link and
- Three-stage Solid State Transformer

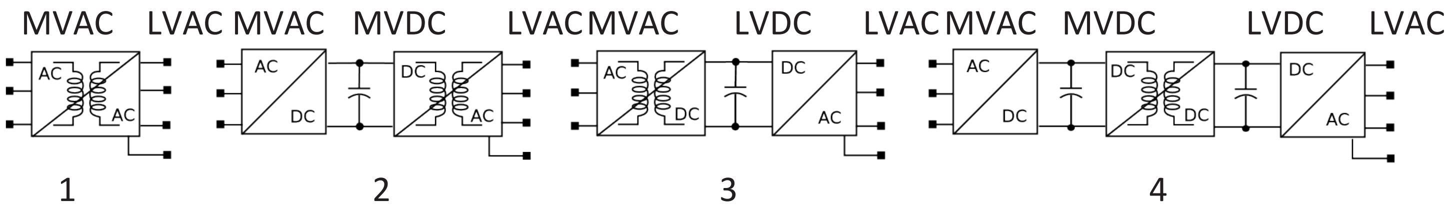


Figure 1: Solid-State Transformer Architectures

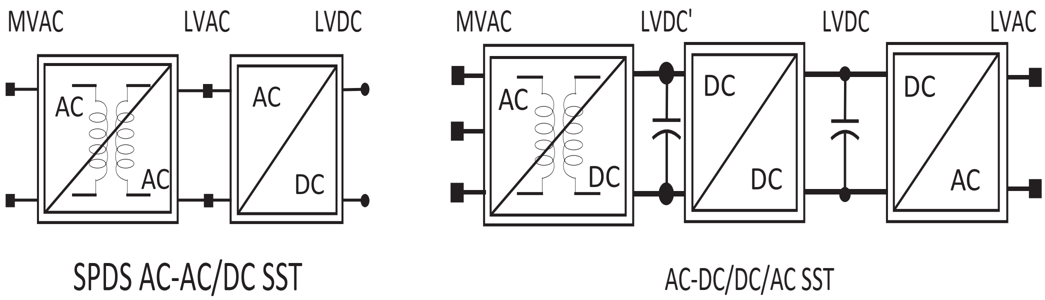


Figure 2: Dual primary single secondary (DPSS) AC/DC-AC SST or single primary dual secondary (SPDS) AC-DC/AC SST.

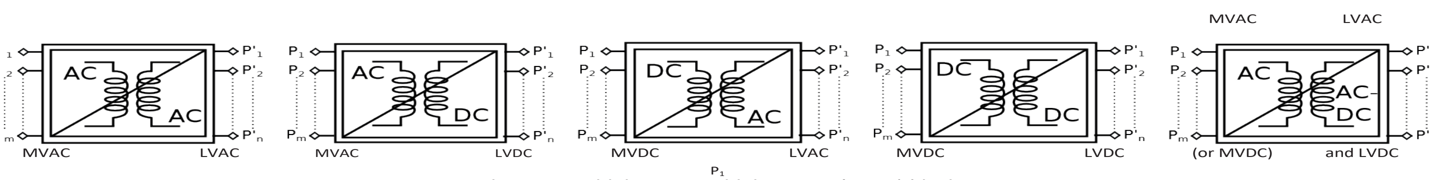


Figure 3 : Multiple Input Multiple Output (MIMO) blocks.

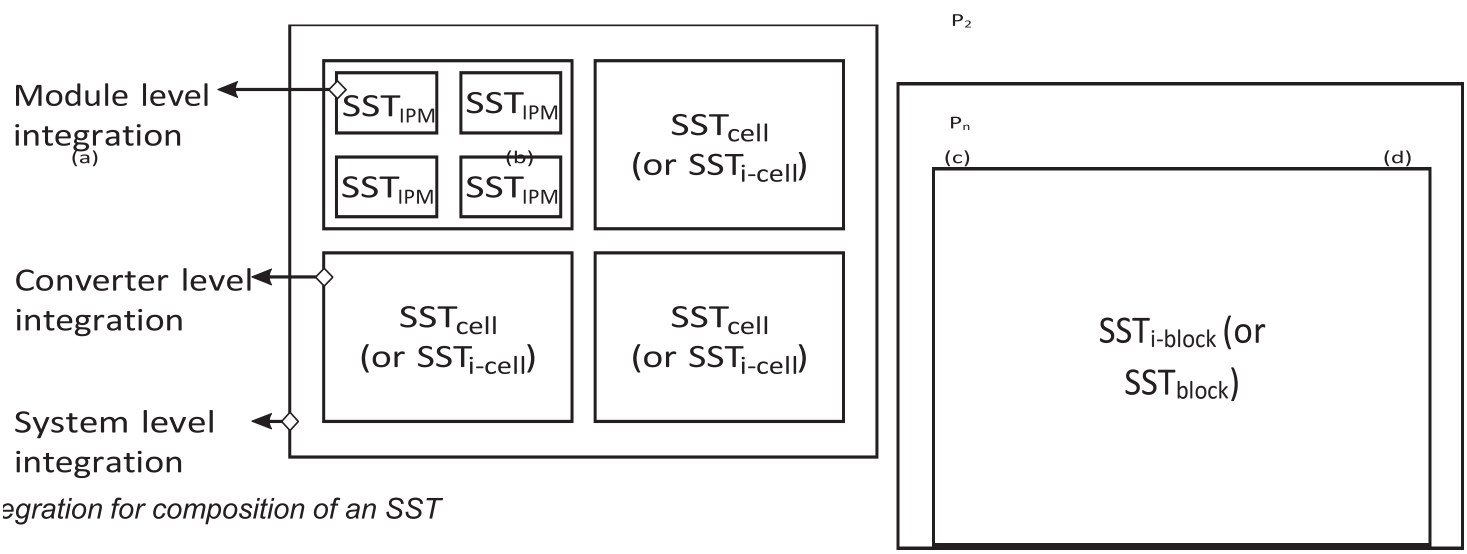


Figure 4: Integration for the composition of an SST

with Medium Voltage and Low Voltage Direct Current-link
- These architectures are shown in Figure 1.

COMBINATION OF SSTS

The circuit in Figure 2 represents the isolating SST and the non-isolating SST. Two-stage SST can be constructed using one isolating SST block and one non-isolating-SST block.

This generates a link, representing a port if the intention is to create an external interconnection. If not, it represents an energy link. Also, more ports can be made at the MFT primary side for back-end isolating-SST- block or at the MFT secondary side for front-end isolating-SST block. SST topology can be a dual primary single secondary (DPSS) AC/DC-AC SST or single primary dual secondary (SPDS) AC-DC/AC SST or Multiple Input Multiple Output (MIMO) blocks as shown in Figure 2 and Figure 3. The integration for the composition of an SST is shown in Figure 4.

THE CLASSIFICATION OF SSTS

SSTs can also be classified based on the following:

1. Power stages
2. Voltage levels
3. Control of the isolation stage
4. Modularity
5. Number of ports per power stage

The detailed classification is shown in Figure 5.

MEDIUM VOLTAGE OR HIGH VOLTAGE SIDE SOLID STATE TRANSFORMER CELL (S) INTERCONNECTION

Medium Voltage levels can be interconnected or interfaced by implementing these procedures (Liserre et al. 2016):

1. Low Voltage, series-connected semi-conductor devices
2. Wideband gap-based semi-conductor devices
3. Multi-level configured converters
4. Multi-cell method or approach

CONSTRUCTION OF SST

For semi-conductor Devices for SST the following should be considered for selecting appropriate semi-conductor devices for SST:

1. Voltage ratings
2. Current ratings
3. Switching frequency
4. Maximum junction temperature.
5. High blocking voltage, high current carrying, capability, and low on-state losses.

MFR-MEDIUM FREQUENCY TRANSFORMER

This device is a key element in Solid-State Transformers. An MFT connected to a power converter yields a low footprint and higher power density while improving efficiency (pipo et al.: 2016).

CORE MATERIAL

The core material is made from a soft magnetic material, which is easy to magnetise and demagnetise, and they have the following features: Low core losses, High saturation flux density and thin hysteresis loop area, High continuous operating temperatures capability, High relative permeability.

Soft magnetic materials include:

1. Iron in powdered form and very fine small particles of iron alloy
2. Composites of silicon and silicon-derived nanomaterials
3. Derivatives of ferrite and pure ferrite material
4. Magnetic materials in Amorphous form
5. Nanomaterials used as Nanocrystalline based cores

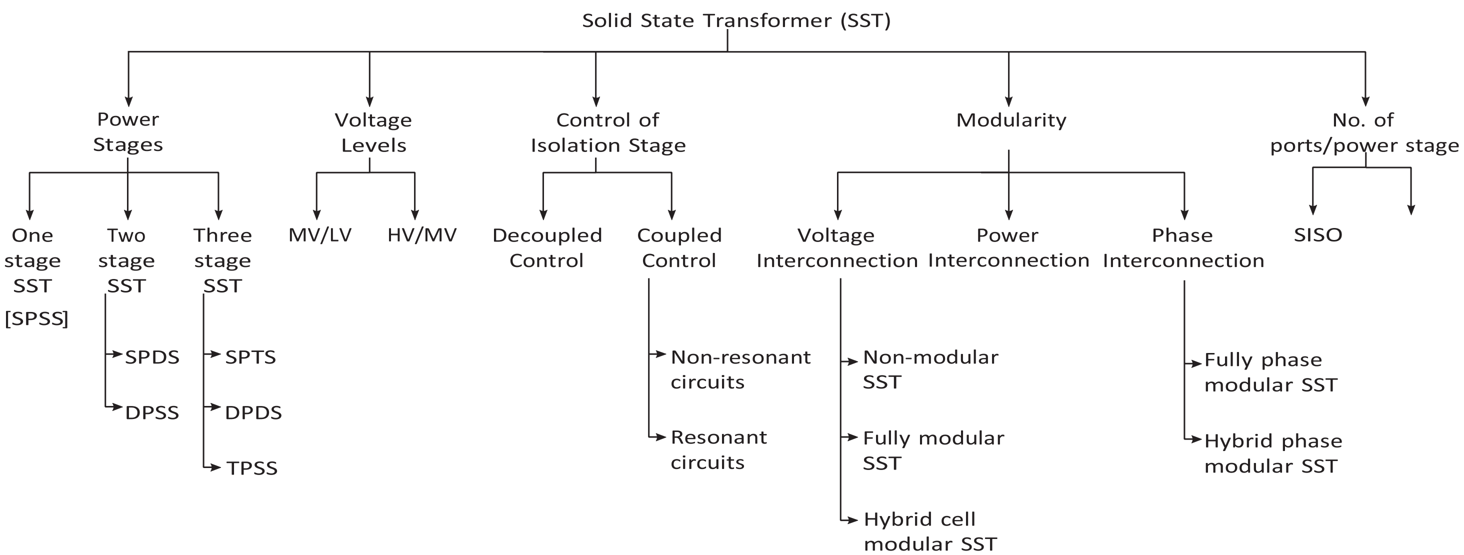


Figure 5: Solid-State Transformer Classifications

WINDING MATERIAL AND ARRANGEMENT

The choice of coil material is copper or aluminium because of the low electrical resistance, Insulation and Thermal Considerations, High dielectric factor, and thermal conductivity, respectively. Tolerance to partial discharge is required for good insulation material selection. Air is normally used for cooling, and epoxy is used as dielectric material where the air is insufficient for handling high voltage levels.

APPLICATIONS OF THE SST IN MODERN OR SMART ENERGY

Due to the above benefits of the SST, it can be applied or used as follows:

1. Transportation: SST is widely used in the transport sector machines like tracking systems and locomotives due to the 75% reduction in weight and 40% decrease in size with a phase of 13.8 kV/ 270 V SST (Grider et al.: 2012). The losses are halved, and one-third of weight and volume reduction for SSTs is achieved compared to transformers in DC/AC applications (Huber and Kolar: 2012).
2. Wind Turbines application benefits from the flexibility and controllability of SST. (Xu She et al.). SSTs can suppress voltage fluctuations caused by the erratic nature of wind energy without needing a compensator for reactive power. A three-stage DPDS AC/DC-DC/AC SST architecture is suitable for wind turbines. The operation of the variable speed of DFIG is managed by a rotor side control, which activates super synchronous or sub-synchronous modes.
3. Interconnection of Grid, Reactive Power and Energy Routing
   The deployment of SSTs in the distribution bus or feeder yields a 1.4% decrease in losses. Hence SST functions as energy interconnectors or routers (Huang: 2019).
4. Traction application can be realised using a fully modular multi-cell AC-DC SST (Besselmann, Mester, Dujic: 2013).
5. SSTs are used as an interface for asynchronous loads and grids. A prototype is made by implementing SPSS AC-AC SST (Liu et al.:2016).
6. Due to limitations in the current and voltage handling capabilities of semi-conductors, semi-conductor failures, thermomechanical failures, measurement errors, control errors, short circuits or over voltage, and lightning surges, SST can be damaged by these effects (Guillod et al.: 2015).
7. A Grid source at 50Hz supplies a load that works at 60 Hz by applying the finite set method predictive control (MPC) with compensation in the delay angle (Liu, Liu, Abu-Rub, Ge: 2016).

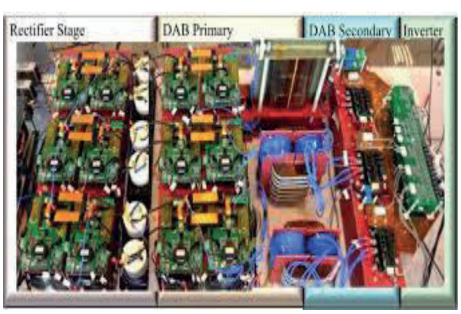
RESEARCH QUESTIONS

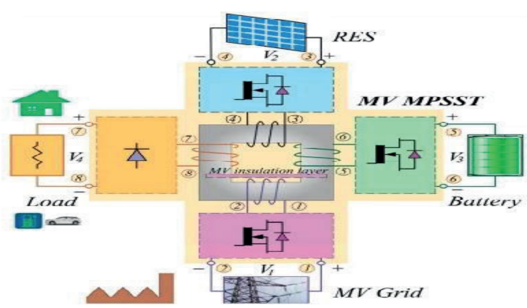
This research tends to answer the following research questions:

1. Can the transformer's ability to regulate voltage due to voltage swell, voltage swage, transients, and transmission line voltage drops that result in end-user low voltage be mitigated?
2. Can the line frequency transformer be changed to the solid-state transformer to improve its ability to handle variable source frequencies and AC/DC voltage sources?
3. Can the solid-state transformer be connected serially or in parallel to handle higher voltages or currents?
4. How to identify and select high-performing magnetic core and winding materials
5. Can the voltage and current capabilities of semi-conductor materials be improved?
6. Selection of a better insulator for the transformer
7. How to improve distributed generation and cogeneration
8. How to change the traditional grid to a smart grid in a smart energy system.

RESEARCH AIM AND OBJECTIVES

This research aims to model and design a solid-state transformer for smart energy that will mitigate the issues like source-load integration, voltage regulation, losses in the grid system, fault and failure detection and prevention,





Printed circuit board SST prototype, Energy integration using SST and SST prototype is shown above.

and improvement of the distributed generation in the smart energy system.

The Research objectives are split into the following sections:

1. The review of solid-state transformers (SST) and line frequency transformers (LFT) from available literature and information repositories.
2. Benefits and cost analysis of SST and FLT to know their viability and economic value
3. Selecting the best SST architecture for high-efficiency applications.
4. Combining SSTs for medium and high alternating and direct current applications.
5. The best possible topology for integrating various sources of electrical energy forms, like SST, is capable of allowing bidirectional current flow, whether alternating or direct current.
6. Based on the above objectives, modelling and simulation of SST that satisfies the requirements mentioned above.
7. The thermal and insulation considerations in smart grid with regards to SST implementation
8. Applications of SSTs in smart energy.

RESEARCH METHODOLOGY AND DESIGN

- The optimised design of a solid-state transformer is important in minimising power quality issues and better use of distributed resources in a smart energy system. Different energy or power sources with their peculiarities and requirements can be integrated using a solid-state transformer model and design, and the environmental issues can be reduced. For example, the liquid dielectric is eliminated in the design of a solid-state transformer, efficient management of different energy sources is ensured, and control and communication topologies are implemented in this design. The research methodology and design are implemented by carefully designing Solid state conversion topologies, control strategies, high-frequency transformer design with improved efficiency, and computer modelling and simulation.
- Solid State Transformer conversion topologies design is shown in Figure 6 to Figure 9.

Single stage and two stages can give desired functions with some limitations. Three stages give the best functionality with the added advantage of a simplified control design (Qin and Kimball: 2013). The three-level topology used in this design includes the clamped diode multi-level converter, multi-level converter with flying-capacitor, and series stacked converter (Merwe WVD, Mouton: 2009). For the medium voltage converter level side, the proposed design is the multi-level cascaded H-inverter configuration (Wang et al.: 2016) or the modular multi-level converter (MMC) or the neutral point Converter (González-Molina et al.: 2015). The bidirectional dynamic current (Dyna-C) is very good because it provides current inverter stages, three-phase alternating current to alternation current power conversion with twelve switches making the input stages and output stages work with an arbitrary number of frequencies and power factors plus a frequency galvanic isolation Chen et al.: 2017). This is useful in designing multiphase direct current and alternating current systems. The 270 kilovolt-ampere solid state transformer, designed on a 10 kilovolt Silicon Carbide metal oxide semi-conductor field effect transistor, is analysed to support a 24-kilovolt input voltage with each device capable of blocking 10 kilovolts. To achieve this configuration and design, three flying capacitors are used to operate a phase-controlled zero-voltage switching (Shri et al.: 2013).

CONTROL STRATEGIES

The linear quadratic regulator method improves dynamic performance, with the integral action feedback to cancel the steady-state errors.

A simple predictive control mainly used for multi-level stage control on the low voltage side or high voltage side is explored. This method uses a predictive control algorithm to generate the reference primary current level and analyse the delay angle optimised between secondary and primary voltage.

The primary, secondary, and tertiary side control hierarchy for power management strategy can be used to control the direct current microgrid (Moonem and Krishnaswami: 2014).

Two communication network control techniques control the modularity among the power modules for efficient and proper management of the distributed energy system (Vargas et al.: 2015).

HIGH-FREQUENCY TRANSFORMER

The high-frequency transformer is an important part of the design of a solid-state transformer to achieve the much-needed reduction in the size of the overall system. For a high-frequency transformer to achieve high current, high frequency, high power, and voltage operations, the following needs to be considered (Ronanki and Williamson: 2018):

a. To achieve high-frequency operations, magnetic material with high power density and low losses at high frequencies must be selected and used.
b. The transformer's windings or coils must be carefully chosen at high frequencies.
c. To avoid thermal breakdown because of high voltage and high-power applications, the thermal

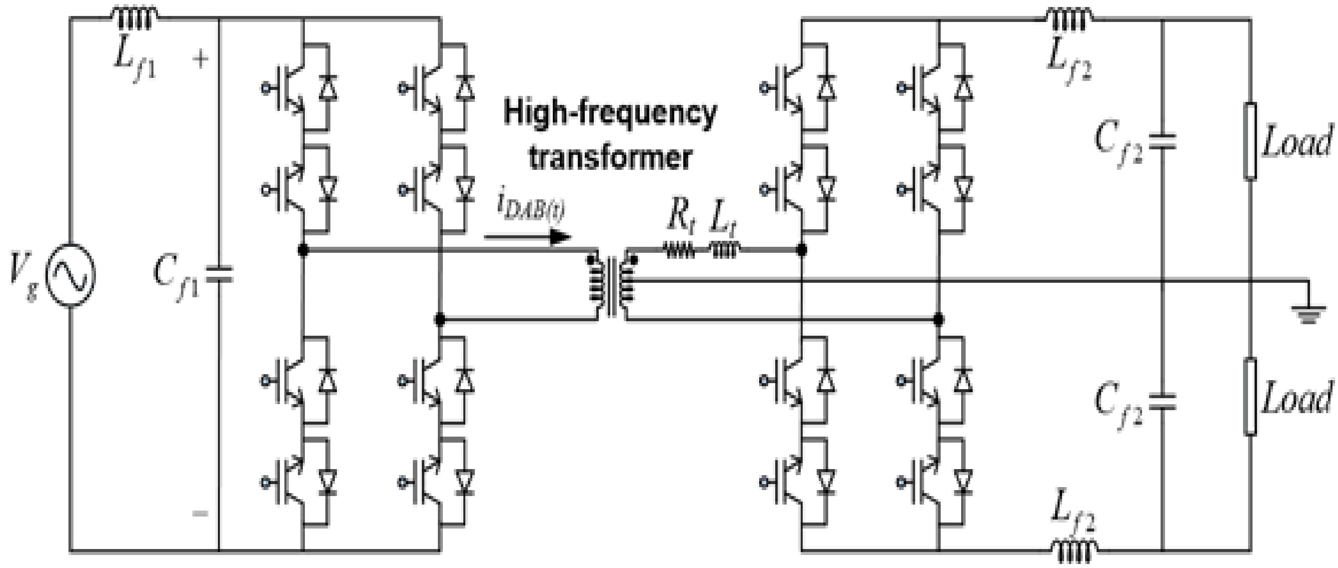


Figure 6: Topology for single-stage solid-state transformer

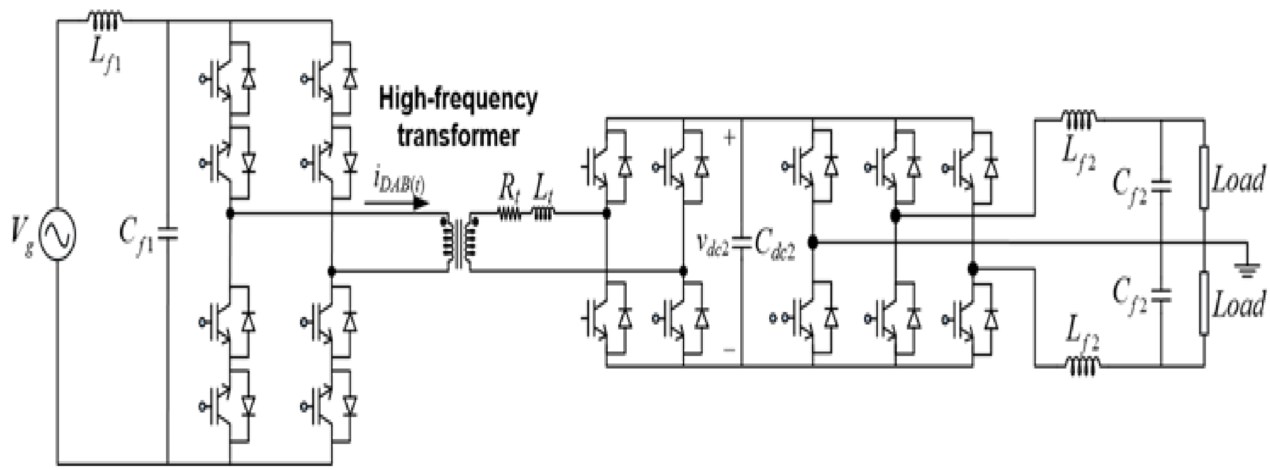


Figure 7: Topology for two-stage solid state transformer.

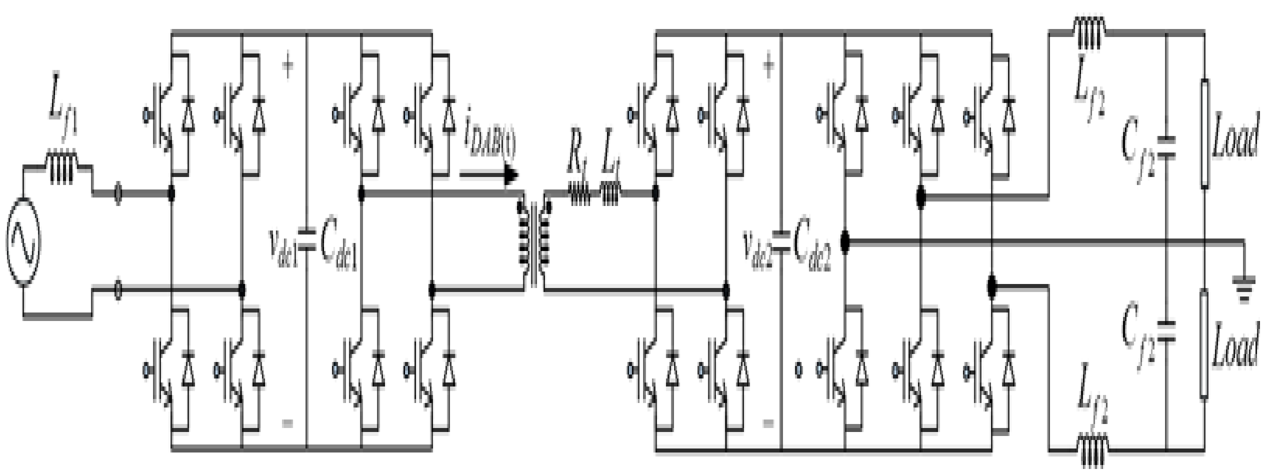


Figure 8: Topology for three-stage solid state transformer.

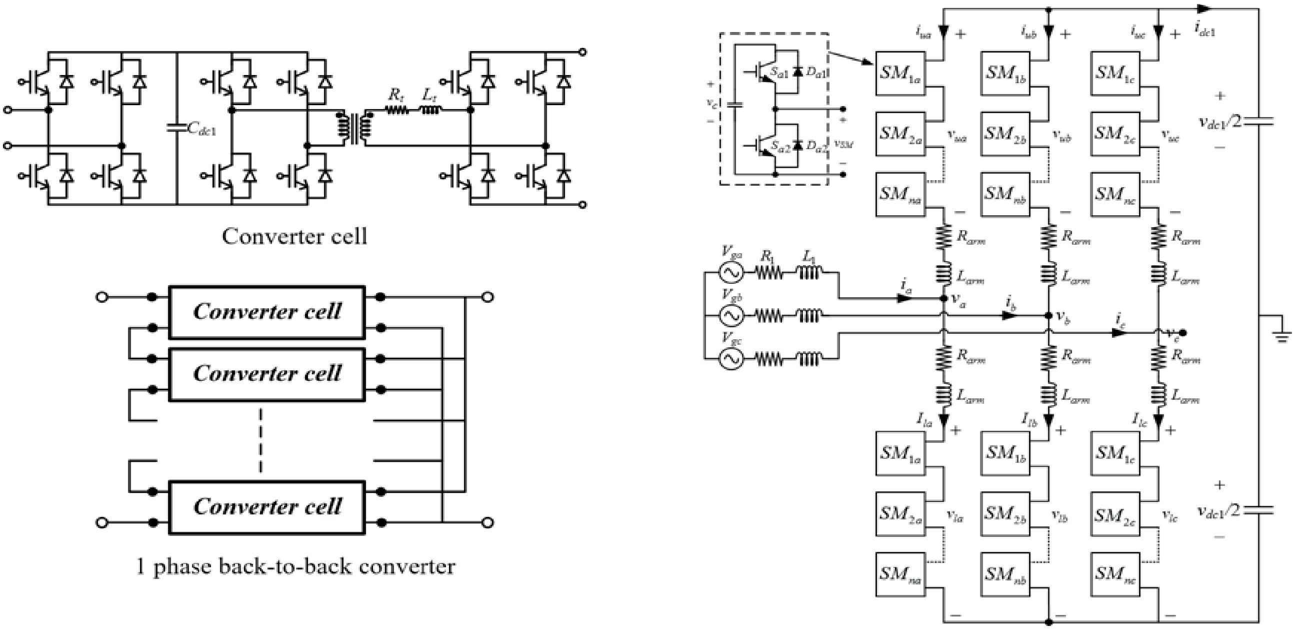


Figure 9: The configuration of a multi-level cascaded SST and configuration for MV based on MMC.

behaviour of the materials used should be carefully considered.

d. Since oil is eliminated in the configuration of the solid-state transformer, insulation is a challenge. This means the insulators to be used must be carefully tested and proven to be appropriate for the SST.

The two most important ratings are power rating and frequency rating. A 24 or 12-pulse rectifier system with a silicon-grained magnetic core can reduce the size by about one-third compared to a conventional transformer operating at 60 Hertz. Metal glass alloy is the best magnetic core material to reduce core losses and optimise leakage inductance (Yu Du et al.: 2010).

By using coaxial coils for the medium voltage and applying the finite elements methods, an efficiency of around 99.5% can be obtained.

THE EFFICIENCY OF THE SOLID-STATE TRANSFORMER

The efficiency of the solid-state transformer can be improved by implementing advanced configuration for the converter stages using control optimised stages for the solid-state transformer, a well-designed high-frequency transformer, and the use of semi-conductors with wide band gaps like silicon carbide semi-conductor.

Energy efficiency can be classified based on performance, operation, equipment, and technology efficiency (POET) as a unifying and complete approach for energy efficiency analysis and classification.

Technology efficiency is an indication and measurement of energy generation, conversion, processing, transmission, and utilisation efficiencies of the thermal utility, often limited by thermodynamic laws that make the overall efficiency less than unity.

Technology efficiency is the overriding efficiency that paves the way for analysis of the other efficiency frameworks.

Technology efficiency information is retrieved from the dimensions or indicators like the feasibility of the technology, life span cost and ROI (Return on Investment), and the converting/transmission rate of change with time/procession coefficient. The solid-state transformer is under technology efficiency.

Performance efficiency is a measure of energy efficiency that is retrieved by external indicators and deterministic system indicators like the environmental impact, cost, technical, energy sources, and production indicators. The SST can be placed under performance efficiency. Operational efficiency is a measure of the system-wide variety of parameters evaluated by coordinating different dimensions or components of the system. This consists of the human physical and time coordination parts.

Equipment efficiency shows the output energy of isolated equipment considering the design specifications of a technology. The equipment is treated as separate from the rest of the system and has low relationship effects with the other equipment or system components. It is evaluated by the following indicators: specifications, maintenance constraints, capacity, and standards.

SIMULATION AND MODELLING COMPUTER SOFTWARE

Computer software for modelling and simulation like MATLAB/Simulink, MATLAB/PLECS, and SPICE is very useful in studying and designing a complete solid-state transformer.

THE EXPECTED OUTCOMES

The outcome expected from this research is the design of an energy-efficient solid-state transformer with minimal losses when operated at high frequency, high power density, high voltage, and high current.

This will mitigate the issues encountered in integrating various energy sources in distributed smart energy systems, from direct current to alternating current, with different frequencies and power densities like solar and wind energy sources.

THE RESEARCH CONTRIBUTIONS

The contribution of this research is as follows:

a. Provision of a universal interface for distributed energy sources with different frequencies, voltage, and power density requirements.
b. Replacement of the conventional power transformer to achieve high power quality.
c. To reduce the size, cost, and weight of the conventional power transformer
d. To support a smart energy system with or without storage units.
e. To provide active harmonic filtering and power compensation to any load.
f. The model developed can be used as plug and play in a smart energy system
g. It reduces circulating current and supports power balancing.
h. Provision of reactive power compensation.
i. Provide maximum power tracking and induction heating with an improved efficiency and power factor.
j. Provision of galvanic isolation of different topologies.

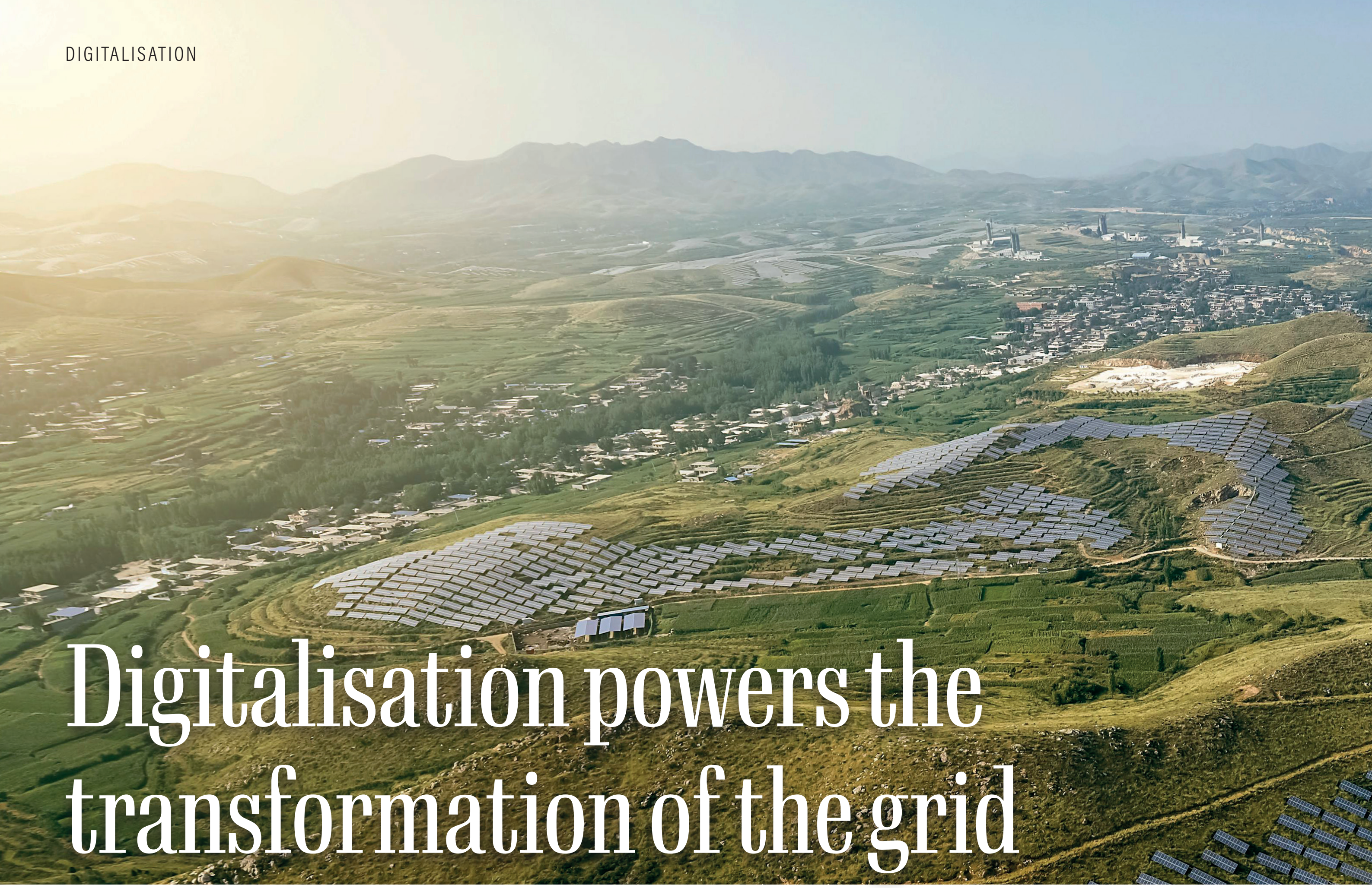
There are many possibilities where SST has proven to be an alternative. Thus it is called the future "energy router" (Vaca-Urbano et al.: 2019) and is at the heart of Energy Internet. Energy Internet is the main reason for smart energy or electric power systems in which there is ubiquitous sharing, ubiquitous use, and ubiquitous ownership of electrical energy in real-time (Huang: 2019).

SSTs support voltage restoration and fault isolation under abnormal conditions. Also, the galvanic isolation with DC ports assists in connecting electric vehicles. This provides fast charging of electric vehicles (Srdic, Lukic, Toward 2019).

CONCLUSION

Energy storage can be added in the form of bus capacitors on the HV and LV DC buses, with an added advantage of Input voltage dip and swell compensation, Harmonic filtering, direct current and high frequency alternating current electrical power supply, significantly improved power quality and efficiency, rapid control of voltage, compensation of the reactive component of apparent power, control of reactive power at the high voltage and low voltage side of the transformer. The SST, modelled and designed, will perform monitoring and management of the power system. Thus, SST is the backbone that integrates various distributed resources located at different places, operating at different electrical behaviour (different frequencies, currents, voltages, and power factors), coordinating, controlling, and detecting faults in the modern power system. SST modelling and design using simulating software tools to produce a prototype. The drawback of SST is the low efficiency, large number of semi-conductors needed to design multi-level stages, reliability and energy losses associated with these semi-conductors, and few experiences and expertise in the field.

Based on the complexity of SST, it is more expensive than its low-frequency counterparts. Still, with technological advances, as time passes, especially the use of silicon Carbide (SiC) and nanomaterials along with other technological improvements, the solid-state transformer will be cheaper, well-suited, and preferred over the current bulky conventional low-frequency power transformer. wn



Digitalisation powers the transformation of the grid

As the world decarbonises its energy system, electricity will be the backbone. There is an accelerated shift from fossil-based to renewable power generation, with growing electrification of the transportation, industrial and building sectors.

By Malvin Naicker, MD, Hitachi Energy, Sub-Saharan Africa

To manage this, digital and energy platforms are needed for the enormous power system energy transition challenges of increased complexity and additional capacity requirements. These platforms will enable greater grid resilience and help manage the shift to a more complex power generation landscape by dynamically matching fluctuations in power supply and demand.

CYBERSECURITY

A significant aspect of resilience is cybersecurity. The world needs a cyber-secure ecosystem for a resilient electric future. Energy is among the top three target sectors for cyberattacks globally. As energy grids become more resilient through digitalisation, attention must be paid to the design and implementation of cybersecurity.

Utilities in South Africa are becoming increasingly aware of the advantages of outage management software solutions to manage the supply to their customer base. Some municipalities are considering deploying Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems (DMS) to manage their networks better.

SELF-GENERATION

Through changes in regulation and technology, large power users can now generate and use their own electrical energy. As this self-generation becomes more prevalent, users will start to trade power with each other, with the grid being the trading platform for such exchanges.

Sophisticated software solutions are available to manage such trading, allowing a real-time power exchange between users and settlement of the resultant commercial transactions.

With the rapid deployment of self-generation underway, saving a kWh of demand is easier and cheaper

than building generation to cater for that demand. Improved energy efficiency is essential if the world is to decarbonise successfully. The digital solutions available today support the implementation of energy efficiency by identifying where energy is used and the actions needed to use it more efficiently.

Solutions such as low-loss transformers enable better use of electrical energy. Even small electrical losses in transformers add up over the lifetime, resulting in significant carbon emissions and wasted power that transformers with enhanced energy efficiency could save. Plus, trans-formers contain large volumes of material that can be made more sustainable through intelligent designs and the use of material.

GRID CONNECTION SOLUTIONS

As the power generation landscape evolves in South Africa, the demand for grid connection solutions is increasing rapidly. It has taken many decades to build the power grid that exists today. There is not enough time to meet the demand for new offtake and grid integration solutions unless new solutions, such as prefabricated substations, are considered to speed up the deployment of such grid connections.

Smart grid solutions consist of three basic components: The devices to collect data and control the grid, the communications network that connects these devices and the software solutions that enable the management of the grid.

The Internet of Things (IoT) has enabled smaller, cheaper devices to be deployed more easily and deeper into power networks. The smart meter can be the hub in the home, enabling control of electricity demand and outage management.

Decarbonisation transforms our energy system, driving an accelerated shift from fossil-based to renewable power generation and electrification of the transportation, industry and buildings sectors. This creates the need to optimise energy locally and system-wide, leading to a complex 'system of systems' that must be integrated and managed.

Digitalisation is the only way to manage this complexity, simplifying the contextualisation of massive data. However, this must be balanced with managing and optimising today's operations.

Hitachi Energy can help you navigate this increasingly complex energy landscape. We have the right combination of connected products, software-based solutions and digitally enabled services to solve real-world challenges and add real value. wn

China's Nuclear Programme

On 22 March 2023, World Nuclear News announced, "China and Russia sign fast-neutron reactors cooperation agreement". The report says, "Russia's Rosatom and China's Atomic Energy Authority (CAEA) have signed a Comprehensive Programme for Long-Term Cooperation in the field of fast-neutron reactors and closing the nuclear fuel cycle". Whilst this may seem to be something new, it is not surprising.

An article in 'Power' journal dated 8 November 2016 by Thomas Overton entitled *"Russia and China Expand Nuclear Cooperation"* states, *"Russia and China have agreed to expand cooperation on nuclear energy, with Russia to build another two reactors in China in addition to expanding cooperation on fast-reactor technology and floating nuclear plants.*

The two nations, which share a 4,200-kilometre-long border, have worked together on nuclear energy for decades. Still, the cooperation has ramped up as Russia has moved to expand export markets for its advanced nuclear technology. China has dramatically expanded its nuclear generation capacity to stay ahead of surging demand." It seems like a 'win-win' situation where Russia have an oversupply of capacity and is exporting nuclear plants, and China desperately need clean power. There is also a different aspect; China is eager to learn and digest as much nuclear knowledge as they can, especially since they have opted for the closed nuclear cycle by employing fast breeder reactors, abandoned by the West who have chosen the less risky but wasteful once through a system that disregards huge amounts of potential nuclear energy and is expensive in nuclear waste disposal.

Only 0.7% of natural uranium is fissile, and 95% of that is discarded in spent fuel, not to mention the other 99.3% of natural uranium, which can be converted into usable fuel. This means that this system uses only 0.035% of natural uranium to generate electricity by this system[1]. Whilst it may be cheaper to use uranium in this wasteful manner, it should be

1. Currently, a tenth of the world's electricity, 2,700TWh (1TWh = 1kWr x 10^9, one thousand million kWh) is generated from 440 reactors in 32 countries from this percentage of extracted natural uranium

By Fred Catlow | FSAIEE

realised that the cost of reprocessing spent fuel is insignificant compared to the vast sums of money governments seem to be prepared to spend on 'so-called green energy solutions.

Making greater use of this precious commodity seems to me to be preferable to industrialising our priceless, irreplaceable countryside with wind and solar power factories which are damaging to wildlife and our environment. In any case, China is testing a thorium reactor which is safer than uranium and does not produce plutonium.

According to Wikipedia, in the early days of nuclear energy (1950 to 1955), China's main interest was in learning how to make nuclear weapons to secure and protect the political system pursued by Mao Zedong. In this, China turned to Russia for help, and the first cooperation between them was the establishment of the China-Soviet Union Non-ferrous Metals and Rare Metals Corporation at Kuldja, China, in March 1950.

The (China) Institute of Atomic Energy was established in 1950 as an offshoot of the Chinese Academy of Sciences to research all things nuclear, e.g., weapons, power, medicine, radioactivity etc.

The China National Nuclear Corporation (CNNC) was set up in 1955 to implement research into practical use for both military and civilian purposes. In December 1958, nuclear power development became the top priority project in the Draft Twelve-Year Plan for Development of Science and Technology.

NUCLEAR-GENERATED ELECTRICITY IN CHINA

In 1970, the Shanghai Nuclear Engineering Research and Design Institute (SNERDI) was established to design and build a Chinese nuclear power plant. This was achieved, and the CNP300, a Chinese 300MW pressurised water reactor, was born based on a submarine reactor design. Three of these reactors were exported to Pakistan.

In Mar 1985, CNNC / SNERDI began constructing the CNP300 (326MWe) reactor at Qinshan in Zhejiang Province. Grid connection was made in Dec 1991.

GUANGDONG AND THE FRENCH CONNECTION (VIA WESTINGHOUSE)

Almost in parallel with these events, a British businessman in Hong Kong, Sir Lawrence Kadoorie, CEO of China

Light & Power (CLP), proposed that a nuclear power plant be constructed to supply electricity to both Hong Kong and mainland China (Guangdong Province) and "to enhance economic links with Mainland China and help to preserve British administration of Hong Kong". Unsurprisingly, the British Prime Minister, Margaret Thatcher, and the President of China, Deng Xiaoping, were enthusiastic about the proposal. It must have come as an unexpected and very welcome opportunity for the Chinese nuclear engineering community.

The Guangdong Nuclear Power Joint Venture Company Ltd (GNPJVC) was founded to finance the project: 75% of which was provided by the Guangdong Nuclear Investment Company Ltd. (GNIC) and 25% by Hong Kong Nuclear Investment Company Ltd (HKNIC), a subsidiary of CLP. Hong Kong agreed to take 70% - 80% of the power. The proposal to build a nuclear power plant adjacent to the densely populated island of Hong Kong was vigorously opposed by many people, especially at the time of the Chernobyl catastrophe. Nevertheless, the decision to proceed prevailed, and the order was placed with the French Consortium (Areva/ Framatome et al.) for two power reactors on one site. It took six years to build the first plant.

Each of the plants was based on the proven, successful Westinghouse three-loop Pressurised Water Reactor (PWR) design, WH 3LP, rated at 900+MWe, almost identical to Koeberg NPP in South Africa, which was known to EdF (Electricité de France) as CP1 and in China as M310. Subsequently, the plants performed well and were listed as two of the world's best-performing plants with average 'Operation', 'Energy Availability' and 'Load' factors for most years in the 89% -100% region. As of 2023, the reactors have been operating for 29 years, trouble and accident-free. (Report HKNIC 2023). The staff at the plant are exposed to very low radiation (0.8 mSv) equivalent to an X-ray.

In Aug 1987, Guangdong Nuclear began constructing two M310 (944MWe) reactors at Daya Bay 1 & 2 in Guangdong Province. Grid connections made in Aug 1993 & Feb 1994

OFFSPRING OF KOEBERG, SOUTH AFRICA

I first became aware of the Guangdong project when I was an engineer on the Koeberg Project Team. I observed radical differences in how the two contracts, Koeberg and Guangdong, were managed and implemented.

Koeberg was the first successful French power reactor export contract. The French were anxious, especially after the aborted project in Iran, that Koeberg should be successful, and the French Government insisted that the contract be managed similarly to the winning formula adopted for the nuclear power plants in France.

Koeberg was, therefore, strictly a turnkey contract carried out by a consortium of French companies under the management of Framateg, a company specifically set up for Koeberg, comprised of EdF (Electricity de France) engineers; civil works by Spie Batignolles; 'nuclear island' (reactor & associated equipment including reactor instrumentation) by Framatome and 'conventional island' (turbo-alternator etc.,) power electrics by Alsthom and control & instrumentation by CGEE- Alsthom. Like the plants constructed in France, there were to be no changes or modifications, except the civil works, which had to be adapted to the geology and seismicity of the site at Melkbosstrand on the Atlantic Coast of Western Cape Province. Eskom, the owners were happy with this arrangement as South Africa had no previous experience with this type of project. The Eskom Project Team (mostly engineers with European nuclear experience & training) oversaw the work. It ensured the plant was built according to the contract specification, quality assurance requirements and South African Regulations. One of my main concerns was that the control circuitry was based on old-fashioned relay logic.

Whilst CGEE-Alsthom had a very good system called 'Controbloc' based on current (solid-state) technology at the time, I was not allowed to use it, as under the terms of the contract, the hardware had to be identical to what was installed on the reference plant, Tricastin Unit 2[2].

One of the problems with the French system was that as the Government had been frustrated in the past by frequent design changes to their earlier discontinued UNGG reactors, the Government adopted a 'no change' policy for the Messmer Plan 'licence agreement', negotiated through Baron Empain, with Westinghouse. Unfortunately, repeating the same design failed to keep up with some technological advances.

I did, however, as one of the improvements recommended after the Three Mile accident in America in 1979, succeed in ordering through Eskom a new control room Critical Function & Monitoring Display (CFM) system to replace the original Sintra control room computer, which in my opinion was inadequate.

The new system was supplied by CGEE-Alsthom in conjunction with Combustion Engineering based on a control room monitoring system at San Onofre Unit 2 (SONGS), California. I requested that the system use the Gould/SEL computer, the "blockbuster", the most powerful 32-bit mini-computer at the time.

2 Subsequently updated control systems were retrofitted to French NPPs see reference

I am not fully conversant with the Guangdong contract. Still, in conversation with French engineers, the contract seemed a boon for the Chinese, who took every opportunity to examine the plant in detail and extract as much information as possible.

French engineers would hold meetings, and when they thought that they had answered all the questions and satisfied the Chinese, the same meeting would be called again with a completely different group of Chinese engineers. Every drawing and every document was scrutinised and discussed in fine detail. For important milestones, French engineers were expected to remain at the plant, even sleeping there.

It seems the Chinese intended to learn as much as they could absorb about the technology and introduce as much local content into the imported plants as they could. Hence the name change of the reactor from CP1 to M310.

The China Guangdong Nuclear Power Company (CGNPC) was established in 1994 out of the Guangdong Nuclear Investment Company, making it China's second nuclear power company to rival CNNC. The French sold four M310 plants, two at Daya Bay and two at Ling Ao.

In May 1997, Guangdong Nuclear began constructing two M310 (950MWe) reactors at Ling Ao 1 & 2 in Guangdong Province. Grid connections made in Feb 2002 & Sep 2002.

FRENCH M310 BECOMES CHINESE CPR1000

After the initial four plants were commissioned, French engineers co-operated in two other plants at Ling Ao, which were improved versions of the M310 and were named CPR-1000 (China Pressurised Reactor 1,000MWe).

Dec 2005, Guangdong Nuclear began construction of two CPR-1000 (1007MWe) reactors at Ling Ao 3 & 4 in Guangdong Province. Grid connections made in Jul 2010 & May 2011

In 2013, the China Guangdong Nuclear Power Company (CGNPC) changed its name to China General Nuclear Power Group (CGN) to signify that its operations were not restricted to Guangdong Province.

18 CPR-1000 units were commissioned between July 2010 and March 2017, 16 by CGN and two by CNNC in five different provinces as listed in the accompanying See Table 1: List of Reactors.

During that time, the local content percentage steadily increased to 85% - 90%. In the early 1980s, no one anticipated what would happen in Guangdong. An opportunity presented itself when Lawrence Kadoorie of China Light and Power proposed a nuclear power station to supply power to Hong Kong. CGN grew from a finance company to a major engineering company able to design, build, operate and maintain nuclear power plants. I believe that Kadoorie acted as a catalyst for the growth of China's nuclear power industry, which mushroomed into an industrial giant.

Whilst CGN were active mainly in the south, providing electricity for people and industry, CNNC, a large research organisation until 1985, was pursuing its own agenda.

- Incorporating some 'borrowed' technology from the French M310 reactor (see Figure 1), the CNP-300 was upgraded to a two-loop reactor, the CNP-600, and connected to the grid in 2002.
- Meanwhile, two 600MWe, Candu 6, PHWR (Pressurised Heavy Water Reactor) reactors were ordered from AECL (Atomic Energy of Canada Ltd) and commissioned in 2002 and 2003. These were the only CANDU reactors bought by China.
- The CNP-600 was continuously improved as new technology developed, and a further five were installed between 2004 and 2016, three at Qinshan, Zhejiang and two at Changjiang. Hainan. (Table: List of Reactors 1)

In 2005 an agreement was signed between AECL & CNNC to explore joint development of the Advanced Fuel Cycle Candu Reactor (AFCR). One of the attractions of the Candu reactors is that they can 'burn' spent fuel from light water reactors. I don't know what progress has been made along that path, but it would seem that the emphasis is currently on fast reactors which can perform a similar function.

Following a 1992 cooperation agreement, Russia supplied China with their first nuclear power plant.

- Two VVER V-428, 1000MWe reactors were installed as Tianwan 1 & 2 in Jiangsu Province Construction began in Oct 1999 and was connected to the grid in May 2006 and May 2007.

Whilst much of the plant was of Russian origin, the control room monitoring systems were raised to recognise international safety standards by the work of an international consortium.

In addition to enhancing the original CNP-300 design, CNNC was also pursuing another path:

- Two CNP-1000 (French / Westinghouse type M310+) were installed at Fuqing in Fujian Province in conjunction with Huadian Corporation. These were connected to the grid Aug 2014 & Aug 2015
- Two (M310+) reactors, CPR-1000 installed at Fangjiashan Nov 2014 &

Jan 2015 (According to the diagram [Figure 1 from Nuclear Engineering International,] the two CNP1000 reactors intended for Fangjiashan were abandoned in favour of the successful CPR-1000 promoted by CGN)

- Two (M310+) reactors, CNP-1000 installed at Fuqing 3 & 4 Sep 2016 & Jul 2017

GENERATION III REACTORS, MAKING SAFE EVEN SAFER

Whilst the CPR-1000 reactor may be considered to be Generation III, since it was upgraded from the Generation II reactor, the M310 (WH 3LP / CP1), a step change was made by major suppliers when they carried out radical re-designs to make their products cheaper, with fewer parts but principally to make them even safer by introducing passive safety to avoid problems such as Fukushima Daiichi, where safety systems were rendered inoperable due to lack of power, because the emergency diesel generators had been swamped by the tidal wave, so that in the event of an accident the reactor could be kept cool for 72 hours by natural circulation without the need for any electrical power. Also, an important factor was to design them for a 60-year lifespan.

The world's first generation III reactor to enter service was Unit 1, VVER1200/392M at Novovoronezh Nuclear Power Plant, Russia, which started commercial operation in 2017: unit 2 was connected to the grid in 2018.

The Westinghouse Advanced Passive reactor, AP1000, a major re-design of their widespread pressurised water reactor, WH 3LP, was approved by the US Nuclear Regulatory Commission (NRC) in 2005. Westinghouse & Areva co-operated to build the first four plants in China.

- In Apr 2009, CNNC began constructing two AP1000 reactors at Sanmen in Zhejiang Province. These were connected to the grid in Jun & Aug 2018.
- In Sep 2009 SPIC began constructing two AP1000 reactors at Haiyang in Shandong Province. These were connected to the grid in Aug & Oct 2018.

The appearance of the AP1000 was supposed to herald a renaissance of nuclear power in the West, but whilst the US companies were procrastinating, China was quicker off the mark and built the four plants at Sanmen and Haiyang. In the meantime, in the USA, Virgil Summer cancelled the plants they had ordered due to the parlous state of Westinghouse's finances; Georgia Power purchased two units, The first unit, Vogtle 3, was connected to the grid in Mar 2023—the first 'new build' in the United States for 44 years[3]. Plans to build an AP1000 in Cumbria, UK, did not materialise.

The first units of the French 1,600+MWe, generation III reactor, EPR, were ordered by Finland in 2003 and France in 2006. However, the world's first to become operational was Taishan 1 in Guangdong, China, and the second was Unit 2, also at Taishan. These were built under an ownership arrangement of 30% French and 70% Chinese.

- In Nov 2009, CGN began constructing two EPR (1660MWe) reactors at Taishan in Guangdong Province. These were connected to the grid in Jun 2018 & Jun 2019.

The EPRs in Finland and France suffered from serious setbacks. The Finnish plant at Olkiluoto was delayed by over ten years before it became operational in 2022; the French plant at Flammanville has yet to start. The two units at Taishan were delayed by a moratorium on constructing new nuclear plants in China until a thorough post-Fukushima safety review was carried out. Nevertheless, the achievement at Taishan is a tribute to Chinese engineers.

A third major company to become involved in nuclear power is the State Power Investment Company (SPIC) which was already involved in all forms of energy, coal, oil, hydro, wind and solar. After starting much later than most of the major nations, China has become the nation with the world's most advanced reactors.

Both CNNC and CGN set about building a Chinese version of a Generation III reactor:

- In Sep 2013, CGN began constructing two advanced CPR1000 (ACPR-1000) versions at Yangjiang (5 & 6) in Guangdong Province, connected to the grid in May 2018 & Jun 2019.
- In Dec 2015, CNNC began constructing its own version of an upgraded M310+ two CNP-1000 at Tiawan (5 & 6) in Jiangsu Province, connected to the grid in Aug 2020 & May 2021.
- In Mar 2015, CGN, in conjunction with SPIC began construction of two more ACPR-1000s at Hongyanhe (5 & 6) in Liaoning Province, which was connected to the grid in Jun 2021 & May 2022.

HUALONG ONE (HPR1000) - BEYOND THE FRENCH CONNECTION

The China National Energy Administration, responsible for standardisation in China, directed CGN, CNNC (& SPIC) to rationalise their reactor designs. Consequently, ACP-1000, ACPR-1000 & AP1000 designs were merged into Hualong One (HPR1000). There are still small differences between the two suppliers, which the regulator accepted. Each

3. Since the reactor meltdown at Three Mile Island 2 in 1979

company has its own supply chain and marketing strategies. The HPR100 has received licence approval in the UK and the EU. One of the first exports was expected to be Bradwell, Essex, UK, but this may have been delayed due to political concerns. However, the UK is desperately in need of reliable energy.

- CNNC & Huadian began construction of the first Hualong One in May 2015 as Fuqing 5 in Fujian Province and was connected to the grid in Nov 2020 & unit 6 in Jan 2022.
- CGN began constructing a Hualong One reactor in Dec 2015 as Fangchengang 3 in Guangxi and was connected in Jan 2023.

In 2023, there are ten Hualong One reactors under construction in China at:

- CGN: Fangchengang 4 began construction in Dec 2016; others began construction between 2019 and 2022 (Huizhou Taipingling 1 & 2, Lufang 5, Guangdong, Cangnan / San'ao 1 & 2, Zhejiang).
- CNNC (& Guodian) Zhangzhou 1 & 2, Fujian; (& Huaneng) Changjiang 3 & 4, Hainan.
- CAP1000 plants (Chinese versions of AP1000) are being constructed by SPIC at Haiyang 3, Shandong and by CNNC at Sanmen 3 & 4, Zhejiang.
- As part of the agreement with Russia, four VVER1200/V491 are under construction; two by CNNC, Tianwan 7 & 8 in Jiangsu Province and two by CNNC & Datang, Zhudabao 3 & 4 in Liaoning Province.

GUOE ONE, BIGGER & BETTER

China is now looking to expand the Hualong One concept into larger units

- SPIC are promoting Guoe One, a 1400 - 1500MWe reactor for use in China and export; construction began in June 2019 on two CAP1400 reactors at Shidaowan 1 & 2, Shandong Province.

The M310, the basic Westinghouse three-loop pressurised light water reactor supplied to Daya Bay, became, in a modified form, the 'de facto' standard for China's nuclear power industry. Later versions incorporated all the Westinghouse Generation III AP1000 passive safety features to become the Hualong One / HPR1000.

Since 1985 China has embarked seriously on nuclear-generated electricity. The Chinese nuclear industry has become largely self-sufficient in reactor and power station design, manufacture and fuel supply. Chinese companies can manufacture all the heavy components, such as large forgings, containment vessels, reactor pressure vessels, steam generators, pressurisers, reactor coolant pumps and control rod drive mechanisms for the main nuclear components using materials produced in China. Major heavy electrical equipment such as turbines, generators, condensers, transformers and switchgear are also manufactured in China, sometimes in cooperation with companies such as Alsthom and Mitsubishi. China can also manufacture and supply control & instrumentation equipment and control room monitoring, sometimes in conjunction with Siemens.

In 38 years, 55 nuclear plants with a total rating of 53,286MWe, of varying types and sizes, overwhelmingly PWRs, were installed in China by CGN, CNNC & SPIC, supplying a mere 5% of China's insatiable consumption of electrical energy. This means that reaching a target of 30% nuclear-supplied electricity will require a further 275 more nuclear plants. Although China's nuclear build-up has been prolific, it may take many years to significantly change the percentage of nuclear-generated electricity in China at the current stage of construction.

Making a comparison, France has 56 reactors, rated power 61,370MWe, i.e., 8,084MWe more than China, yet supplying 68% of the country's electricity out of total consumption of 554.8TWh which is only approximately one-twelfth of China's total consumption of 6,872TWh. On a different level, the single reactor in Finland, a 1,600MWe EPR, will supply approximately 14% of the country's needs.

China's total consumption of 6,872TWh[4] is already greater than the 4,392TWh of the United States, of which about 20% is nuclear.

China currently gets about 63% of its electricity from coal, i.e., about the same as France gets from nuclear; to replace coal with nuclear power would require approximately 400 more nuclear plants of 1,600MWe similar to Taishan 1 or 2 (Olkiluato, Finland or Hinkley C). As of May 2023, there were only 436 power reactors operational worldwide (approx 300 are PWRs) in 32 countries, most of which are smaller than 1,600MWe. World consumption of energy is 26,833TWh, of which China's share is 25.6%, and the USA is 16.36; India 6.05%, Russia 4.18, Japan 3.89%, Germany 2.22%, France 2.06%, South Korea 2.18%, Canada 1.92%, Brazil 1.9%, Saudi Arabia 1.44%, Britain 1.15%, South Africa 0.94%. At present, most of the world's electricity, about 60%, is produced either from coal or gas, with a further 17% from hydro and 10% from nuclear.

SMALL MODULAR REACTORS (SMR)

Many engineers believe small modular reactors to be the future of nuclear energy because of their safety, cost and versatility. Nuclear power can also be distributed to where it is needed, unlike wind turbines which have to be located where the favourable wind is likely to entail building expensive transmission lines. This is a problem in China to get wind-generated electricity from remote areas to where it is needed.

4. 63% coal; 17% hydro; 5% wind; 5% nuclear; 3% natural gas; 3% solar; 2% biofuels & waste (Source WNA)

A proliferation of companies worldwide is working to produce a successful design.

China is working on a 100MWe scaled-down version of the AP1000:

- ACP100, a 100MWe pressurised water reactor, one-tenth the normal size output, is under construction at Changjiang SMR 1 in Hainan Province. Completion is expected in 2026

Various designs have been approved for licensing in the US, Canada, Argentina, the UK, the EU, and Russia. The World Nuclear Association provides a list of projects on its website.

GENERATION IV REACTORS

According to Wikipedia: *"No generally accepted definition of a Generation IV reactor exists. However, the term is intended to refer to nuclear reactor technologies under development as of approximately 2000 and whose designs were (at least at that time) believed to represent "the future shape of nuclear energy." The six designs selected at that time were: the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), the molten salt reactor (MSR), the sodium-cooled fast reactor (SFR), the supercritical-water-cooled reactor (SCWR) and the very high-temperature reactor (VHTR)."*

The majority of reactors in operation worldwide are considered second and third-generation reactor systems, as the majority of the first-generation systems have been retired.

PEBBLE BED REACTOR

China claims to be the first country to operate a demonstration Generation-IV reactor, the HTR-PM Small Modular Reactor of the pebble bed type."

- The first HTR-PM, 200MWe high-temperature gas-cooled pebble bed reactor, was connected to the grid Mar 2021, Shidao Bay 1 HTR SMR 1 in Shandong Province.

HTR-PM reactors are multi-function and can generate electricity, provide district heating, desalinate water or produce hydrogen.

MOLTEN SALT THORIUM REACTOR

China has been prototyping a thorium reactor which it hopes can be exported to desert regions along the 'Belt and Road' project. After successful tests were conducted in 2021, approval was given to proceed to the next stage, which should be completed in 2024. If it proves successful, it will be a breakthrough. In addition to being much more plentiful than uranium, Thorium is perceived to have various advantages as fuel but is also not without problems.

CLOSING THE CYCLE REDUCE, REUSE, RECYCLE

China chose the closed-loop nuclear fuel cycle when it first embarked on nuclear power, just as other nations such as the USA, UK, Russia, France and Japan did. Still, one by one, most of them have abandoned this route due to fears of plutonium proliferation.

Like most other nations, Russia did not close down their Fast Breeder Reactor (FBR). Still, it kept it operational and has progressed to the world's longest continually operating commercial FBR. They have two, the Beloyarsk 3, BN-600, which is a 600MWe sodium-cooled reactor that has been operational for 42 years since 1981 and the Beloyarsk 4, BN-800, which is an 800+MWe reactor which has been operational since 2016—a third reactor the BN-1200 is planned to start construction about 2025.

The principle behind the fast reactor is that it closes the cycle; the spent fuel (unused fissionable fuel, 95%) from conventional reactors is fed into the fast reactor and reduces waste. The fuel is recycled and can be reused in the conventional thermal reactor. In addition, the new 99.3% of natural uranium forms a 'blanket' around the reactor, and this is converted into plutonium which is used as fuel, hence the term 'breeder' reactor since it 'breeds' fuel, i.e. it can produce about 60 times more fuel that it takes in. The FBR has been abandoned in the West because it produces plutonium which can be used to make weapons; also, there is a plentiful supply of natural uranium cheaper than recycled fuels.

The reason that it is called a fast reactor is that unlike the conventional reactor, where the moderator slows down the neutrons from fission to increase the probability that fission will again take place to maintain a 'chain reaction', the fast reactor produces an assortment of neutrons, like a 'blunderbuss'. The core is either plutonium or highly enriched uranium so that a chain reaction can be maintained without a moderator.

China has had a small 20-25MWe experimental reactor BN-20 operating since 2011. The reactor was built by a Russian company. Two CFR-600, not dissimilar to the Russian one, began construction in Dec 2017 and Dec 2020.

GRID CONNECTIONS ARE EXPECTED IN 2023 AND 2026

China has probably become the world's major player in nuclear power, not only for electrical energy but also for other purposes, e.g., district heating, hydrogen production and desalination.

FUSION RESEARCH

In addition to fission reactors, China claims to have made a huge advancement in fusion power; "The Experimental Advanced Superconducting Tokamak generates and sustains plasma for nearly seven minutes – four times as long as its previous record" in April 2022.

Table: List of Operational Reactors – 1
(Data: Nuclear Power Association, WNA & International Atomic Energy Authority, IAEA)

	CGN	Month/Year	CNNC
1		'Dec 1991	CNP-300 – Qinshan 1
2	Daya Bay 1 - M310	'Aug 1993	
3	Daya Bay 2 - M310	'Feb 1994	
4		'Feb 2002	CNP-600 – Qinshan II 1
5	Ling Ao 1 - M310	'Feb 2002	
6	Ling Ao 2 - M310	'Sept 2002	
7		'Nov 2002	CANDU 6 (III-1) - Qinshan
8		'Jun 2003	CANDU 6 (III 2) - Qinshan
9		'Mar 2004	CNP-600 – Qinshan II 2
10		'May 2006	VVR1000/V-428 – Tianwan 1
11		'May 2007	VVR1000/V-428 – Tianwan 2
12	Ling Ao II 1 – M310/CPR1000	'Jul 2010	
13		'Aug 2010	CNP-600 – Qinshan II 3
14	Ling Ao II 2 – M310/CPR1000	'May 2011	
15		'Nov 2011	CNP-600 – Qinshan II 4
16	Ningde 1 - CPR1000	'Dec 2012	
17	Hongyanhe 1 - CPR1000	'Feb 2013	
18	Hongyanhe 2 - CPR1000	'Nov 2013	
19	Yangjiang 1 – CPR1000	'Dec 2013	
20	Ningde 2 - CPR1000	'Jan 2014	
21		'Aug 2014	M310+ - Fuqing 1
22		'Nov 2014	M310+ - Fangjiashan 1
23		'Jan 2015	M310+ - Fangjiashan 2
24	Hongyanhe 3 - CPR1000	'Mar 2015	
25	Yangjiang 2 – CPR1000	'Mar 2015	
26	Ningde 3 - CPR1000	'Mar 2015	
27		'Aug 2015	M310+ - Fuqing 2
28	Yangjiang 3 – CPR1000	'Oct 2015	
29	Fanchengang 1 - CPR1000	'Oct 2015	
30		'Nov 2015	CNP600 – Changjiang 1
31	Ningde 4 - CPR1000	'Mar 2016	
32	Hongyanhe 4 - CPR1000	'Apr 2016	
33		'Jun 2016	CNP600 – Changjiang 2

Table: List of Operational Reactors – 2
(Data: Nuclear Power Association, WNA & International Atomic Energy Authority, IAEA)

	CGN	Month/Year	CNNC
34	Fanchengang 2 - CPR1000	'Jul 2016	
35		'Sept 2016	M310+ - Fuqing 3
36	Yangjiang 4 – CPR1000	'Jan 2017	
37		'Jul 2017	M310+ - Fuqing 4
38		'Dec 2017	VVR1000/V-428M – Tianwan 3
39	Yangjiang 5 – ACPR1000	'May 2018	
40	Taishan 1 - EPR(1660MWe)	'Jun 2018	
41		'Jun 2018	AP1000 – Sanmen 1
42		'Aug 2018	AP1000 – Sanmen 2
43		'Aug 2018	AP1000 – Haiyang 1
44		'Oct 2018	AP1000 – Haiyang 2
45		'Oct 2018	VVR1000/V-428M – Tianwan 4
46	Yangjiang 6 – ACPR1000	'Jun 2019	
47	Taishan 2 - EPR(1660MWe)	'Jun 2019	
48		'Aug 2020	M310+ – Tianwan 5
49		'Nov 2020	Hulalong One - Fuqing 5
50		'May 2021	M310+ – Tianwan 6
55	Hongyanhe 5 - ACPR1000	'Jun 2021	
56		'Dec 2021	HTR-PM(200MWe) – Shandong Shidaowan HTR
57		'Jan 2022	Hulalong One - Fuqing 6
58	Hongyanhe 6 - ACPR1000	'May 2022	
59	Fanchengang 3 – Hualong One	'Jan 2023	

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The Underlying Issues and Way Forward for the National Electricity Supply

The current electricity crisis in South Africa (and elsewhere in the world) was fundamentally rooted in the policy decisions made in the 1990s. In the case of South Africa, this was to move away from the Eskom obligation to supply (and related monopoly) to a presumed better free market solution in the 1998 Electricity Policy.

By | Prof David Nicholls

Historically the worlds electricity systems were built on the philosophy of a regulated & socialised utility to get "electricity for all" and avoid the syndrome where the only people with electricity were the rich individuals and the heavy industry – which was the way the market was going in the 1930s when this approach was adopted.

In the 1990s, there was a drive to believe the free market could fix all issues. This, however, removed any effective long-term central planning as the market forces would only respond to reasonably short-term (5-year?) pressures. This leads to a drive to short-term payback solutions such as natural gas and renewable energy. Even these required sovereign guarantees against policy changes and payment of PPAs, so not really a free market system! In South Africa, the 1998 free market policy providing the new build requirements did not begin to work until the state provided PPA guarantees unrelated to market value.

It is also important to understand the difference between the quoted cost of intermittent sources and dispatchable power as needed 24/7 by society. This can be seen in the recent REIPPP bids and the parallel RMIPPP quotes. The intermittent, technology-based REIPPP bids came in in the order of R0.40/kWh; however, the somewhat dispatchable (but technology-neutral) RMIPPP bids came in the order of R1.50/kWh, over three times as much.

Despite the almost universal adoption by "Western" countries of this "free market" model, the current reality is that the world is still virtually dependent on "classic" energy sources, largely built under the previous, centrally planned model, as these plants have a 40+ year life.

Unfortunately, the existing installed base is now ageing and is not being replaced.

It can be argued convincingly that this new model of free market based largely on RE has failed in many markets and required massive state financial and regulatory support – to the detriment of the population. Essentially the system privatised the profits and socialised the losses.

Interestingly, the recent quoted example of a "successful roll-out of renewables" has been seen in Vietnam. Since 2020 Vietnam has installed close to 20GW of rooftop and IPP solar. What is not mentioned is how they did it and their plan for the next ten years (their PDP VIII to 2030). To get this amazing success, there was a standard feed-in-tariff of $0.0935/kWh with a twenty-year PPA, or 18% higher than their domestic tariff (and four times the PV bids in the most recent South African REIPPP bid window). In their next plan (issued October 2022), Vietnam plans by 2030 to install some 25,000MW of a new LNG plant, 12,000MW of a new coal plant and 7,000MW of a hydroelectric plant. The plan includes only 708MW of new PV plant and 6000MW of wind! Like the German experience, this does not support the belief that renewables are the effective solution for a grid-like ours.

There is also the belief that battery technology will provide the storage solution to unlock the intermittency challenge of PV and wind power in a net zero carbon-constrained world. The issue with batteries is that while the cost of Lithium Ion batteries has fallen dramatically over the last two decades, they have now reached the point where the material costs (lithium, cobalt, nickel etc.) make up some 75% of the manufacturing costs, so further significant reductions seem unlikely.

The best national reference for installation and grid-scale costs is the current Eskom Battery Storage System. This is quoted as having 1449MWh storage capacity and to cost R11bn. An exchange rate of R18:$1 leads to a storage cost of over $400/kWh. It is accepted that battery storage system costs must get below $100/kWh, and probably around $50/kWh, to make the PV/battery solution the lowest cost option for large-scale grid applications. (If there is a belief that battery prices are falling to levels not seen before, it is worth noting that the Lead-Acid battery, invented in 1859, is still the lowest cost option for batteries in cars with internal combustion engines – Li-Ion batteries are used in electric cars because of power density.)

In South Africa today, we need three plans. The first is a credible long-term (2050) solution that meets the national need for reliable 24/7 dispatchable power and which achieves the net-zero requirement, a short-term solution (24 months) to stop (or at least limit) load shedding and a transition plan to bridge the gap.

There is a belief in many circles that the free market can achieve this, and as such, the trading system (the grid) should be available for any IPPs, consumers or traders who can make a business case for themselves. The state has to, however, provide the base upon which the country can grow. The size of this base will be affected by the success (or otherwise) of the free market unsubsidised by the state.

Given the current state of technology and the lack of any significant hydro potential in South Africa, the major portion of the long-term plan needs to be nuclear to achieve the dispatchable and zero carbon requirement. The world experience of large nuclear programs, such as France, Sweden, Ontario, Russia etc., has shown that they are highly competitive in the long term. A further debate is whether this should be based on large, Koeberg-style reactors or more distributed Small Modular Reactors.

In terms of schedule, the European programs of the 1970s/80s show that if a process was started, the first units could be online by the early 2030s and have a capacity equivalent to Eskom's current coal fleet built by the 2040s.

The short-term plan has to be to improve the performance of the current Eskom fleet (and extend their lives as far as possible). Given the actual age of the Eskom fleet (and some relaxation of the current environmental proposals), they should be able to achieve the 70+% EAF needed to stop load-shedding. Their age means there would be a shortfall in the capacity as they decommission before the nuclear build comes online.

The transition is best met by a roll-out of natural gas-fired plants with the related infrastructure (pipelines, LNG terminals, storage facilities etc.). If initiated rapidly, these could have a credible business case before being closed down by the rising nuclear capacity and 2050 deadline for net zero.

Some major technological breakthroughs may change the potential economics (such as low-cost batteries, commercial carbon capture and storage, economic hydrogen systems or nuclear fusion). When these become game changers, they will change the game – but we cannot bet our future on them. wn

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JUNE 2023

19/06/2023	Transformer Construction, Operation, Maintenance, Testing and Protection
20/06/2023	Probabilistic planning for future networks
20/06/2023	Fundamentals Of Developing Renewable Energy Plants
21/06/2023	Substation Design and Equipment Selection
21/06/2023	ACTOM Webinar: Renewable Energy opportunities for local manufacturers
22/06/2023	SAIEE President's Invitational Lecture: Is a power blackout possible in South Africa?
27/06/2023	Financial Modelling of Renewable Energy Projects
27/06/2023	Operating Regulations For HV/MV Systems
27/06/2023	Road to Registration
28/06/2023	Technical Report Writing
28/06/2023	USNC Micro Modular Reactor – Small Reactor, Big Potential
29/06/2023	Legal Liability: Occupational Health and Safety Act (OHS act)

JULY 2023

04/07/2023	New Engineering Contract (NEC)
04/07/2023	Photovoltaic Solar Systems
05/07/2023	Design Thinking and Innovation for Engineering Professional
11/07/2023	Fundamentals of Power Distribution
12/07/2023	Select, Maintain & operate your Rotating Electrical Machines like a Pro
18/07/2023	Planning Strategic Feasibility Studies
18/07/2023	Finance Essentials for Engineers
18/07/2023	Photovoltaic Solar Systems (East London)
19/07/2023	Partial Discharge Detection and Measurement
20/07/2023	Photovoltaic Solar Systems (Port Elizabeth)
26/07/2023	Blockchain and Money

Section & Chapter, Centre Webinars — SAIEE Academy Online Training — SAIEE Academy Classroom Training

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