wattnow

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POWER

THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | JUNE 2021

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SAIEE

ISSN: 1991-0452

Dear Valued Reader

This Power issue of the wattnow discusses Supply Metering, System Design and fee management systems.

Page 24 sports a paper on "Minimizing Fuel Consumption and increasing Longevity for Paralleled Generator Sets". It discusses how certain features can be attained at minimal cost while still maintaining the reliability of the power system.

In the past decade, we have witnessed an unprecedented acceleration of the energy transition. Two examples illustrate the growing speed of renewable energy penetration (mainly wind and solar) and the significant strides made in energy access. These changes have been facilitated by several factors, among which technological advancement and growing political support stand out. However, extraordinary as this evolution has been, there remain some critical challenges to delivering sustainable and affordable energy while improving access and security. Read this report on page 32.

China has become the world's largest electrical energy user and the largest user of renewable energy, which includes solar energy, wind energy, and hydroelectric energy. Read Dudley Basson's article on China's Mega Volt Power on page 62.

Herewith the June issue; enjoy the read!

Minx

SAIEE Coffee table book

Second Edition

In 2001 the SAIEE published a coffee table book titled "Sparkling Achievements". The book was compiled and edited by Michael Crouch, a Past President of the Institute and published for the SAIEE by Chris van Rensburg (Pty) Ltd.

This first book surveyed Electrical Engineering in South Africa and included material from 43 local organisations. The second edition's objective is to include new companies and their history and achievements during the past two decades from 2001 to 2021.

Work contacting organisations started in February 2019 and went well until the onset of the Covid 19 pandemic, after which it gradually became challenging to entice companies to participate. Numerous companies had retrenched staff and were in serious financial difficulties. However, we eventually gathered together sufficient material to make the book viable.

One of the most outstanding inputs is from the Square Kilometre Array (SKA) Radio Telescope organisation in the Western Cape. All inputs are exciting, and we feel confident that the book will be an outstanding success.

This softcover book will be available at R350 (incl. VAT) from the Institute and uploaded onto the SAIEE website. The book will be ideal to grace the company entrance foyer and CEO's office and will go to press during April 2021. The cover of the book is shown here.

To order your book, please contact Dudu Madondo either via email: reception@saiee.org.za or contact her on 011 487 3003.

Dear Valuable SAIEE member,

SAIEE CHARGE REWARD PROGRAMME

Dear SAIEE member,

I hope that you receive this letter in good health and spirits.

The Charge Reward Program is now in full swing since being introduced, with members in good standing eligible to gain points for attending SAIEE events. This process is automatic for you and the appropriate points are allocated post-attendance. Please remember to use the unique hyperlink that was sent to you to check the number of points that you have already accumulated.

A bug was detected in the system in the last few months whereby intended accumulation and redemption points for various activities were incorrectly programmed into the system, allowing members to gain far more points than was intended. This was subsequently corrected, and you can rest assured that the points allocated to you do stand. Redemption opportunities were also revised to align them with the actual cost of the service. Do remember that we are constantly refining the program to ensure that you get the most out of it and your SAIEE membership.

The Program operates on a 5-year cycle starting from 01 December 2019. Members will be able to accumulate points for 5 years, after which the points are reset to 0 and a new 5-year cycle begins. Within the 5-year cycle members can redeem points for listed redemption (discharge) events. The matrix for Charge and Discharge events is shown elsewhere in this publication.

Wishing you all the best in Charging up!

Yours Sincerely,

For more information, on how this programme works, click here.

Yours faithfully,

Leanetse Matutoane
Acting CEO

CHARGE REWARD PROGRAMME

MEMBER LOYALTY

We appreciate our Member's support for 110 years

REWARD

A unique reward programme exclusive to SAIEE Members

FEEDBACK

We received your feedback and we listened to added benefits

EARN POINTS

Earn Charge Rewards by attending events, courses or writing articles

SATISFACTION

We want you, our Valued Member to feel satisfied when working with us

LOYALTY PROGRAM

Redeem your Charge Points towards CPD credits

QUALITY

We guarantee top quality events, courses, and services

SERVICE

We are here to serve you, our Valued Member better

RESPECT

We respect you and want to see value for your hard-earned money

SUPPORT

We are here to answer any queries you might have

For more information:

Visit your Membership Porthole on the SAIEE Website:
www.saiee.org.za

Alternatively, call Connie on 011 487 3003.

SAIEE CHARGE rewards programme

SAIEE Past President awarded the coveted UP Chancellor's Medal

Andries Mthethwa
UP Chancellor's Medal Recipient

The University of Pretoria's Chancellor's Medal is an honorary award made to individuals to recognise achievements and contributions to society in fields other than those exclusively falling within the academic sphere.

The award consists of a gilded medal accompanied by a scroll. The Council authorises the award of a Chancellor's Medal upon completion of the prescribed process.

CRITERIA FOR SELECTION

The Chancellor's Medal is awarded to individuals to recognise achievements and contributions to society in fields other than those exclusively falling within the academic sphere. Relevant contributions will have a national or international impact that signifies a creative spirit and intellect. Mere success in a career or on a social level is insufficient. There should be evidence of public achievements and contributions related to the University of Pretoria's vision, mission, values, strategic goals, and objectives.

This year, SAIEE Past President, Mr Andries Mthethwa, was the recipient of this coveted award.

Mr Mthetwa was the founding Chairman of City Power Johannesburg for the period 2001 to 2003. From 2003 to 2005, he was Chairman of Johannesburg Water. He is a Fellow of the South African Institute of Electrical Engineers (SAIEE) and served as President for 2011. He still serves on its Council. In 2017, Mr Mthethwa received the prestigious SAIEE President's Award. In 2008 he served as President of the RailRoad Association of South Africa (RRA).

From 2014 to 2018, he was a member of the Board of Trustees of Sci-Bono. He is a trustee of the Ithemba Institute of Technology, Soweto. He has been a member of the Faculty of Engineering, Built Environment and Information Technology Industrial Advisory Board at the University of Pretoria since 2014 and established the DENI Bursary Fund at the University of Pretoria in 2015.

Mr Mthethwa is Deputy Chairman of the Board of the South African Electro-Technical Export Council (SAEEC). In 1985 he co-authored a research paper with Prof RG Harley, titled "Induction motor behaviour in the presence of unbalanced supply voltages", which received the Eskom Award. wn

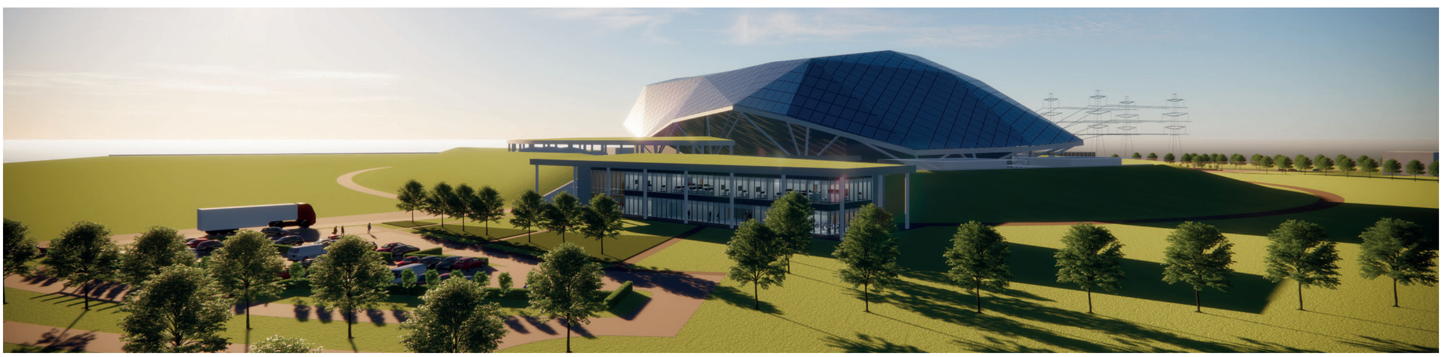
Watch the video here.

One-touch, advanced power quality analysis Troubleshoot, quantify energy usage and perform quality of service

COMTEST is offering the Fluke's range of Three-Phase Power Quality Loggers - 1742, 1746 and 1748 - giving users fast, easy access to the data they need to make critical power quality and energy decisions in real-time.

Compact and rugged, these Three-Phase Power Quality Loggers are designed specifically for technicians and engineers who need the flexibility to troubleshoot, quantify energy usage and analyze power distribution systems. Fully compliant with international power quality standards such as IEC 61000-4-30 and capable of simultaneously logging up to 500 parameters while also capturing events, the Fluke 1740 Series helps uncover intermittent and hard-to-find power quality issues easily. The included Energy Analyze plus software quickly assesses the quality of power at the service entrance, substation, or at the load, according to national and international standards like EN 50160 and IEEE 519.

An optimized user interface, flexible current probes, and an intelligent measurement verification function allows for digital verification and correct connections make setup easier, considerably reducing measurement uncertainty. The devices also allow users to minimize time spent in potentially hazardous environments, while reducing the need to suit-up in PPE by using a wireless connection (WiFi) to view data directly in the field. wn



Rolls-Royce delivers 9-MW emergency power solution to bank data center

Rolls-Royce has installed and commissioned eight mtu emergency gensets with 9.2 MWe power output at a major bank in the vicinity of Madrid. The gensets will secure power supply to the bank's data center should public power grid fail.

The overall solution consists of two types of mtu-brand diesel generator set: four mtu 12-cylinder 4000 DS1650 units, each with 1,425 MWe power output, and four 16-cylinder mtu 2000 DS1100 units, each with 880 MWe power output. "For the customer, the reliability of the power supply takes precedence. That's why they opted for the mtu brand," said Pablo Vivancos, head of mtu- product sales at Rolls-Royce's Spanish subsidiary.

The emergency generator sets were built at Rolls-Royce's series assembly facility in Ruhstorf, Germany, and then placed in 20 and 40-ft containers at PSH Energia, a partner of Rolls-Royce's Spanish subsidiary.

Before the turnkey systems were handed over to the customer, they were successfully put through their paces in the usual factory acceptance tests, and in further tests designed to prove that the power node requirements specific to the project were being met. wn

Sub-zero, high-altitude challenge for Trafo Transformer

Designing a dry-type transformer to function at minus 40˚C temperatures at an altitude comparable to Everest's base camp is one of the latest achievements of Johannesburg-based Trafo Power Solutions.

Supplying to a gold mine expansion in Kyrgyzstan, the company has provided a 3,000kVA transformer with a primary 6,3kV and a secondary 400V specification, which will operate at 4,020 metres above sea level.

"The altitude alone presents particular challenges to the design, in terms of cooling," says David Claassen, managing director of Trafo Power Solutions. "Most large electrical equipment is rated for 1,000 metres or below, so we had to derate this unit to account for the altitude. The higher the location, the less efficient the cooling – and the temperature range on site is between minus 40° C and plus 25˚C."

The eight tonne outdoor transformer has a specially designed enclosure to keep out snow, dust and moisture, while also extracting heat. Claassen notes that there is a risk of condensation when the transformer is turned off under these conditions.

"We therefore built into our design a control system for automatically heating the enclosure when the transformer stops operating for any reason," he says. "The heaters will then, of course, be turned off again once the transformer resumes operation."

Under the demanding environmental conditions, the enclosure was coated with a corrosion resistant C5 paint plan.

The design also included a neutral earthing resistor with special surge protection elements. He highlights that Trafo Power Solution's strategic partner TMC Transformers – a leading manufacturer based in Italy – has extensive experience in producing transformers for these severe conditions.

"A dry-type transformer is well-suited to these cold conditions as there is no fluid involved in the cooling process, and it is fairly straightforward to provide the necessary heating and cooling as required," he says. "There is also very little maintenance required, which is a great advantage in a remote location like this."

With travel restricted by the Covid-19 pandemic, the customer could remotely witness the factory acceptance test conducted at TMC's IEC-approved facility in Italy, which allows all routine and special testing to be done in-house.

"The online factory acceptance test uses communication technology and cameras around the test bay, including cameras focussed on the technician performing the test," says Claassen. "This allows the customer to check in detail all aspects of the specifications, and to interact freely with the TMC and Trafo Power Solutions team during the witness test."

At the start of a project, Trafo Power Solutions will provide customers with a published theoretical test report of the tolerances – in terms of aspects such as losses and impedance – expected by the IEC. These are then compared to the actual readings obtained during the factory acceptance test, where he says the results are invariable well within IEC requirements. wn

A 3,000kVA transformers has been supplied by Trafo Power Solutions to a gold mine in Kyrgyzstan.

Concrete poles for Electricity Lines that withstand the test of force

The days of using wooden poles for electrification projects have long passed with the advent of superior quality concrete poles that offer government and private sector infrastructure projects greater longevity, no-maintenance requirements and cost efficiencies. Rocla, part of the IS Group of companies, recently subjected their concrete cast pole to 11m-8kN of force testing at their plant in Roodepoort.

Rocla is renowned for its precast concrete manufacturing excellence and their cast concrete pole has become the preferred option for electrification and electric power line projects. "Our cast pole is manufactured using the conventional concrete casting method" said Rocla's Civil Engineer, Mohammad Bodhania. "It is essential that we continually conduct quality checks to ensure that the concrete pole is standing up to the required standard, and the result of the recent test show that our concrete poles reach the required SANS470 concrete pole code easily. In fact, the final test result was that our poles reached a load of 10kN without collapse".

The recent 8kN force testing means that the pole should be able to support a load of 8kN applied at 300mm from the tip. This is known as the ultimate load of the pole. The pole has a safety factor of 2.5, meaning that in practice the pole might be subject to a maximum load of 2.5 times less than the ultimate load. This is known as the working load. The proof load of the pole is 10% higher than the working load. At proof the load must comply with the deflection, crack width and permanent set criteria set out in the SANS470 concrete pole code.

Bodhania said "We loaded our concrete pole to proof. At proof, the deflection and maximum crack width is measured. The load at which the first hair crack appears, is also noted. After loading the pole to proof, the load is released and the permeant set is measured. We then load the pole again to ultimate and the 10kN without collapse was achieved. We are proud of the recent quality assessment results on our cast concrete pole. Safety and quality are all important features in the Rocla manufacturing processes. We believe we deliver a superior product, and our test results confirm that" concluded Bodhania. wn

Kouga's sad state of affairs...

BY JANE BUISSON-STREET | FSAIEE | SAIEE COUNCIL MEMBER

I cannot tell you the impact it made on us here in St Francis Bay. There is less than 1.5% water that can be used for agricultural purposes; after that, it is impossible. The Kouga Dam 'was' built to service the citrus farming in the Patensie area and Port Elizabeth.
Earlier this month, I believe divers went down to determine the water level more accurately.

Kouga Dam (previously the Paul Sauer Dam), last Saturday, was 4.29% full. The dam is a double curvature arch dam 82 m high with a storage capacity of 128,7 million m3. Provision was made in the design to allow for a future raising of the water by 15,2 m. A small hydroelectric power station with three turbines of 1 200 kVA was constructed on the right bank. This makes use of the energy available from the water discharged into the downstream canal.

However, power generation at this station is presently not economical, and there is no water. wn

Find out more here.

SOLAR INVERTERS FOR PV GENERATION PLANTS

The WEG ESW 750 centralised inverter station, housed in a 12 metre container installed on site.

As solar energy contributes increasingly to cleaner, renewable energy for a more sustainable world, WEG has introduced its complete ESW line of central inverter stations for photovoltaic power generation plants. These are available through Zest WEG, WEG's South African operation.

The WEG ESW 750 centralised solar inverter stations are custom-engineered for large scale solar plants, comprising a range of WEG's SIW 750 inverters, with a modular design to promote greater flexibility in their application. They can easily be integrated to suit the specific requirements of each solar power plant, and can withstand even the most extreme weather conditions including ambient temperatures from minus 10 ˚C to plus 50 ˚C.

Available in capacities up to 10MW at 1,500V, these WEG solar stations represent an integrated solution with central inverters developed and manufactured with cutting-edge technology. Their design allows for quick installation and simplified operation and maintenance.

As one of the world's largest manufacturers of electric motors, electronic equipment and systems, WEG has the know-how to ensure that every solar station is fit-for-purpose and assures safety, efficiency and reliability.

Solar power has become an increasingly competitive renewable energy source around the world, and offers fast installation with low environmental impact. Developed to support this important global trend, WEG's central inverters provide a complete solution for investors who want to take the lead in contributing to a more sustainable future. wn

Why is short term insurance important?

Navigating through tough economic times and cutting back on non-essential costs is always a challenging task at hand. When it comes to short term insurance, this could be very difficult as you might expose yourself if you are not adequately covered.

According to the latest statistics from the South African Insurance Association, about 65% of drivers on South African roads are not covered by insurance, leaving you wide open to quite a few costs in the event of an accident, and you are not adequately insured. You might very well find yourself in the position that you would need to pay for costly repairs, towing and storage, and legal fee's even if the accident was not your fault.

We at SAIEESURE have partnered with market leaders in the industry to ensure we minimise your risk at the best possible rates - exclusive to SAIEE members. Therefore, reducing your risk in an accident or loss event also help keep your costs down to a minimum. We have chosen our partners in the personal and retail space according to their market presence and share and value for money benefits, member benefits, and client-focused approaches.

During our pilot phase, we have contacted and quoted over 40 SAIEE members. We managed to save members money on their monthly premiums, in some cases up to 45%. We also managed to enhance their policies significantly and reduce their exposure for loss.

Another significant benefit that members would qualify for is the rewards program. In this instance, members could save a substantial amount of monthly costs by receiving up to 50% of their fuel purchases back at any BP or Shell service station, depending on their driving behaviour and engagement in the rewards program.

Additional refunds and discounts are available through 3rd party partnerships with retailers like Tiger Wheel & Tyre on purchases of tyres, shocks, batteries, and vehicle services and preventative maintenance through the Bosch Car Service Centre networks, ensuring your vehicle is always safe and reliable at a reduced cost.

We believe we can reduce insurance costs for all SAIEE members through the discounts on the already highly competitive rates combined with the refunds and discounts through partner spend.

We are not solely savings driven. We offer additional benefits that further enhance our offering by keeping you safer. Our world-leading impact alert system alerts the necessary emergency personnel in the event of an impact alert on our telematics device that monitors your driving style and builds a personal driving profile. This device is installed in your vehicle by conveniently booking a pre-inspection at a Tiger Wheel and Tyre close to you. After the impact alert is installed, you have also earned your first driving rewards points, starting the savings process.

Another benefit of the telematics device is that you start building up a driving behaviour profile. Thereby, if you should get hi-jacked or your car stolen, the unit sends an alert to the relevant authorities and gets the help you need when you need it.

Despite all the fantastic benefits that are included in the plan, standards like

car-hire and a flat excess structure, we can customise or tailor-make your policy should you require something a little more specialised some of these benefits include :

WRITE OFF ACCELERATOR: This benefit reduces the amount of damage your vehicle needs to sustain to be rendered unrepairable.

SHORTFALL COVER: This is a prevalent option. This benefit will cover the difference between the outstanding finance amount at any of the registered lending institutions and the current market value of your vehicle as most financed vehicles have a substantial difference between these two values, and this might leave you out of pocket.

No Average: Any specified item would be paid out according to the specified amount if proof had been submitted at the underwriting stage.

EXPRESS CLAIMS: Any mobile or computing device would be replaced within 48 hours after receiving the claim documentation.

NO EXCESS ON ACTS OF GOD: On specific plans, there would be no excesses payable on acts of God such as wind, hail, lightning and flood damage.

FLAT EXCESS STRUCTURE: We offer a flat excess structure to eliminate any surprises at the claim stage.

24H LEGAL ASSISTANCE: Members qualify for a 24-hour telephonic legal assistance service.

EMERGENCY ASSISTANCE: Members have access to emergency services in damages to plumbing, electricians or security.

These are some of the benefits our members can look forward to.

If you are interested in getting a no-obligation free quote, please get in touch with us by any of the following methods:

- Send your current insurance schedule as well as a list of any claims in the last three years
- Please specify what you need to be covered and mail it to us at the address below
- Please send your contact details with a quote me in the mail subject
- Send a please "SaieeSure contact me" with your name to 0825535039 wn

For more information, contact:
Hano Muller
T: 082 553 5039
Email: insure@saiee.org.za

SAIEESURE
AN INSURANCE BENEFIT FOR SAIEE MEMBERS

Introducing 'climate-smart' mining on the road to Industry 4.0

Reducing our carbon footprint to mitigate the impact of climate change, as outlined in international treaties like the Paris Agreement, and accelerating the journey to the all-electric mine, is a business priority for many mining companies and their customers. This is an important focus in South Africa, where mining continues to be a mainstay of the economy and a major employer.

BY EDUARDO APARICIO
LOCAL BUSINESS AREA MANAGER,
MOTION, SOUTH AFRICA, ABB

There are three major trends fundamentally transforming the mining industry into what can be termed 'climate-smart' mining.

Firstly, there is the shift from diesel to electrification as a main power source. Secondly, digitalisation not only increases productivity, but allows for ease of maintenance. Thirdly, customers can reduce their total cost of ownership by standardising on high-efficiency motors and drives. This means that assets are deployed optimally in a sustainable manner that reduces the overall environmental impact.

Of course, it is not exactly certain how all of these trends are likely to play out over the next five to 15 years. What we do know, however, is that the future is invariably shaped by the innovations of today, which are transformed into the advances of tomorrow. Every company that operates in or serves the mining sector can participate in shaping this future – and can begin to have an immediate impact. Let us all join forces as we co-develop and collaborate to set these new 'smart' standards for mining.

The switch to remote services accelerated in 2020 due to the Covid-19 pandemic. This also resulted in a more rapid uptake of Industry 4.0 solutions in the mining industry in terms of automating operations for optimised productivity, reducing equipment downtime and costs, carrying out predictive rather than preventative maintenance and enhancing safety for mine personnel so as to introduce a 'zero harm' culture.

Connected mines will result in a wealth of digitalised data from equipment, assets and applications. By the time this data reaches operators, it will already have been analysed, and can be accessed easily and interacted with on any number of smart devices. Such a connected process results in rapid,

smart and informed decision-making that will have a major impact on the bottom line.

Mining is one of the key industries where our drives, motors, generators, mechanical power transmission products and integrated digital powertrain solutions stand to play a major role in ushering in this new connected era. It is an example of the leading role we as a global innovator play in transforming both society and industry to achieve a more productive and sustainable future for all. Therefore, I am very excited to join ABB Southern Africa as Local Business Area Manager in its Motion business unit. This means I get to be part of the South African mining industry's incredible ongoing transformation.

Assisting major South African industries such as mining to adopt the latest technology on the country's path towards energy efficiency, reduced emissions and, ultimately, carbon neutrality is my main goal in my new position. This has been an important focus for me throughout my career in Spain and Mexico.

As we all know, South Africa faces power constraints, coupled with lagging economic growth and development. Here I also see electrification and automation and power and water as critical business development areas for us as a business.

In Mexico, for example, a career highlight for me was overseeing the establishment of a new Energy business unit that merged Power and Water to focus on the Oil and Gas industry. This is a sector where we enjoy a global footprint, with clients as far afield as Europe and the US. It is a burgeoning sector in Africa, especially with the latest oil and gas discoveries, presenting tremendous opportunities throughout the continent.

As a business, we succeed by adding value, which is a combination of our innovation, expertise and experience. Dealing with customer requirements is much more than offering technical solutions, but depends on understanding a customer's business and how best to optimise it. Our customers are our true assets, because if we help them to succeed, then we succeed in turn. But it goes even further, as we have both a commitment and a drive to make the South African mining industry succeed and benchmark itself against the best in the world.

With South Africa contributing the bulk of our revenue on the continent, my plan is to maintain this strong foothold, while continuing to expand into the rest of the continent, where mining especially is an important driver for growth and socioeconomic development. The mining industry has always demanded the latest technology, and our solutions have been tried-and-tested in major markets such as North America and Europe.

As our recent White Paper entitled 'Achieving the Paris Agreement: The vital role of high-efficiency motors and drives in reducing energy consumption' states, the technology to dramatically improve energy efficiency is available right now. For example, high-efficiency motors and drives are well established and time-tested. I aim to increase the uptake of such technology especially in mining, as well as to educate the market about the importance of our long-term sustainability goals as a future-orientated business.

Of course, the benefits of greater energy efficiency go well beyond the fight against climate change. They contribute broadly to environmental conservation, cleaner air and water, better public health, energy independence and stronger economic growth and development. Nowhere is this more critically important than in the South African mining industry, which is taking significant strides towards a 'climate-smart' future. wn

Natural gas a vital element in mission net zero: GECF

The Gas Exporting Countries Forum (GECF), as an intergovernmental coalition of 19 of the world's leading gas producers together representing 70% of the proven natural gas reserves, 52% of gas pipeline, and 51% of LNG exports, echoes the International Energy Agency (IEA)'s recent report 'Net Zero by 2050'.

The GECF is convinced that natural gas, as an abundant, affordable and clean hydrocarbon source, has a central role to play in the energy transition while simultaneously supporting progress on several sustainable development dimensions including the guardianship of ecosystems, human health, and the economy.

In fact, our member countries are already demonstrating their manifold commitment to environmental stewardship by reducing emissions from their own operations and wherever they hold equity to accelerate decarbonisation.

The GECF's in-house developed Reference Case Scenario (RCS) implies a realistic approach when it comes to governments – including some of the most energy-poor nations – increasing their ambitions from current Nationally Determined Contributions (NDCs) and net zero pledges.

The RCS takes into account adopted and announced national energy policies, while building its long-term assumptions, based on pragmatic assessment of policies' implementation as well as progress in technologies that support carbon mitigation.

Based on the latest estimates in the GECF RCS, global primary energy demand is projected to increase by 24% over the next three decades, boosted by cumulative economic and population growth drivers.

The only approach to achieve energy market stability, responsible and inclusive economic growth, as well as sustainable development goals is to consider natural gas as a destination fuel that will always be an essential element in achieving a lower-carbon energy system.

It is obvious that the structure of the energy mix is becoming more diversified thanks to the expansion of renewables. However, fossil fuels are projected to remain dominant, accounting for 71% in 2050. According to the latest GECF estimates natural gas will become the leading source in the global energy mix by mid-century, increasing its share from 23% today to 28%.

The GECF believes in the right of countries, particularly the developing economies, to have access to abundant, affordable and clean source of energy. We don't condone restriction of

policies on upstream development and directing investment resources instead towards expensive decarbonisation options and technologies, some of which are yet to be proven.

For the time being, it is widely recognised that the net zero pathways rely on technologies which are not currently available in the market. This technology challenge is further exacerbated when considering the developing countries that have no access to technologies and financial resources.

The move away from investment in upstream gas resources can substantially affect the security of supply and prevent countries from accessing competitive and clean energy sources, such as natural gas, which is compatible with sustainable development.

There is an expected growth in LNG consumption in future decades because of population growth, growing economic prosperity in developing countries (e.g., China and India), favourable government regulations and actions to reduce air pollution and eliminate coal.

Regardless of any financing structural changes due to market ambiguities, the level of investment is expected to grow in the long-term.

It is estimated that total gas investment, including upstream and midstream activities between 2020 and 2050 will reach about $10 trillion, representing a compound annual growth of 1.26% from a total of $258 billion in 2020 to $375 billion in 2050. wn

OBITUARY - ANDY POLLARD

ANDREW POLLARD
1941 - 2021

Andy Pollard was the dominant and pre-eminent engineer in the discipline of Utility Telecommunications in ESKOM during the period 1960-1999 and made profound contributions to creating the technically excellent telecoms system that ESKOM enjoys today. What follows here is the tribute to Andy written on behalf of the SAIEE.

BY | ANTHONY BRITTEN PR ENG | FSAIEE
TIM LAMBERT BSC (HONS)

Andrew Francis Pollard was born in Durban of British parentage on 21 July 1941 and died in the Sandton Medi-Clinic on 16 March 2021. In January of this year, he had undergone a successful appendectomy. He was recuperating well from this and other procedures when he suffered a sudden relapse and passed away peacefully at 8H40m on 16 March 2021. The SAIEE wish to offer their heartfelt condolences to his widow Denise and his three adult daughters.

As he was always known (Andrew to his intimates), Andy was a leading practitioner in telecoms systems engineering as well as a recognised specialist on the arcane subject of power line carrier systems in high voltage networks.

Andy began his technical career as a technician in the South African Post Office (SAPO, now known as TELKOM) in 1959. He had earlier attended (1954 – 1958) Parktown Boys High School and matriculated in 1958. Although Andy obtained a university pass, he decided, for reasons unknown, not to go to University and joined SAPO on a bursary scheme. This ensured that he would get good training on radio systems and multi-channel carriers used on the open-wire telephone circuits lines of which there was a profusion.

After he completed his training with SAPO, he joined Eskom in 1964. He was seconded to the Telecoms Department (located at Simmerpan and managed by the late Dennis Bacon) of the Rand and Orange Free State Undertaking. The fact that the undertaking was expanding its infrastructure provided the lucky break and challenges which Andy grasped with both hands. Andy played a leading role in the creation of a reliable telecoms system. By 1967, the elements of a reliable telecoms network had been created and comprised fixed VHF/UHF telecoms network based on power line carrier and an ageing pilot cable network (pilot cables used for line protection and operational telephony/telecontrol and telemetry.) Maintaining the pilot cables became a "nightmare", mainly because of insulation failures and conductor burnout problems. Andy did much of the post-failure analysis.

It should be noted that the reliance on pilot cables was not Andy's choice; operations engineers established in the erstwhile VFP (Victoria Falls Power Company), which created the networks which later, in 1949, became the Rand and Orange Free State Undertaking [2]. In 1965-1970 Andy's developing managerial skills were revealed. It was decided that the telecoms services required would not be outsourced and that the telecoms infrastructure would be expanded. Andy seized the opportunity by taking part in the consolidation of the design, operation and maintenance of the telecoms infrastructure, which had earlier been established in the Rand and Orange Free State Undertaking. Of course, Andy was supported in this work by an excellent and highly motivated team, including the late Dennis Bacon and Kees Berkeljohn. They gave Andy the managerial latitude to develop his skills. He was exposed during this period to a myriad of engineering problems, which undoubtedly helped him hone his skills in telecoms and make him so effective as an engineering practitioner and as a natural leader of a highly technocratic activity.

In 1974 he moved from Simmerpan to Head Office in Braamfontein, where, working with the late Lionel Zeederberg, he concentrated on power line carrier engineering and the many attendant telecoms engineering challenges associated [TB1] with this technology. At the same time, Andy developed and defined a telecoms transmission level plan to ensure stable and high-quality circuit performance as the telecoms network expanded. He became Chief Engineer Telecoms in 1984, responsible for the planning, design and procurement of systems at the national level. After a reorganisation in the early 1990s, Andy was assigned to plan a new national digital network to accommodate transmission, switching and data requirements, a role he fulfilled until he retired from Eskom in 1999. He went on to work a few years more for the consulting company Kennedy & Donkin on telecoms projects in the SADC region. He also wrote a chapter for the Eskom Power Series Book [5]; it dealt with the influence of the power line carrier circuit on the line configuration and vice versa.

During Andy's career, technology advanced rapidly and profoundly, from the era of the rotary-dial telephone, electro-mechanical exchanges, copper cables, thermionic valves to present-day digital microwave and fibre-based systems. Andy was a leader in introducing new technologies and was always abreast of opportunities for system improvement. Appropriate training for technical staff was high on Andy's agenda, and he developed and conducted numerous training courses.

Anyone who knew Andy would soon become osmotically aware of his uncompromising commitment to quality, accuracy, thoroughness, high integrity and appropriate technical expertise, which he demanded of himself and anyone else involved in his ambit. He was widely known amongst the telecoms fraternity of South Africa and internationally and respected as a serious and highly competent practitioner across the vast field of telecoms engineering. The epithet "Mr Telecoms" was well and unanimously earned by Andy.

By working closely with Lionel Zeederberg (one could almost say that they were "joined at the hip"!) on various theoretical aspects, Andy made significant contributions to improving the reliability and dependability of the carrier accelerated distance protection schemes on ESKOM's long series compensated 400 kV lines. Andy led the research into the carrier's behaviour in high noise conditions created by line faults and switching of isolators in the respective 400 kV equipment yard. Lionel and Andy together drove the research teams doing the measurements with such vigour and determination that they became affectionately and respectfully known by the soubriquet "THE ZOLLARD"! This appellation has evolved into the "ZOLLARD EFFECT" (See footnote number 2.)

Andy always tried to get to a "doable" solution to an engineering problem. He was also widely respected by his peers as a "good engineer". He had the ability and judgement to recognise an important technical issue and knew when and how to act expeditiously in resolving it. Thereby avoid wasting valuable time and resources on following "red herrings". As an example of his determination, Andy, who started his career as an unqualified Post Office technician, wrote and passed the qualifying SAIEE examinations for registration as a Professional Engineer by the then SACPE (the South African Council for Professional Engineers).

Andy's analytical skills were more practical than academically focussed; he always broke a problem down to its essential elements. After that, he applied his excellent technical judgment in coming to a workable conclusion.

On one occasion, I (AC Britten) witnessed how quickly his mind could absorb the essential details of a problem and propose effective remedial measures: we were doing end-to-end carrier frequency attenuation measurements in the 400 kHz range; we noticed that the losses were increasing too much higher values than the 1/square root of the frequency variation would have led us to expect; Andy's vast experience with end-end attenuation measurements allowed him to recognise an unknown mechanism in the carrier propagation, namely, that a half-wavelength resonance condition had occurred because the half-wavelength at frequencies in the region of 400 kHz was about 425 m which was close to the average tower span length for a 400 kV line. As the carrier would not work with insertion losses of at least 50 dB and severe impedance mismatches, Andy realised that the only way to avoid the problem would be to choose lower carrier frequencies. Here Andy used his knowledge of signal propagation on power lines to good effect and resisted the temptation felt by some of his research colleagues to do a major-and unnecessary- study of the phenomenon. More examples of Andy's practical approach could be given, but space does not allow for this.

What was Andy like as a person? Andy had a solid work ethic and was never happier than aligning a power line carrier link at some ungodly hour at some remote and off the beaten track substation. An example would be the substation Perseus and the nearby "dorp" of Dealesville in a cold snap.

He was technically very strong and articulate, well-grounded (no pun intended!). He could get to the heart of a technical issue with insight and conciseness: and without projecting a high level of ego. He did not, in general, display a significant degree of ego or arrogance and was modest to a fault.

What also stands out in my mind is his whacky, "goonish" sense of humour and his capacity to think laterally.

Here is one example that comes to mind: when I once asked him why he did not own a car, he responded by saying that owning a car was the same as smearing your hands with grease and cutting R10 and R20 notes small pieces. Eventually, he relented and acquired a fire-engine red Peugeot 504, a most sensible choice, whose attributes mirror Andy's personality, namely, reliability, dependability, fitness for purpose, "no-frills and "what you see is what you get."

You might ask what Andy's legacy is? We believe that it is the selfless example he set on how to go about work with integrity and humility and apply his talents to create an affordable and efficient telecommunications service.

Furthermore, the systematic way he allocated work to his subordinates showed the importance of the confidence he placed in their ability to do a job. This form of recognition was a crucial factor in his ability to delegate work successfully and motivate staff.

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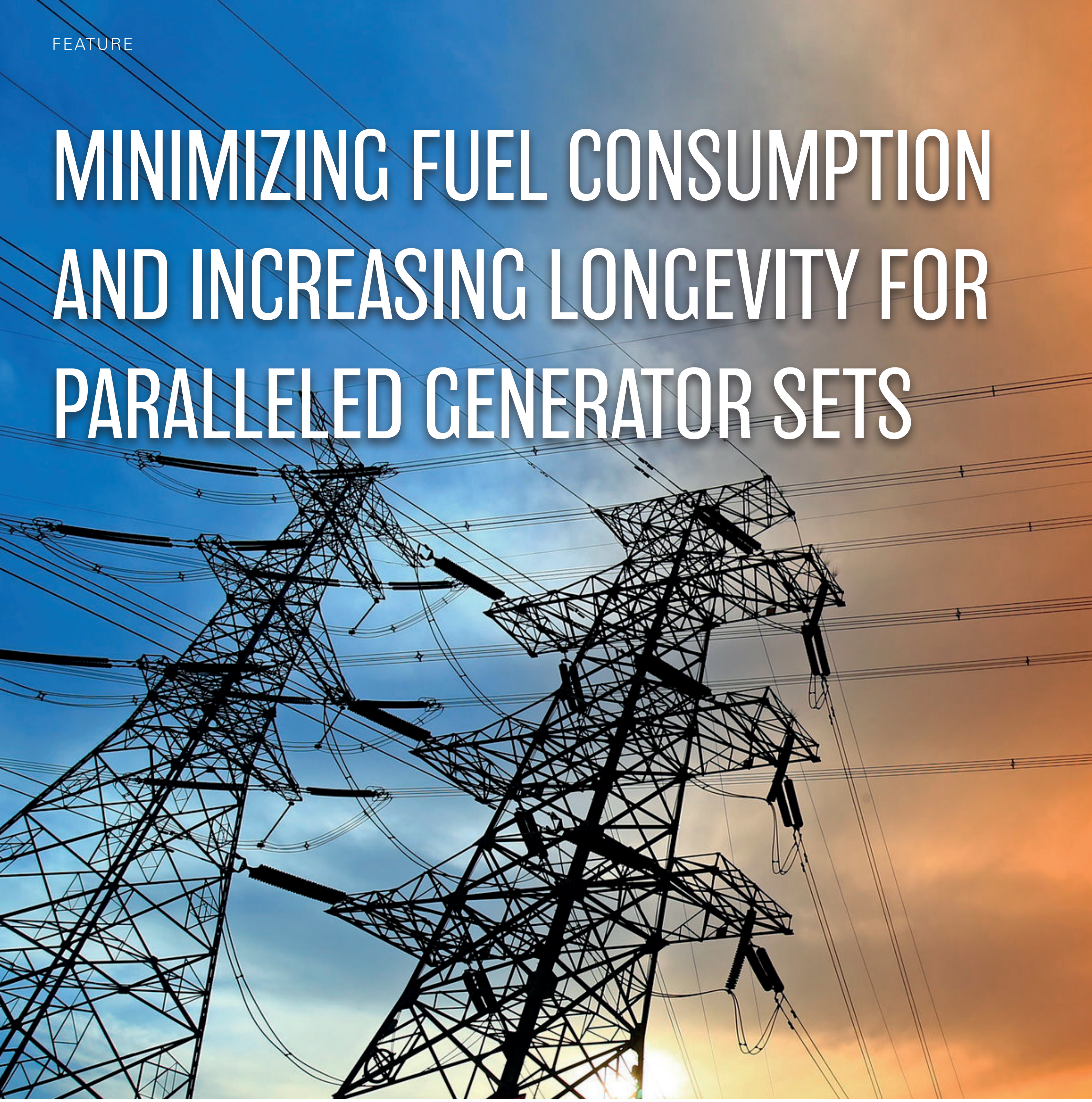
FOOTNOTES

1. The successor to SACPE is The Engineering Council of South Africa, established in 2006.
2. The word "Zollard" was coined in 1977 by Mr Michael J Hopkins (a gifted research Engineer working in ESKOM's Electrical Research Division, now living in New Zealand.)' Lionel and Andy both saw the humour and originality in the word and accepted it without reservation. wn


ZEST

MINIMIZING FUEL CONSUMPTION AND INCREASING LONGEVITY FOR PARALLELED GENERATOR SETS



Reducing fuel consumption, maintenance cost, and generator set wear by controlling the power generation capacity to match load needs are attractive features to prime and standby power systems owners. This paper discusses how such features can be attained at minimal cost while still maintaining the reliability of the power system.

BY: HASSAN OBEID

Generator sets are essential for providing backup power and prime power to both critical and non-critical loads. Depending on the size of the power system, the number of generator sets which can be paralleled together on single or multiple buses vary from a few units to dozens of units. Since this generating capacity varies, there are situations in which not all loads are connected to the system at any given time. The online power capacity is much greater than what the loads are demanding.

For example, suppose the system is comprised of multiple paralleled generator sets with a total capacity of 8 MW (2MW/generator set) and a total connected load of 1.5MW, Figure 1. In that case, only one generator set is needed to power the loads, while three generator sets can be shut off to reduce fuel consumption, engine runtime and wear and tear on the generator sets. Additionally, the operating unit(s) will be at a more efficient load level than if all the units were operating unnecessarily.

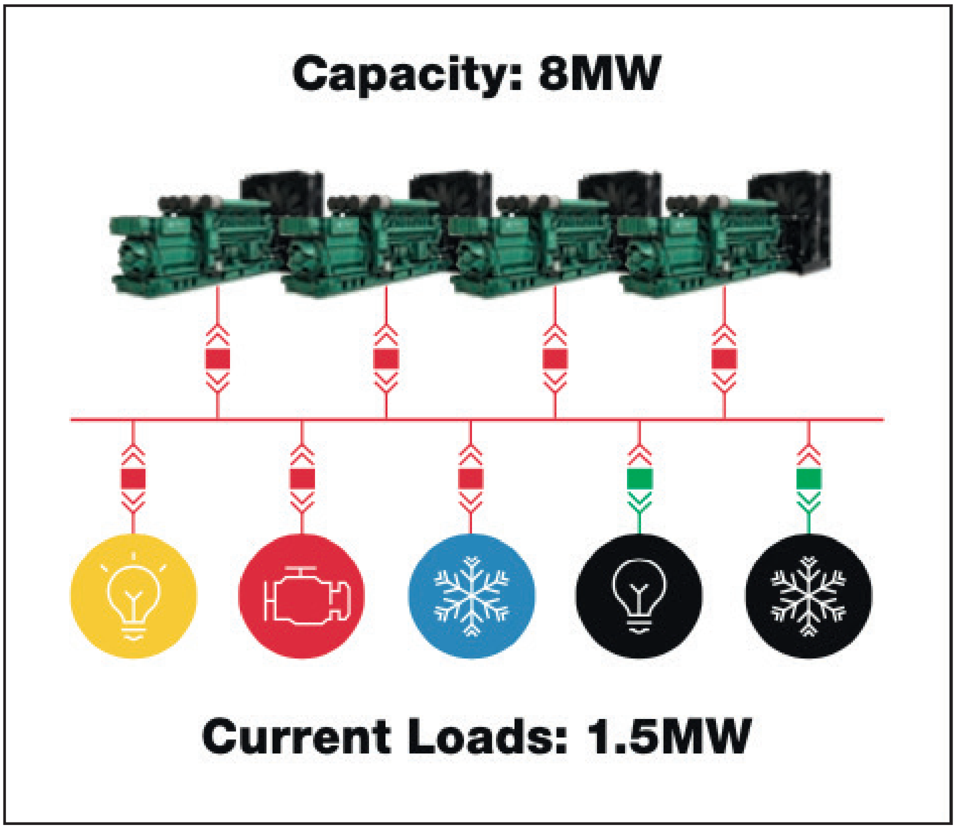


Figure 1 – Capacity vs. Loads

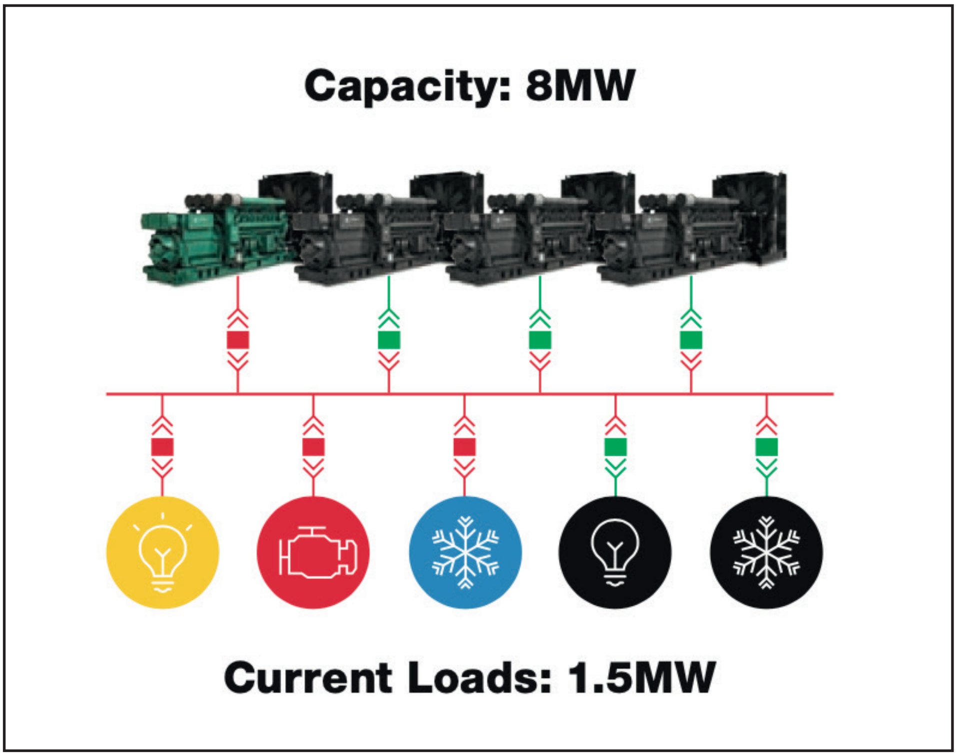


Figure 2 – Load Demand Concept

To match generation capacity as closely as possible to load consumption, a control algorithm needs to determine the total load on the AC bus, available capacity of operating generator sets, and available capacity of non-operating generator sets. The algorithm processes this information and matches the generating capacity to the load requirement by starting/stopping generator sets to run the minimum number of generator sets required to operate the loads. This enables the generator sets to run more efficiently, conserving fuel and prolonging the life expectancy of the generator sets. Another advantage of not running all the generator sets is the increased load factor on the connected sets, thereby preventing the connected units from operating at lightly loaded conditions which causes wet stacking over time. In the example in Figure 1, if all the generator sets are operating with only 1.5MW of load, the generator sets would be 18% loaded.

The control algorithm can be referred to as load demand. In Figure 2, load demand stops three generator sets since the load is only 1.5MW and the generating capacity is 8MW. In this instance, the one operating generator set would be 75% loaded.

In some applications, the user might want to trade fuel efficiency and decreased wear and tear for higher redundancy (N+1) to prevent exposure to failure of a single generator set. In this situation, the load demand algorithm allows the operator to create an N+1 or more configuration. For example, in Figure 3, two generator sets are running (N+1 configuration) to power the 1.5MW loads to provide redundancy, and the operating generator sets would be approximately 37% loaded.

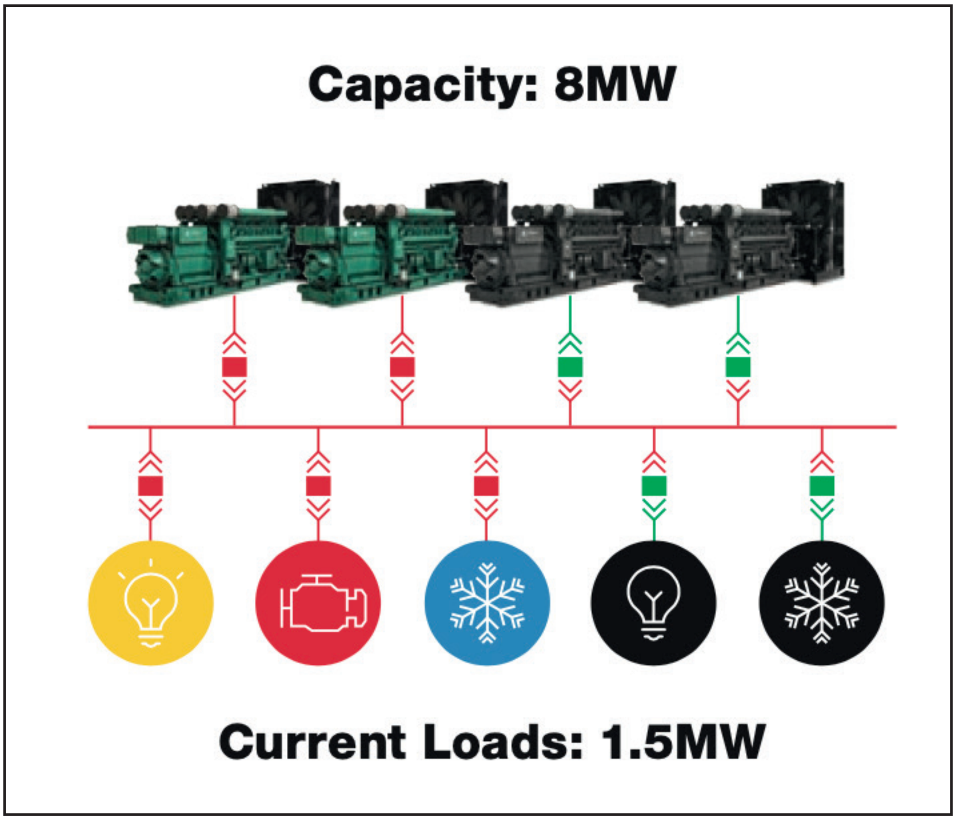


Figure 3 – N+1 Configuration

LOAD DEMAND VERSUS LOAD CONTROL

Load demand is not the same as load control. Load demand refers to capacity management-simply put starting and stopping generator sets. Load control (or load add/shed) refers to load management- connecting and disconnecting loads.

Load add/shed is a load control algorithm that loads onto the power system after standard power to the loads has been interrupted. This load staging ensures that power quality is maintained and generators do not become overloaded during the application of loads.

In addition to the orderly addition of loads, the load control algorithm also monitors the generator sets, e.g. an under-frequency signal. It removes lower priority loads from the system if the generators become overloaded, keeping the system and higher priority loads energised.

If load control is not available, the operator can have extra generator sets online to accommodate overloading conditions. The tradeoffs of this configuration are reduced fuel efficiency and increased wear and tear on the generator sets.

The operator must understand the load profile, load priorities, most significant load steps, and specific site needs for the best possible load demand performance. Using this information, the operator then can optimise the load demand settings for best performance.

The load demand algorithm can either be implemented in a PLC-based master control or an integral part of the generator set paralleling control. The latter may be referred to as Masterless Load Demand (MLD). Cummins offers load demand on both platforms: digital master and the PowerCommand autonomous microprocessor-based generator set control. Whether implanted in a PLC-based master or in a generator set control, load demand must always maintain the integrity of the power system:

- Upon system start, all generator sets must be started and brought online to verify their availability and ensure that all loads can be accommodated. Then load demand can trim the online capacity accordingly
- If an overload condition is detected, then all generators sets must be brought back online as quickly as possible
- The algorithm should automatically assign a low priority to a set with an active fault even if the set was next in line in the startup sequence
- Load demand settings should be adjustable while the system is operating without compromising system integrity
- If a shutdown condition takes down a generator set that is running, then all other sets in the system should start immediately
- Allow for redundancy configuration: N+1, N+2, N+n, etc.

HANDLING LARGE LOAD STEPS

There might be a need to step huge loads in some applications, such as single loads rated 25% or higher than the rating of a single generator set. The owner/ operator may still want to optimise fuel efficiency and reduce wear and tear without jeopardising the system's reliability. This can be accomplished in two ways. One straightforward method is to have more generator sets connected on the bus so that the large block of load can always be picked up. However, this scenario can compromise fuel efficiency.

A sophisticated way of optimising fuel efficiency and reducing wear and tear is to have a load anticipation input in the control system activated just before the load is to come on. This will cause the algorithm to decide whether or not more generator sets should be brought on first; then, the control system sends a signal back to the load when it is ready to take the load step.

GENERATOR SETS STARTING AND STOPPING PRIORITIES

The load demand algorithm to decide which generator sets to start and stop can be accomplished in multiple ways. The algorithm must allow the operator to select the shutdown/restart thresholds, time delays, and other parameters for maximum system optimisation. Two control methods are discussed herein:

- Fixed priority sequence
- Run hours equalisation of generator set

Fixed priority sequence is often used in prime power applications so that not all the generator sets require service simultaneously. In this setup, the generator sets can be serviced one at a time at varying intervals and never get to the point where they all need service simultaneously.

Alternatively, run hours equalisation is used when it is desired to have a more efficient service simply by performing maintenance on all the generator sets in one service call.

Figure 4 shows a setup screen from a generator set integrated load demand algorithm with some parameters that can be adjusted, such as time delays and per cent and actual kW set points

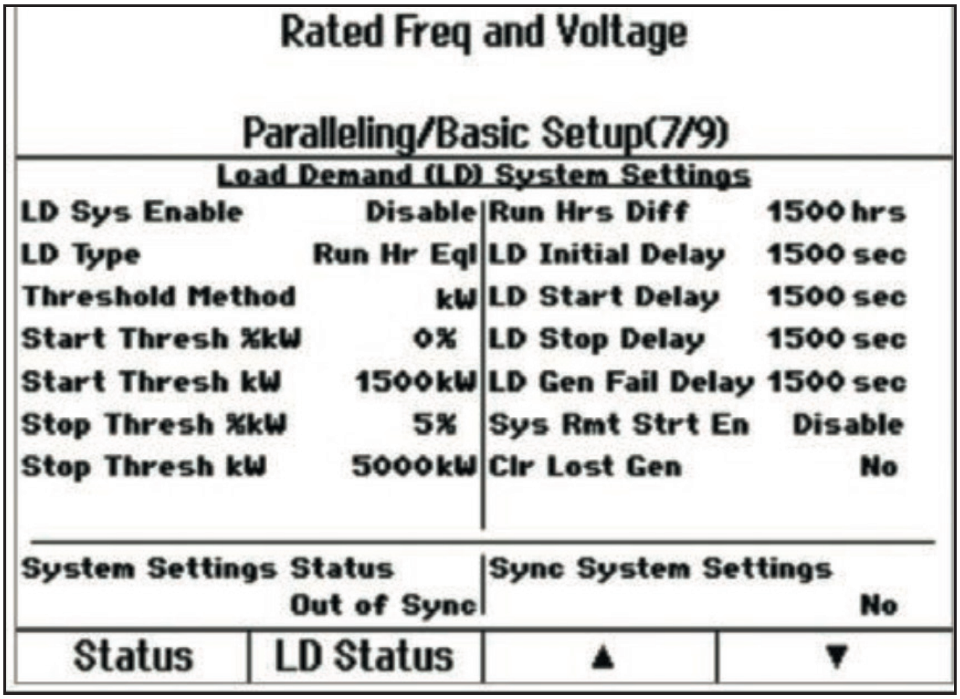


Figure 4 – Load Demand Setup Screen

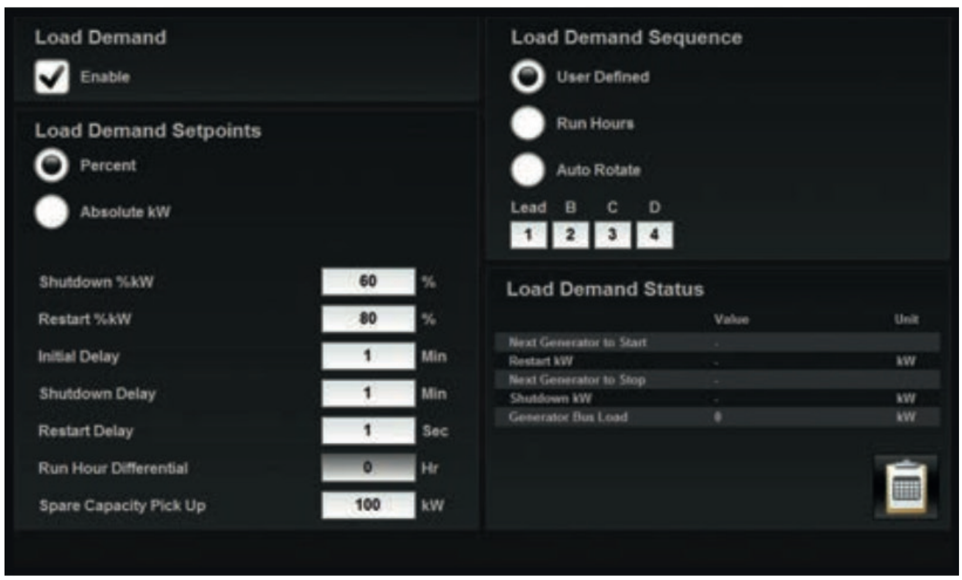


Figure 5 – PLC-Based Load Demand Setup (Four Generators)

for starting/ stopping generator sets. These parameters give the owner/ operator the flexibility to optimise the power generation capacity while still maintaining the power system reliability.

FIXED PRIORITY SEQUENCE

The load demand method called fixed priority sequence allows the generator set priority to be manually assigned by an operator. Therefore, each generator set is assigned a fixed priority: 1, 2, 3, 4, etc.

This sets the sequence of starting or stopping the generator sets as the system load increases or decreases.

For example, the unit assigned to be Lead as shown in Figure 5, or assigned Priority1 as shown in Figure 7, never

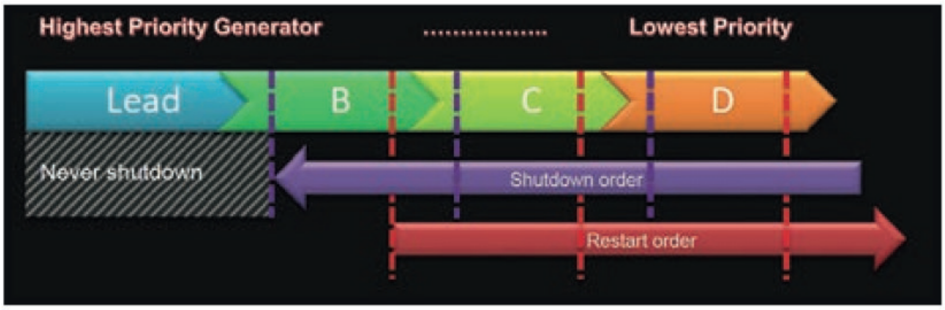


Figure 6 – Load Demand Start/Stop Sequence

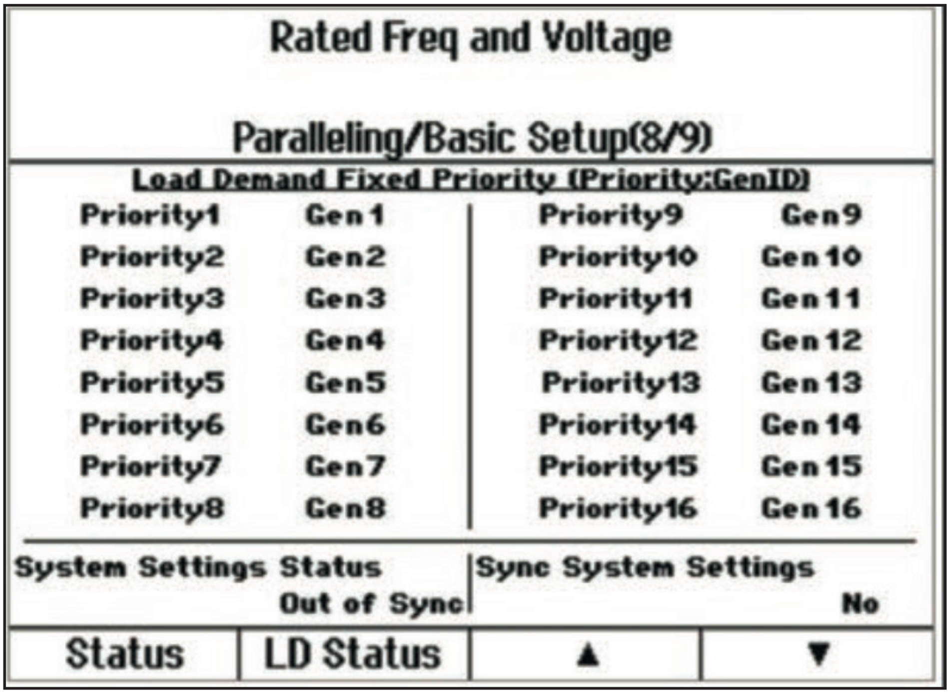


Figure 7 – Generator Set Priority Sequence

Figure 8 – MLD Rental Application

shuts down. Figure 6 shows that Unit 4 (D) will shut down first, then Unit 3 (C), then Unit 2 (B). And the Masterless Load Demand screen in Figure 7 shows that a generator assigned to be Priority16 will stop first, followed by the generator set assigned Priority15, and so forth.

RUN HOURS EQUALISATION OF GENERATOR SET

The load demand method run hours equalisation works to balance the number of run hours of the generator sets. The generator sets with the lowest number of run hours will have a higher priority to run compared with the sets with a higher number of run hours. This can be accomplished by monitoring the engine run hours and monitoring a run hours differential parameter. When the difference in run hours between the next generator to stop and the next generator to start exceeds the run hours differential, the system starts up the generator set with fewer running hours and shuts down the one with the higher number of hours.

LOAD DEMAND IN A PLC-BASED MASTER VERSES IN THE GENERATOR SET CONTROL

As stated before, load demand can either be implemented in a PLC-based master control or integrated into the generator set control (MLD). Having load demand part of either of those two options, as Cummins does, gives the system designer a higher level of flexibility to choose which method to implement depending on the application.

In applications where a digital master system-level control is not required, such as simple paralleling and rental applications, the owner would still like to benefit from the fuel cost savings and other advantages of load demand. Using MLD would be a significant advantage since it is integral to the generator set control, and no external controllers are required. Figure 8 shows a power rental application with multiple paralleled generator sets where MLD is used for load demand.

For applications where a digital master is required for complete system-level control, the system designer can utilise the load demand function of the digital master. Additionally, as the digital master is PLC based, the load demand algorithm can be more customisable to fit the needs of the application. If fixed sequence and run hours are not suitable or the system comprises multiple generator sets with different controls, they cannot communicate with each other.

GENERATOR SET FUEL CONSUMPTION AND EFFICIENCY

The generator set's electrical energy power output efficiency depends on multiple factors such as fuel quality, generator set loading, site conditions, and how well the generator set is maintained.

While the owner cannot improve operating efficiency by adjusting site conditions, efficiency can be improved by using appropriate fuels and fuel maintenance, avoiding operation at light load levels for extended periods, and operating the generator system at optimum efficiency levels based on the load of the system. Figure 9 shows the typical fuel consumption of a 2000kW generator set, and Figure 10 shows that fuel efficiency is highest for the same generator set when running near the rated load.

Figure 10 is the electrical energy power output per chemical energy input versus per cent load (kWh/gal versus % load).

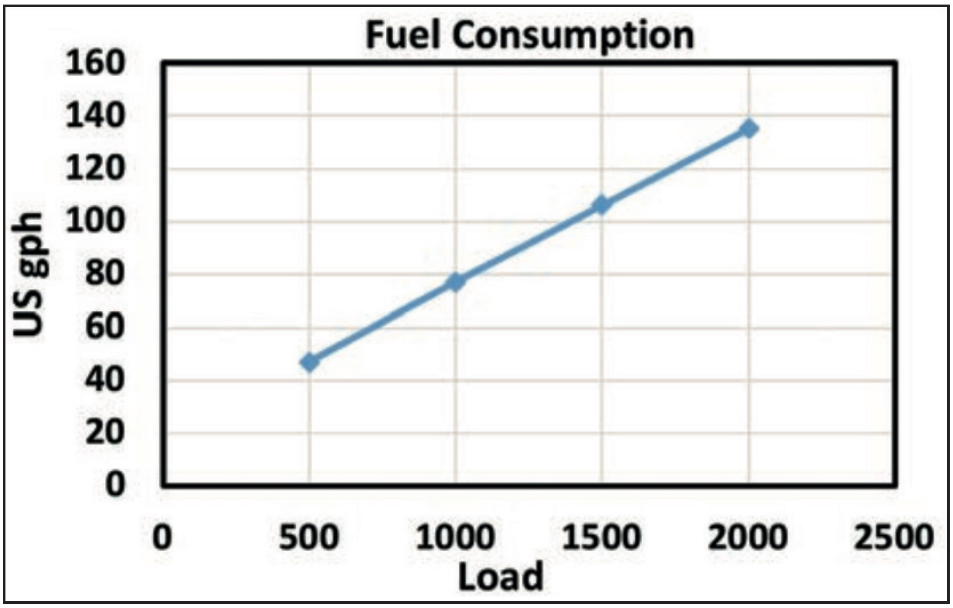


Figure 9 – Typical Fuel Consumption of a 2000kW Generator Set

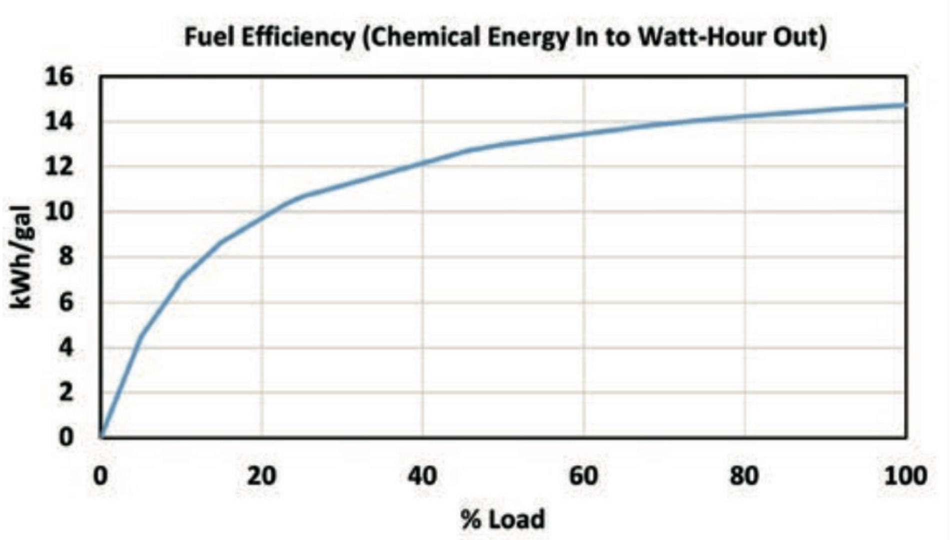


Figure 10 – Typical Diesel Generator Set Fuel Efficiency

LOAD DEMAND EXAMPLE

The daily load profile for this prime power application example is shown in Figure 11.

The system is comprised of four 2MW generator sets (8MW total capacity), and the fuel efficiency characteristics for each generator set is shown in Figure 10. Without a load demand feature, the four generator sets run continuously regardless of the load profile. However, with load demand set as, e.g., 60% and 80% for shutdown and restart threshold respectively Table 1, the number of generator sets connected to the system bus varies between one and four depending on the load. The difference in gallons of fuel consumed and savings are tabulated in Table 2 for a 365 days operation. Figure 12 shows the total system efficiency with and without the load demand feature over 24 hours. In addition to the fuel savings, the total

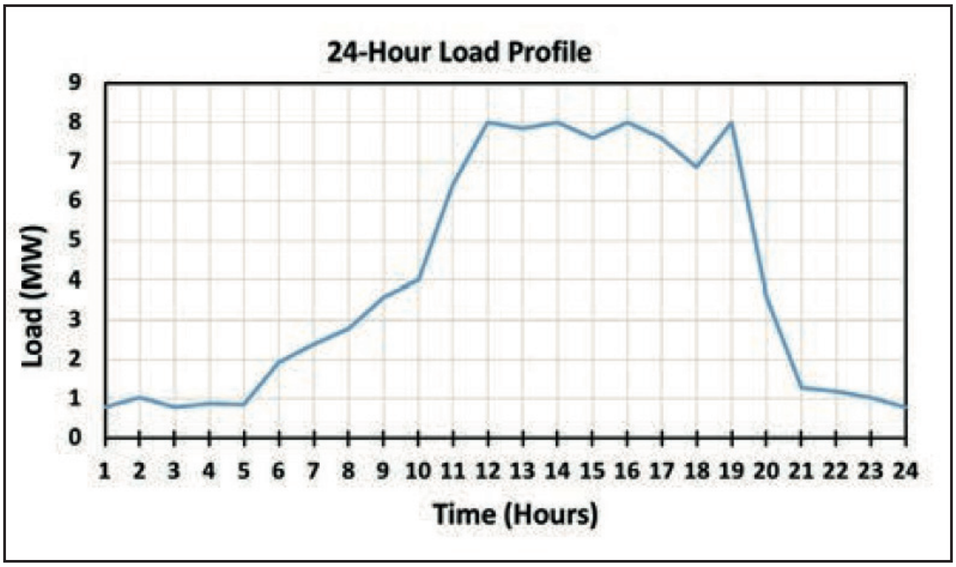


Figure 11 – 24-Hour Load Profile

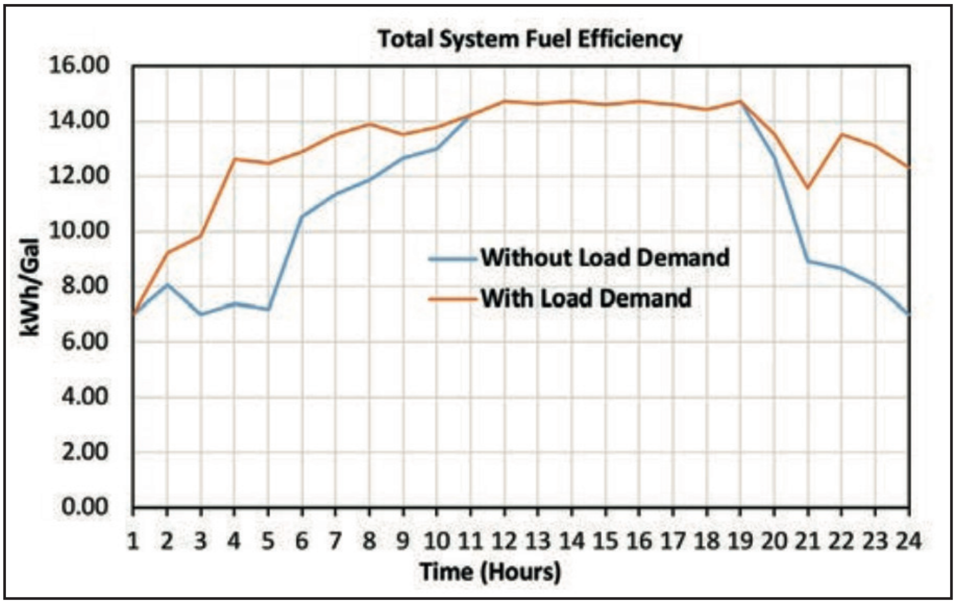


Figure 12 –Total System Efficiency

	Bus Capacity	Shutdown kW 60%	Restart kW 80%
1 Unit Online	2000	-	1600
2 Units Online	4000	2400	3200
3 Units Online	6000	3600	4800
4 Units Online	8000	4800	6400

Table 1 – Generator Sets Shutdown and Restart Thresholds

Gallons/Running Generator Set Over 365 Days	
Gallons Used Without Load Demand	63,936,560
Gallons Used With Load Demand	58,853,951
Gallons Difference	5,082,609
Savings	
Diesel Price/Gallon ($2.557)	$12,996,231

Table 2 – Fuel Consumption Comparison

Engine Runtime Over 365 Days	
Without Load Demand	35,040 (hrs.)
With Load Demand	24,455 (hrs.)
Runtime Difference	10,585 (hrs.)

Table 3 – Engine Runtime Comparison

engine runtime is reduced when load demand is utilised.

Table 3 translates into capital cost savings, increased generator sets longevity, and operational cost savings due to less frequent maintenance intervals.

CONCLUSION

The concept of a load demand control algorithm is to run the minimum number of generator sets required to energise the connected loads while still maintaining the overall integrity of the power system. By doing this, there will be fuel savings and benefits such as prolonging the life expectancy of the generator sets. These attractive features allow load demand to be used in various applications ranging from military to mining to data centres to healthcare.

The power system operator can find the right balance between fuel savings, reduced wear and tear, and redundant online capacity when configuring the load demand feature. To fully utilise the load demand control feature and maximise the fuel savings, the operator must understand the sites total loads, most significant step loads, generator fuel consumption rate, load priorities, and redundancy needs. wn

Fostering Effective Energy

In the past decade, we have witnessed an unprecedented acceleration of the energy transition. Two examples illustrate the growing speed of renewable energy penetration (mainly wind and solar) and the significant strides made in energy access. These changes have been facilitated by several factors, among which technological advancement and growing political support stand out. However, extraordinary as this evolution has been, there remain some critical challenges to delivering sustainable and affordable energy while improving access and security.

BY | ROBERTO BOCCA, MUQSIT ASHRAF, STEPHANIE JAMISON

Transition

A year has passed since the world was hit by what became the most significant global health challenge in over a century. The crises generated by the COVID-19 pandemic continue to affect countries across the world in multiple ways, underscoring key unsolved societal issues.

For example, as economic development has stumbled or reversed, the health emergency has exacerbated inequality and hampered efforts to tackle energy poverty. Unilateral approaches adopted by governments in handling challenges during the pandemic, from personal protective equipment to the approval and dissemination of vaccines, have also raised concerns about the international community's ability to come together in coordinated action across countries and sectors.

Moreover, uneven compliance to recommended public health measures, driven either by economic reasons or differences in values, illustrates the challenges in mobilising all sections of society in a cohesive response to a shared problem. The latter is critical as we look to take effective collective action on energy transition.

This report discusses the key findings from the Energy Transition Index 2021. For this report, we have made a few changes in the methodology to reflect the rising sense of urgency of climate change. We have refreshed some of the indicators to use available data more effectively. The ETI supports decision-makers with a transparent fact-base on the progress and gaps in the energy transition, the complexity of that transition, and its interdependence with social, political, environmental, economic and institutional elements. Coming out of a challenging 2020, and based on discussions with key global experts, this edition pays special attention to the climate component. In addition, we address how to improve the robustness and resilience of the transition and how to tackle elements that could derail the successful transformation of our energy systems. One key finding is a call for coordinated, multi-stakeholder action to achieve an adequate energy system evolution. To that end, the World Economic Forum encourages the sharing of leading practices and its platform for public-private collaboration to facilitate energy transition around the world.

The past decade has established the initial solid momentum to transform the energy system for the decades ahead. The scaling of nascent technologies and an increased focus on climate change have fixed global attention firmly on the decarbonisation of energy systems.

This journey is far from over. As of 2018, 81% of the world's energy was still supplied by fossil fuels,1 global greenhouse gas emissions rose through 2019, and more than 770 million people worldwide still lack access to electricity.[2] The transformation of our energy systems needs to increase its momentum to help achieve critical objectives such as the UN's Sustainable Development Goals and the Paris Agreement.

A DECADE INTO THE ENERGY TRANSITION MARKS A NEW HIGH, BUT ACCELERATION IS REQUIRED

This edition marks the 10th anniversary of the World Economic Forum's benchmarking of countries on their energy transition progress. We have taken the opportunity to look back at the lessons learned from the past decade while also looking forward to the journey ahead.

- Aggregate ETI scores rose over the past decade for countries collectively accounting for 86% of global total energy supply and 88% of global CO_2 emissions from fuel combustion.
- The ranking of top countries on the ETI has remained broadly consistent over the past decade. Denmark, Finland and the United Kingdom, the highest improvers in the top 10 positions, improved their energy system performance and sustainability outcomes thanks to a stable regulatory environment, diversified energy mix and cost-reflective energy pricing.
- Countries with rising energy demand, such as China, India and Sub-Saharan African nations, have registered the most significant gains. Still, their scores on the ETI remain low in absolute terms.

STRIDES MADE ON ENERGY ACCESS; RELIABILITY IS THE NEXT FRONTIER

Over the past ten years, more than 70% of the countries in the ETI made progress on the energy access and security dimension, primarily due to improvement in levels of electricity access around the world.

However, more efforts are needed to improve the quality of electricity supply in newly electrified areas.

This is critical for the delivery of public services, such as testing and vaccination programmes for COVID-19.

Moreover, increasingly frequent and unpredictable extreme weather events have exposed the vulnerability of grids, underscoring the urgent need to modernise and enhance the resilience of electricity transmission and distribution infrastructure.

SUBSTANTIAL GAINS MADE IN ENVIRONMENTAL SUSTAINABILITY, BUT SIGNIFICANT GAPS REMAIN

Encouraging progress has been made in environmental sustainability over the past ten years, with countries accounting for 88% of global total energy supply improving their scores on this dimension.

- Global average energy intensity fell by 15% between 2010 and 2018. However, this improvement has yet to translate into meaningful gains fully, as the carbon intensity of the energy mix was broadly flat over the same period.
- While there has been encouraging progress in rising levels of investment and political commitment, progress has been far slower in translating ambitions into actions and in realising the transformation of the energy system structure itself.
- The total amount of electricity generated from coal has been on an upward trajectory over the past ten years. Identifying viable ways for the early retirement of carbon-intensive assets will be needed to accelerate the transition.

ASSESSING THE RESILIENCE OF ENERGY TRANSITION

Over the past ten years, only 13 of the 115 benchmarked countries have made consistent gains (defined as consistently above-average performance improvements on the index). This demonstrates the difficulty in sustaining progress and the complexities of the energy transition.

Systemic disruptions such as the pandemic have underscored the impact of external shocks. The energy transition has shown signs of resilience through COVID-19, highlighting the resilience of renewables in particular.[3]

However, despite the short drop in emissions during the pandemic, global emissions have since rebounded, according to the International Energy Agency.[4]

As we head deeper into the decade of action[5] – during which we must accelerate progress towards transition and halve emissions by 2030 to remain on track to meet the 1.5 °C Paris Agreement goal – we cannot afford to lose momentum or, worse, go into reverse.

This report identifies three imperatives to increase the resilience of the energy transition:

1. DELIVER A "JUST TRANSITION" FOR ALL. Inequality is on the rise, and broad stakeholder buy-in is a prerequisite for resilience. The energy transition itself will change resource flows and reset sectors of the energy system in ways that, if not planned for, could lead to unintended consequences and leave entire communities adrift. Policymakers should prioritise measures to support the economy, workforces and society at large as countries shift to a low-carbon energy system. This will require an inclusive approach to evaluating energy policy and investment decisions.

2. ACCELERATE ELECTRIFICATION AND GO BEYOND. Electrification and the scaling up of renewables are critical pillars of the energy transition and need to be ramped up quickly. However, coordination on the demand side and the contribution of other energy sources are necessary to achieve the full impact required. Increased R&D funding and cross-sector collaboration are needed to fully decarbonise energy systems, from green hydrogen and negative emission technologies to digitally-enabled demand optimisation.

3. DOUBLE-DOWN ON PUBLIC-PRIVATE SECTOR COLLABORATION. The UN Intergovernmental Panel on Climate Change (IPCC) estimates that annual investments in clean energy and energy efficiency need to increase by a factor of six by 2050[6], compared with 2015 levels, to limit warming to 1.5 °C. Despite the growing inflow of capital into the sector, significant funding gaps remain, particularly in emerging markets and nascent technologies. Collaboration between public and private sectors, including risk-sharing as low-carbon solutions mature, will attract the diversified, resilient sources of capital needed for multi-year and multi-decade investments into energy systems.

Building an effective and resilient energy transition requires all hands on deck. As countries seek to recover from the impact of COVID-19, there is an opportunity to reset and rethink the way we power our economies, produce materials and even how we travel and live. It is critical to root the energy transition in economic, political and social practices so that progress becomes irreversible.

The past decade saw transformative changes across the energy system. In 2011, the average price for crude oil was close to $100/barrel.[7] Solar and wind energy were economically uncompetitive compared to fossil fuel-based electricity generation, and just over 70 GW[8] of solar and 238 GW of wind capacity had been installed globally. From 2011 to 2019, global installed capacity grew sevenfold for solar PV and approximately threefold for wind energy,[9] supported by improving cost competitiveness and operational efficiency. Global investment in the energy transition rose from less than $300 billion per annum in 2011 to almost $500 billion by 2020[10]. Eight out of the world's ten largest economies have committed to achieving net-zero emissions by mid-century.[11]

However, clear challenges remain. As of 2018, 81% of the world's energy came from fossil fuels,[12] global emissions rose steadily over the period to 2019, and more than 770 million people worldwide still lack access to electricity.

IS THE ENERGY TRANSITION RESILIENT?

A resilient transition maintains the direction, speed and required rate of progress towards a secure, affordable, sustainable and inclusive energy system even in disruptions.

Throughout 2020, the World Economic Forum engaged global experts from the public and private sectors and across the energy value chain. The broad consensus is one of "cautious optimism" but with explicit recognition of the work still needed, especially concerning climate change and emissions targets. As we continue through the decade of action and delivery on tackling the climate change challenge, it is more urgent than ever to accelerate the energy transition. This report will focus on the environmental sustainability dimension of the energy triangle and how leading countries have achieved progress on that dimension, even in the face of emerging risks and challenges.

The report summarises insights from our analysis of the ETI and the lessons from 10 years of benchmarking countries on energy transition. We then assess the evolving risk landscape and some critical considerations for increasing the momentum and building resilience into the energy transition.

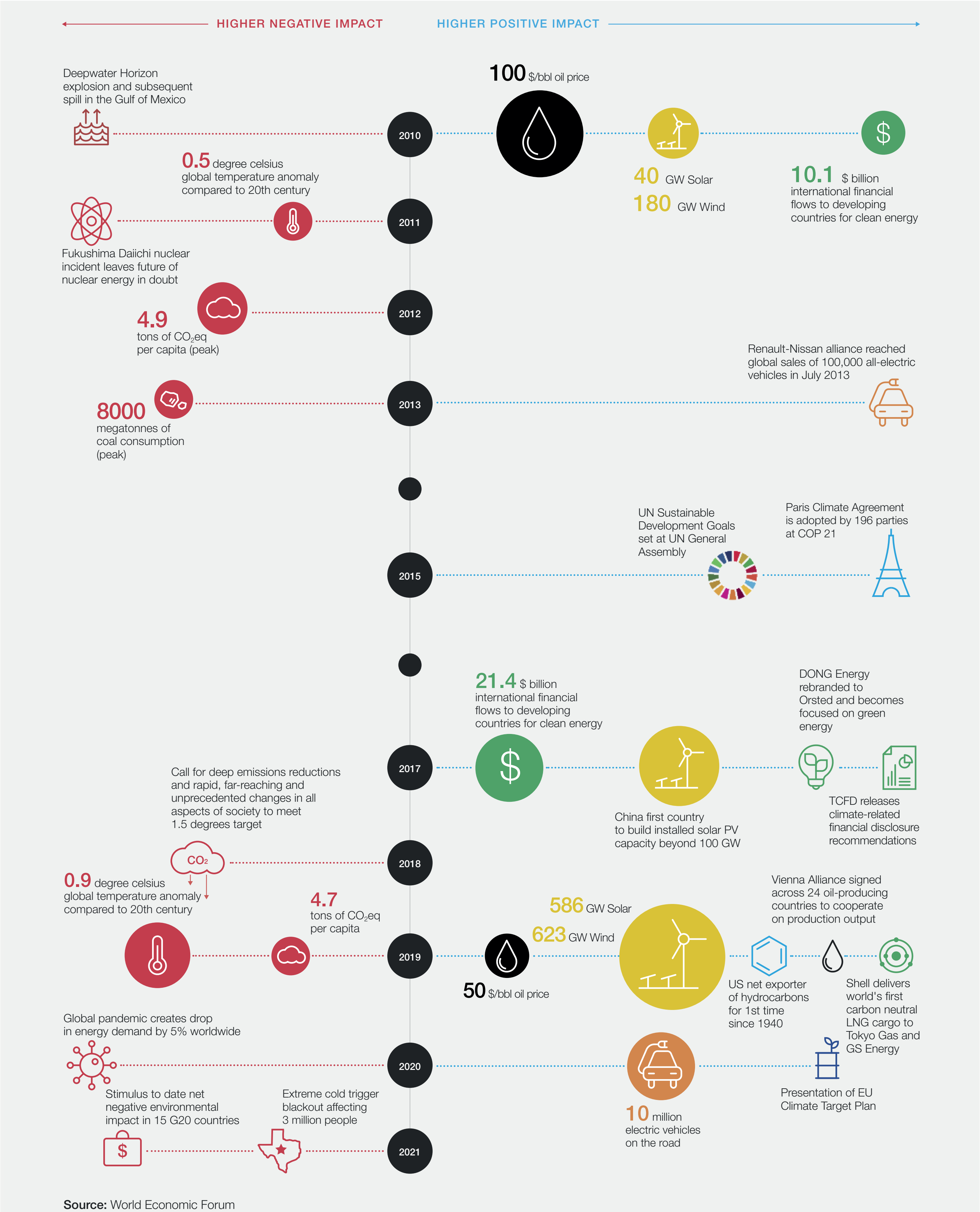


Figure 1: Energy transition over the last decade

2010		LATEST YEAR
250 $ billion global investment in the energy transition	↗	**500** $ billion global investment in the energy transition (2020)
0.38 $/kWh solar PV LCOE; **0.086** $/kWh onshore wind LCOE	↘	**0.07** $/kWh solar PV LCOE (2019); **0.053** $/kWh onshore wind LCOE (2019)
19% share of electricity from renewables, incl. hydro	↗	**26%** share of electricity from renewables, incl. hydro (2019)
0.5 million cumulative global EV and plug-in sales	↗	**10** million cumulative global EV and plug-in sales (2020)
5.4 MJ/$ energy intensity	↘	**4.6** MJ/$ energy intensity (2018)
33 gigatonnes emissions fossil fuel combustion and industrial processes - CO_2eq, world	↗	**34** gigatonnes emissions fossil fuel combustion and industrial processes - CO_2eq, world (2020)
1.2 billion # of people without access to electricity	↘	**770** million # of people without access to electricity

Source: Bloomberg New Energy Finance, International Energy Agency, International Renewable Energy Agency, Sustainable Energy for All, and others

Figure 2: Key trends within the energy transition

THE ENERGY TRANSITION INDEX IN A DECADE TO DELIVER

The ETI provides a data-driven framework to foster understanding of the performance and readiness of energy systems across countries for transition. This year's edition includes methodological updates (see Box 1) to reflect changes in the global energy landscape and the urgency of the task ahead, particularly in taking actions that will reduce carbon emissions.

Previously published as the Energy Architecture Performance Index (EAPI) series from 2013 to 2017, the ETI was developed to reflect the interdependencies of energy system transformation with the macro-economic, political, regulatory and social factors determining a country's readiness for transition. The ETI framework comprises two equally weighted sub-indices (see Figure 3): the current energy system performance and the enabling environment for the energy transition.

An effective energy transition can be defined as a timely transition towards a more inclusive, sustainable, affordable and secure energy system that provides solutions to global energy-related challenges while creating value for business and society without compromising the balance of the energy triangle.

System performance provides an assessment of a country's energy system performance across three key priorities:

- the ability to support economic development and growth
- universal access to secure and reliable energy supply
- environmental sustainability across the energy value chain

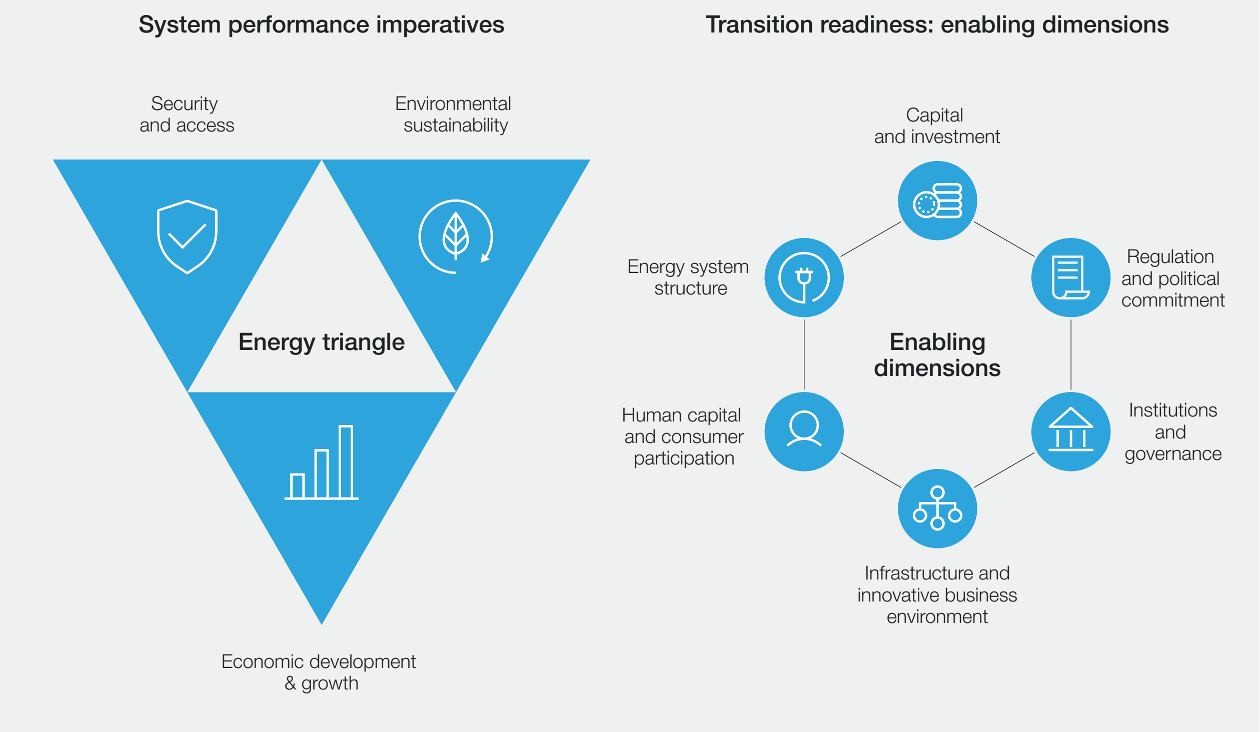
The objective of energy transition in a country should be to simultaneously deliver across these three priorities, thereby maintaining a balanced energy triangle. Pursuing a long-term goal of a balanced energy triangle can support the choice of appropriate policies and instruments and synchronise efforts across countries.

The progress on energy transition in a country is determined by how a robust enabling environment can be created.

This includes political commitment, a flexible regulatory structure, a stable business environment, incentives for investments and innovation, consumer awareness and the adoption of new technologies. The ETI measures progress along these dimensions in the transition readiness sub-index.

The energy transition is not restricted to linear shifts in fuel mix or the substitution of production technologies. Instead, the social, economic and technological systems need to co-evolve13 to shape the transition.[14]

Countries are scored along 39 indicators (see Appendix) on a scale of 0 to 100. Countries scoring the global maximum



Source: World Economic Forum, *Fostering Effective Energy Transition: A Fact-Based Framework to Support Decision Making*, 2018

Figure 3: Energy Transition Index framework

Rank	Country	ETI score (2021)	SP[1]	TR[2]
1	Sweden	79	84.4	72.7
2	Norway	77	82.7	70.8
3	Denmark	76	74.8	78.2
4	Switzerland	76	79.9	73.0
5	Austria	75	75.2	75.2
6	Finland	73	73.5	73.0
7	United Kingdom	72	75.8	69.2
8	New Zealand	71	76.5	65.6
9	France	71	77.6	64.4
10	Iceland	71	75.0	66.9
11	Netherlands	71	71.2	70.6
12	Latvia	71	73.1	68.4
13	Uruguay	71	78.3	62.9
14	Ireland	69	70.2	67.5
15	Lithuania	69	72.6	64.9
16	Estonia	69	67.8	69.4
17	Spain	68	69.7	66.9
18	Germany	68	67.4	69.2
19	Portugal	68	71.6	64.8
20	Belgium	67	67.8	66.3
21	Singapore	67	67.1	66.9
22	Canada	67	70.0	63.5
23	Croatia	67	71.8	61.4
24	United States	67	70.7	62.3
25	Albania	66	74.5	58.3
26	Costa Rica	66	73.0	59.3
27	Italy	66	71.2	61.1
28	Israel	66	71.2	60.7
29	Colombia	66	71.4	60.4
30	Brazil	66	74.9	56.8
31	Slovenia	66	70.8	60.4
32	Hungary	65	71.0	59.8
33	Georgia	65	67.4	62.9
34	Chile	65	68.2	62.0
35	Australia	65	68.8	61.1
36	Paraguay	65	73.8	55.2
37	Japan	64	65.6	63.4
38	Romania	64	70.3	58.4
39	Malaysia	64	68.5	59.5
40	Luxembourg	64	62.1	65.7
41	Malta	64	68.4	59.3
42	Peru	64	73.6	53.5
43	Slovak Republic	63	68.3	57.9
44	Azerbaijan	63	69.5	56.3
45	Czech Republic	63	68.2	56.9
46	Mexico	62	67.7	56.4
47	Argentina	62	74.3	48.8
48	Ecuador	61	71.9	49.9
49	Korea, Rep.	61	63.3	58.3
50	Panama	61	63.7	57.8
51	Cyprus	60	64.5	56.5
52	Montenegro	60	62.2	58.0
53	Qatar	60	61.5	58.5
54	Greece	60	66.7	53.2
55	Thailand	60	64.0	55.4
56	Ghana	59	69.3	48.9
57	Armenia	59	63.6	53.7
58	Bulgaria	59	60.5	56.7
59	Namibia	58	57.7	58.6
60	El Salvador	58	64.4	51.8
61	Kenya	58	60.3	55.9
62	Poland	58	63.7	51.8
63	Turkey	58	60.9	54.2
64	United Arab Emirates	57	55.6	59.4
65	Vietnam	57	61.0	54.0
66	Morocco	57	64.9	48.7
67	Philippines	57	66.5	47.0
68	China	57	55.4	58.0
69	Sri Lanka	57	67.1	46.3
70	Bolivia	56	70.1	42.7
71	Indonesia	56	67.8	44.8
72	Jordan	56	51.7	60.6
73	Russian Federation	56	66.0	45.7
74	Oman	55	55.5	54.5
75	Tajikistan	55	55.7	54.3
76	Egypt, Arab Rep.	55	58.6	51.3
77	Guatemala	55	60.9	48.4
78	Dominican Republic	54	59.4	49.4
79	Algeria	54	66.2	41.6
80	Tanzania	54	57.0	50.6
81	Saudi Arabia	54	57.4	50.2
82	Brunei Darussalam	54	57.8	49.7
83	Kazakhstan	54	64.1	43.4
84	Serbia	53	59.4	47.6
85	Trinidad and Tobago	53	61.6	45.3
86	Jamaica	53	53.0	53.2
87	India	53	58.2	47.3
88	Tunisia	52	57.5	46.7
89	Honduras	52	58.1	46.1
90	Republic of Moldova	52	64.3	39.8
91	Ukraine	52	58.1	45.5
92	Nepal	52	52.2	51.1
93	Cambodia	52	58.4	44.7
94	Kyrgyz Republic	51	52.3	50.3
95	Zambia	51	51.0	51.2
96	Nicaragua	51	56.8	45.2
97	Bangladesh	50	59.1	41.8
98	Bosnia and Herzegovina	50	54.6	46.2
99	Iran, Islamic Rep.	50	55.9	44.8
100	Cameroon	50	56.6	44.0
101	Nigeria	50	57.1	43.1
102	Kuwait	50	51.5	48.2
103	Ethiopia	49	53.0	45.9
104	Pakistan	49	56.2	41.6
105	Botswana	49	53.9	43.2
106	Senegal	48	51.2	45.7
107	Mozambique	48	55.6	41.3
108	Bahrain	48	42.9	53.8
109	Benin	48	53.0	43.1
110	South Africa	48	55.5	40.5
111	Venezuela	48	60.3	34.8
112	Lebanon	44	42.7	46.0
113	Mongolia	44	51.5	37.0
114	Haiti	42	46.7	37.1
115	Zimbabwe	39	39.2	39.5

Advanced Economies
Commonwealth of Independent States
Emerging and developing Asia
Emerging and developing Europe
Latin America and the Caribbean
Middle East and North Africa
Sub-Saharan Africa

ETI 2021 score
ETI progression since 2012
2021 Global Average (59%)
[1]System performance 2021
[2]Transition readiness 2021

For the ETI 2021 methodology, see the methodology addendum published separately.

Note: The Energy Transition Index benchmarks countries on the performance of their energy system, as well as their readiness for transition to a secure, sustainable, affordable, and reliable energy future. ETI 2021 scores on a scale from 0 to 100.

Source: World Economic Forum

Figure 4: ETI 2021 results table

68.2 ↑2%

30% | 13% | 10.1t

Advanced economies

Advanced economies have improved the group average score by 2 points over the past decade, though the improvements have plateaued. Progress has been made in reducing CO_2 per capita and the CO_2 intensity of the fuel mix, however emissions remain structurally higher than the rest of the world. Economic development and growth considerations, reliability of energy systems from increased intermittency and decarbonization of hard-to-abate sectors will be focus areas for energy transition in this group.

% of global CO_2 emissions

% of global population

CO_2 per capita

58.6 ↑2%

5% | 8% | 2.4t

Latin America and the Caribbean

Latin America and the Caribbean region's average ETI score remained consistent over the last decade. The region leads in environmental sustainability, due to a heavy hydroelectric-installed base. Further improvements can be unlocked through improving energy affordability – electricity prices on a purchasing power parity basis remain high in the region. Although the region has achieved near-universal access to electricity, the quality of supply remains challenging in many countries. Increased diversification of the import counterparts and diversifying the energy mix can further improve energy security.

52.8 ↑2%

7% | 7% | 3.9t

Middle East and North Africa

Scores in the Middle East and North Africa fell last year but the overall trajectory remains moderately positive. Heavy reliance on oil revenue continues to present challenges to sustainable growth. Diversification of the economy and the energy system can improve prospects. Challenges remain in access and security, with heavy concentration in primary energy sources. Several countries in the region have set out ambitious renewables targets for 2030. For this region, the coming decade presents opportunities to invest in an energy transition that can unlock significant cross-system benefits.

56.8 ↑5%

6% | 3% | 8.5t

Commonwealth of Independent States

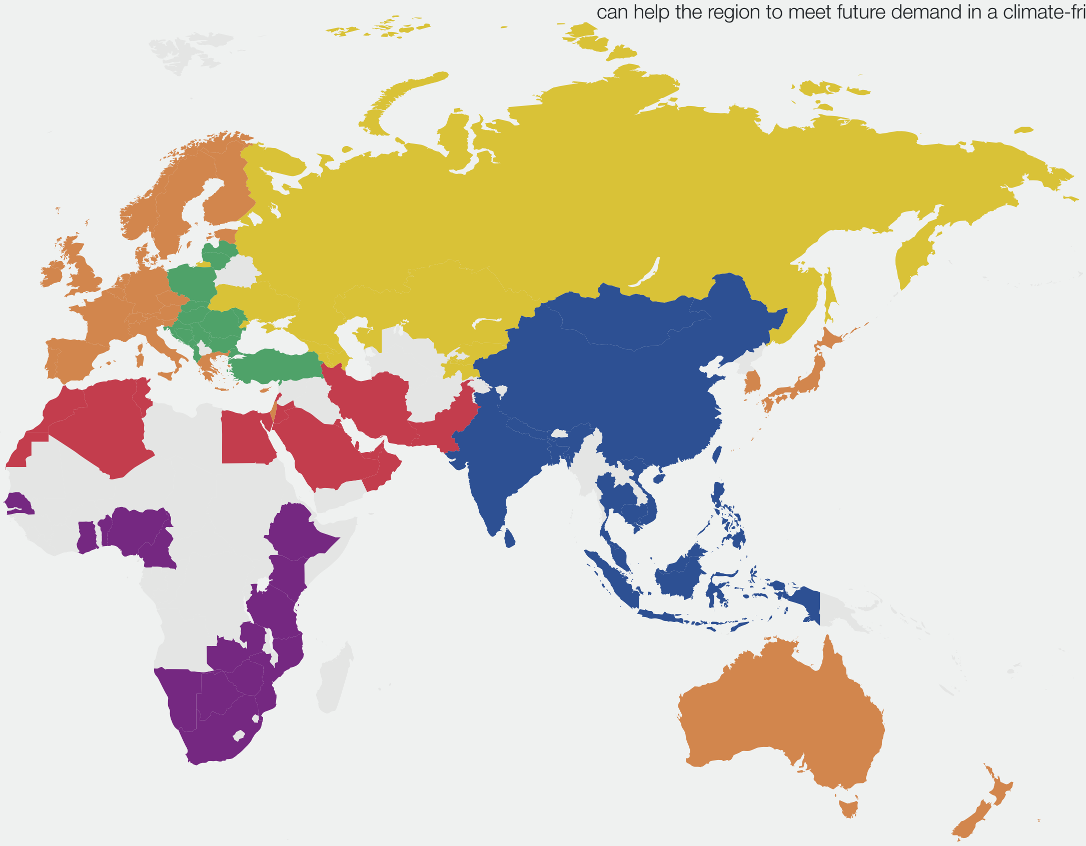
The Commonwealth of Independent States improved their aggregate ETI scores by 5% over the last decade. Average scores on the economic development and growth dimension have declined as fuel export revenues fell due to commodity market volatilities. However, progress is encouraging in environmental sustainability, energy access and quality of electricity supply. Looking forward, efforts towards economic diversification and a stable regulatory environment to support energy transition will be critical.

54.9 ↑6%

40% | 47% | 3.74t

Emerging and developing Asia

Emerging and developing Asia has improved at the fastest rate compared to other regions – 6% since a decade ago. Gains have been especially pronounced in energy access and security. However, challenges over the next decade abound. Energy demand per capita has grown 18% in the last decade and is projected to double by 2050. Recent trends indicate that coal continues to play a significant role in the energy mix. Creating a robust enabling environment to support investments and accelerate deployment of new technologies, while pursuing "just transition" pathways, can help the region to meet future demand in a climate-friendly way.



61.0 ↑5%

3% | 2% | 5.2t

Emerging and developing Europe

Emerging and developing Europe's average ETI score increased by 5% between 2012 and 2021. The region saw a balanced improvement across all three dimensions of the energy triangle. Improved diversity of energy mix, higher quality of electricity supply and strong energy intensity reductions were primary improvement levers. However, this region has a higher share of coal than the European average and flexibility remains low, which may prove challenging as the share of renewable energy grows in power generation. According to IRENA, renewable sources could cover more than one third of energy demand in this region, with benefits in savings from energy costs, health and reduced dependence on imports for primary energy.

50.7 ↑2%

2% | 8% | 1.1t

Sub-Saharan Africa

Sub-Saharan Africa's trajectory on the energy transition journey has been a positive one, although the region remains the most challenged globally in access and security. Access to electricity and basic energy services remains lowest in this region at 56%. The region has great potential to leapfrog by avoiding expensive, inefficient and more polluting energy infrastructure. Countries should consider all avenues to improve access, including off-grid electrification given the falling costs of solar panels. Improving the enabling environment for the energy transition, including policies for energy efficiency and electrification of transport, can accelerate progress in the region.

F igure 5: Regional scores and critical insights: average scores by peer group – ETI 2021 and change from ETI 2012 (recalculated)

METHODOLOGICAL REVISIONS IN ETI 2021

The Energy Transition Index (ETI) is regularly refined to reflect changes in the global energy landscape and improve the quality of insights delivered to stakeholders. Due to the revisions made this year, this year's index results are not directly comparable to ETI 2020. For trend analysis, we have recalculated historical scores using the revised methodology.

CHANGES HAVE BEEN MADE IN THREE KEY CATEGORIES:

- Framework weights. As we enter a crucial juncture of global action towards a sustainable energy future, we have adjusted the weights of several core energy system indicators. We have done this to emphasise the urgency of country action needed to decarbonise their energy systems. Countries that take more significant action to shift their energy systems away from fossil fuels will see greater improvements in their scores going forwards.
- Thresholds. The ETI adopts a min-max method to normalise indicator scores on a standard scale of 0-100. In most cases, the data ranges are narrowed to control for outliers. The min-max thresholds need to be updated at regular intervals to account for natural evolution in the spread of cross-sectional data. This year, in line with the broader methodology review, we have updated the thresholds in line with the most up-to-date data. Out of the 39 indicators, ten have been updated, covering 30% of the total index weight.
- Data sources. We have also updated the data sources for several of our indicators due to data recency and availability considerations.

on a given indicator are assigned a score of 100 on that indicator.

Given the systemic and endogenous nature of the energy transition, country scores result from a blend of factors, including resource endowments, geography, climate, demography and economic structure. Moreover, country scores in some dimensions are based on factors beyond the scope of national decision-making, such as commodity market volatility, geopolitics, international climate change action and financial market sentiment. Therefore, country rankings should be considered in the context of a country's unique set of circumstances and not a clear-cut diagnosis of energy transition accomplishment.

OVERALL RESULTS

This year marked the highest global average scores since the inception of the ETI, with the progress made across both system performance and transition readiness.

Figure 6 shows global average scores across the ETI in energy system performance and transition readiness for 2012 and 2021. However, progress is uneven. High-income countries are making more progress in environmental sustainability relative to the rest of the world. Progress in emerging economies has tended to come from improved access and security as countries develop.

Sweden leads the global rankings, followed by Norway and Denmark. Among the world's ten largest economies, only the United Kingdom and France feature in the top 10. The top 10 account for only around 3% of energy-related CO_2 emissions and around 2% of the global population.

The list of top performers in the ETI has stayed broadly consistent over the decade. Although each country's energy transition pathway is different, they all share common attributes, including:

- low levels of fossil fuel subsidies,
- enhanced energy security from a diversity of fuel mix and import partners,
- improving carbon intensity,
- reduced dependence on fossil fuels in the energy mix, and
- a healthy regulatory environment to drive the energy transition.

Denmark, Finland and the United Kingdom – the top improvers in the top 10 – were able to translate developments in leading indicators such as regulatory environment and energy mix into improved outcomes in system performance, particularly on the environmental sustainability dimension.

Figure 7 shows countries' ETI score progression between 2012 and 2021. Out of 115 countries, 92 countries have made progress over this period, but only 68 have improved their scores by more than two percentage points. Notably, large emerging centres of demand, such as China and India, have seen substantial improvements. Meanwhile, scores in Brazil, Canada, Malaysia, Singapore and Turkey have been relatively stable. Only 13 out of the 115 countries have made steady gains (defined as consistently above-average performance improvements on the ETI). This demonstrates the difficulty of sustaining progress and the inherent complexity of the energy transition. In the next decade, consistent, accelerated progress is key to meeting the world's climate targets and the UN's Sustainable Development Goals.

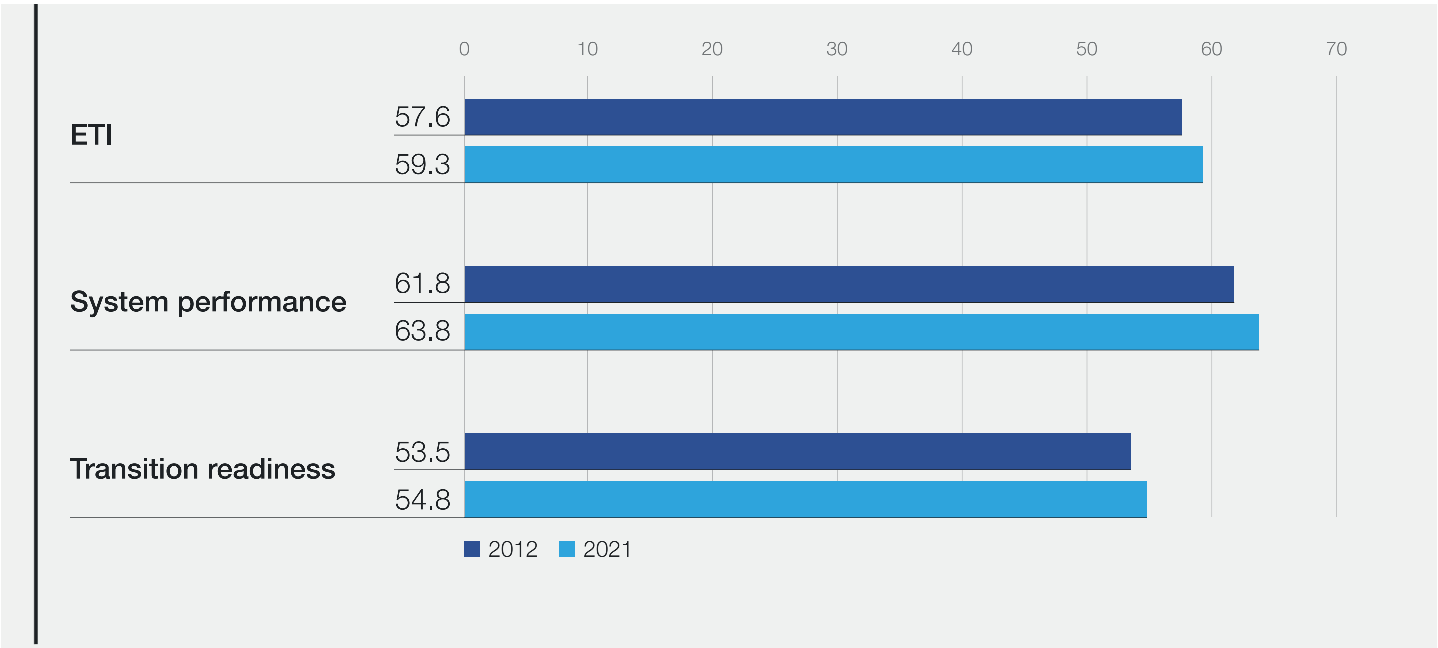


Figure 6: ETI 2021 Global average scores

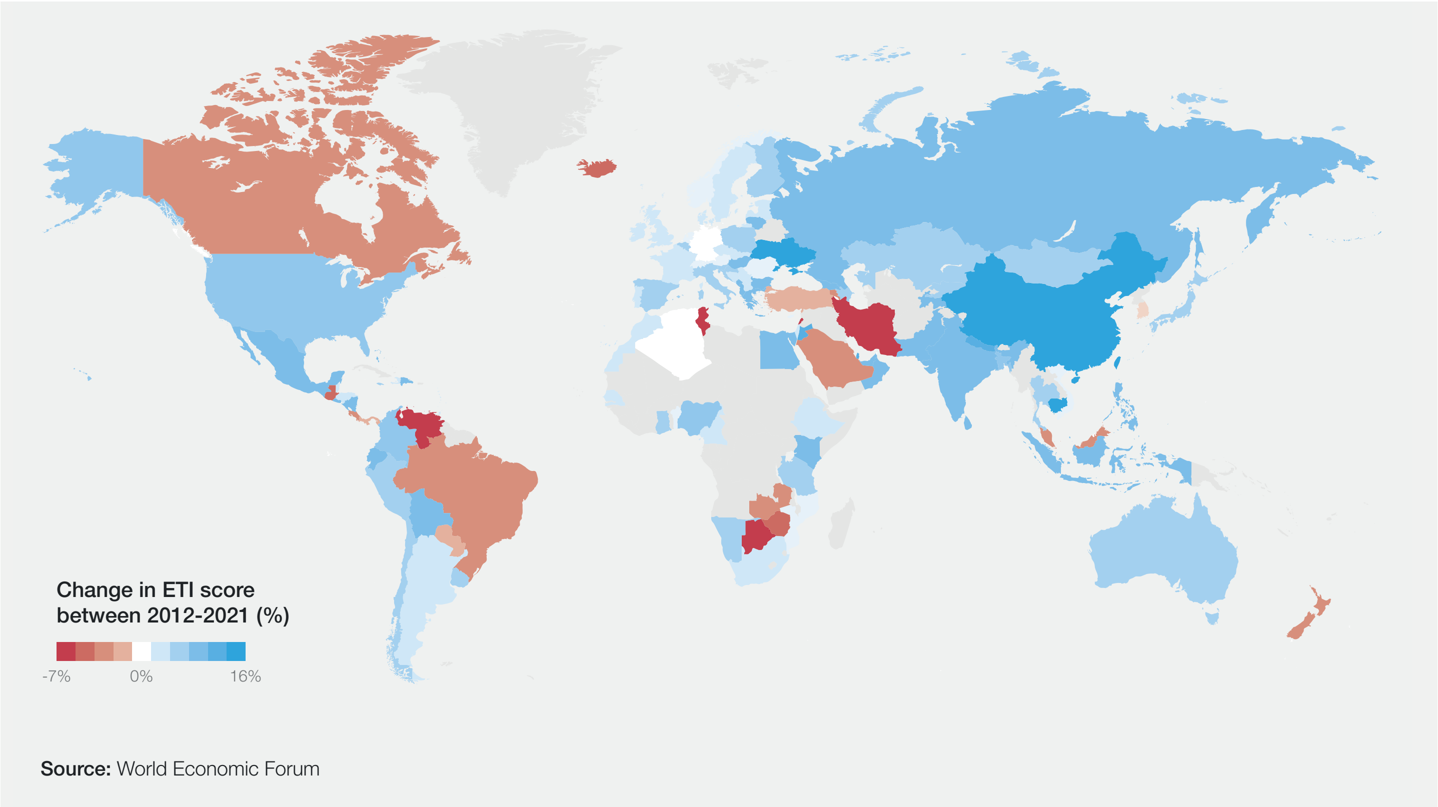


Figure 7: Countries' change in Energy Transition Index score, 2012-2021

SUB-INDEX AND DIMENSION TRENDS

KEY FINDINGS

The overall ETI score comprises two sub-indices described in the previous section: energy system performance and transition readiness. Figure 8 shows the distribution of countries across four quadrants, depending on their scores on these two sub-indices in 2021, and the cumulative GDP (nominal) and CO_2 emissions from fuel combustion of countries in the respective quadrants in 2021 and 2012 to reflect net progress over this period. The figure assigns each country to one of four quadrants:

- Leading countries – with well-performing energy systems and high transition readiness
- Leapfrog countries – with below-average system performance but high transition readiness
- Emerging countries – with below-average system performance and below-average transition readiness
- Countries with potential challenges – with above-average system performance but below-average transition readiness

In the category of countries with potential challenges, with a high level of current system performance but a weak enabling environment, there has been relatively less movement since 2012. The strong performance of energy systems in these countries is supported by abundant natural resource endowments and the robustness of legacy energy infrastructure. However, these attributes can impede accelerated progress on energy transition, given the inertia from a legacy-installed base.

Over the past decade, the trajectory of leading countries has been broadly consistent, displaying the advantages of building a stable enabling environment and continuing the momentum of policies that support the energy transition. For countries with below-average energy system performance (mainly those countries with an increasing energy demand), there has been significant movement from the "emerging" to the "leapfrog" category, signalling the gradual strengthening of enabling environments in emerging demand centres.

The energy transition is an opportunity for emerging economies to avoid the risk of carbon lock-in by leveraging the increasing cost-competitiveness of new energy technologies.

SYSTEM PERFORMANCE

Over the past decade, 70% of the countries tracked by the ETI have improved their energy system performance scores, providing a solid indication of the growing capacity of their energy systems to deliver across the following three performance dimensions:

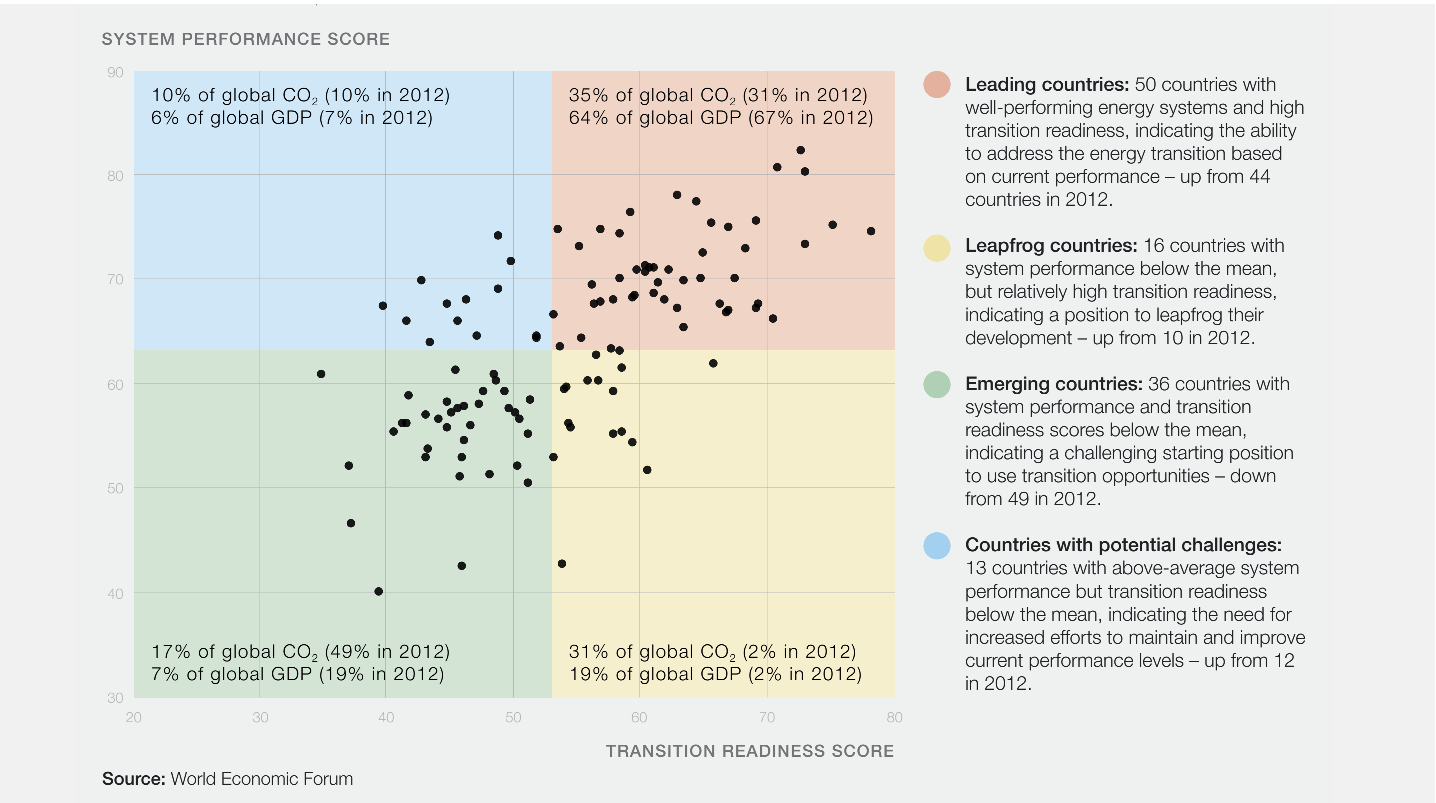


Figure 8: ETI system performance and transition readiness scores, 2021

- Economic development and growth
- Energy access and security
- Environmental sustainability

However, the pattern of improvements in system performance varies by dimension. More than 70% of countries (representing 86% of global total energy supply) have improved their energy access and security scores since 2012. Countries achieved higher relative gains in emerging and leapfrog categories, driven by improvements in energy access. Leading countries have only managed to achieve marginal improvements, which is expected given the maturity of their current energy system infrastructures. The environmental sustainability dimension displays similar trends, with a comparable number of countries improving on this dimension. However, the gains on environmental sustainability are higher for countries in the emerging and leapfrog categories, supported by strengthening their enabling environments.

The economic growth and development dimension trends have been mixed, with more than half of countries regressing over the past decade. In relative terms, economies in the emerging category have made faster progress on this dimension, but their average scores remain 30% lower than leading countries.

The following sections provide further insights into the evolution of countries on these dimensions over the past decade.

ECONOMIC DEVELOPMENT AND GROWTH

The economic development and growth imperative of energy transition stems from the critical role played by the energy sector in socio-economic development. Current economic growth pathways rely on the availability

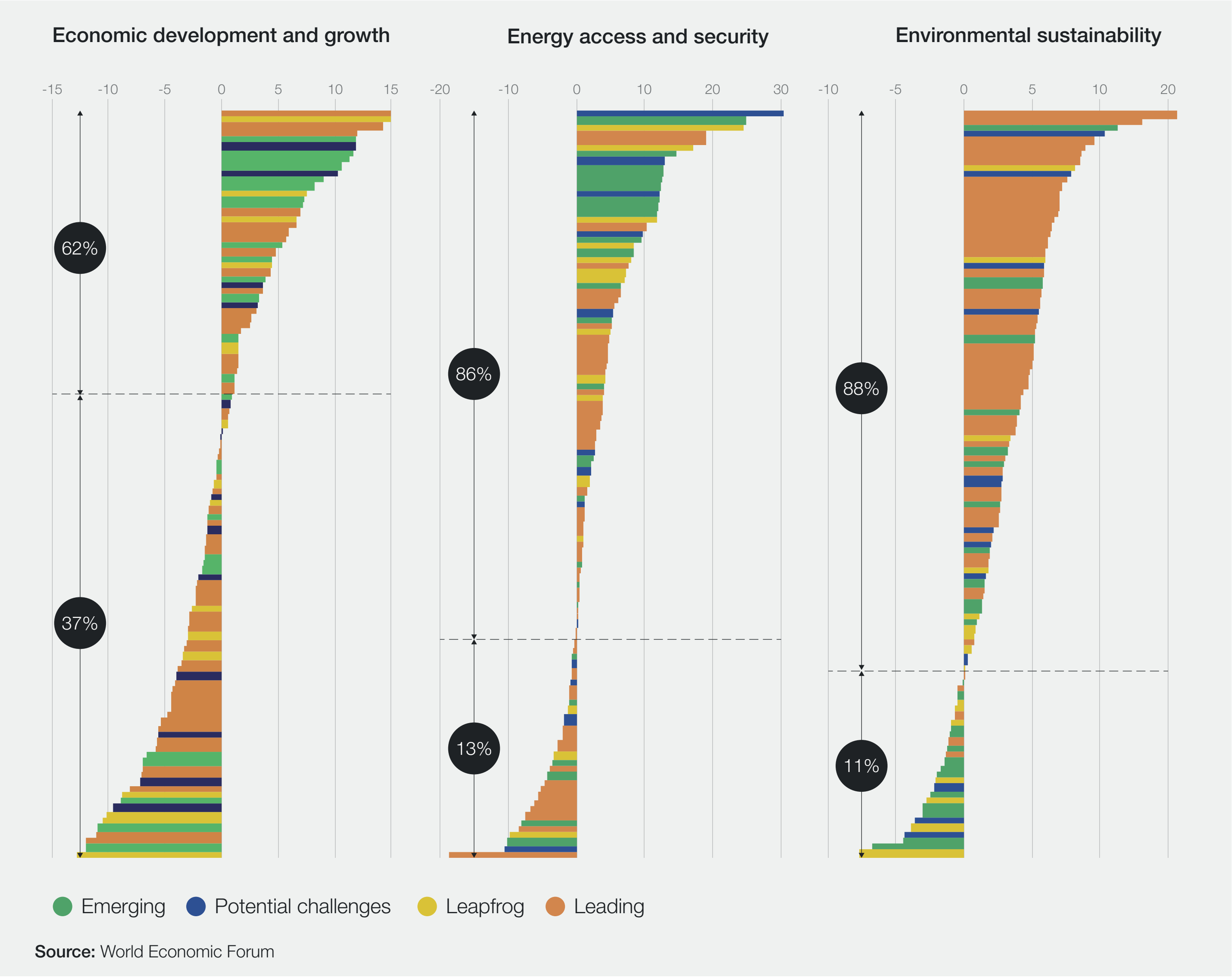


Figure 9: Change in system performance dimension scores by country archetype, 2012-2021

of abundant, secure and affordable energy supplies. As is evident in emerging economies worldwide, the energy demand is growing as they progress along their economic growth journeys. While economic growth may not be the sole objective of the energy transition, the economic benefits should outweigh the costs.

The ETI's economic development and growth dimension track the affordability, competitiveness and fiscal implications of the energy sector in countries. Over the past decade, the average global scores for this dimension have been essentially flat, reflecting the continuing challenge to decouple economic growth from energy production and consumption. However, the trends vary depending on the stage of each country's economic development.

While more than three-quarters of the countries tracked increased their aggregate ETI scores over the past decade, fewer than half could do so while also increasing their scores on the economic development and growth dimension. The effect is more pronounced for advanced economies, with the primary factor being a 25% real-term increase in average household electricity tariffs over the past decade for this peer group. For example, the increase in the European Union (EU) retail electricity price outpaced the consumer price inflation index between 2010-2019.[15.] At the same time, the externalities of energy consumption continue to be inefficiently priced, which risks exacerbating the affordability challenge. While the cost of failing to deliver on energy transition might be higher than the cost of the energy transition, distributional considerations remain at the centre of this challenge, especially in a global climate of widening income inequality.[16]

The impact of the energy transition on labour markets is central to the "just transition" challenge (see Box 2). While energy transition will create substantial employment because of policies and investment, it also leads to job losses in the fossil fuel sector. According to the International Labour Organization (ILO), the shift towards sustainable practices is expected to create 18 million net jobs by 2030.[17] As shown in Figure 10, countries leading on the ETI have a larger share of jobs in low-carbon sectors as a share of the total domestic labour force. Evidence suggests that jobs in renewable energy and energy efficiency are geographically more diversified, more gender-diverse[18] and more likely to employ young people instead of the more localised, gender-biased and ageing workforce of the fossil fuel sector.[19] However, in the short term, geographical redistribution and timing of availability of new jobs can create labour market dislocations, disproportionately affecting communities reliant on fossil fuel sectors. Focused social programmes for the reskilling and rehabilitation of fossil fuel workers and investment in developing low-carbon value chains locally. These measures are critical to gaining employment dividends from the energy transition. The ongoing reallocation of public funds to fuel the economic recovery from COVID-19 is an opportunity for countries to address this imbalance.

The COVID-19 pandemic has led to a shift in energy consumption patterns – primarily due to remote working arrangements, a decline in business travel and the exponential rise of digitally enabled services. Additionally, an increasing number of major automobile manufacturers are aggressively pursuing the electrification of their product lines. These trends could have a lasting impact on the oil demand. While forecasts of peak oil demand vary considerably, some analysts argue that the pandemic might have fast-tracked the timeline, with implications for countries across the oil supply chain.[22] For oil-producing countries, this increases the urgency to diversify their economies to maintain a steady revenue source and harness the synergies from legacy technological and operational expertise to obtain a competitive advantage in the new energy landscape.

For energy-consuming countries, consumption tax on road transport is a significant component of their tax base (e.g. 5% for OECD countries), which risks erosion from potential changes in travel habits and transportation electrification.[23] This underscores

JUST TRANSITION

A just transition is commonly defined as the move towards an environmentally sustainable economy while contributing to decent work goals for all, social inclusion, and the eradication of poverty. Decent work, poverty eradication and environmental sustainability are three of the defining challenges of the 21st century. Economies must be productive to meet the needs of the world's growing population. Societies must be inclusive, providing opportunities for decent work for all, reducing inequalities and effectively eliminating poverty. This will ensure that no one is left behind as the world's economies adapt and adjust to the changes required to mitigate the impacts of climate change.[20]

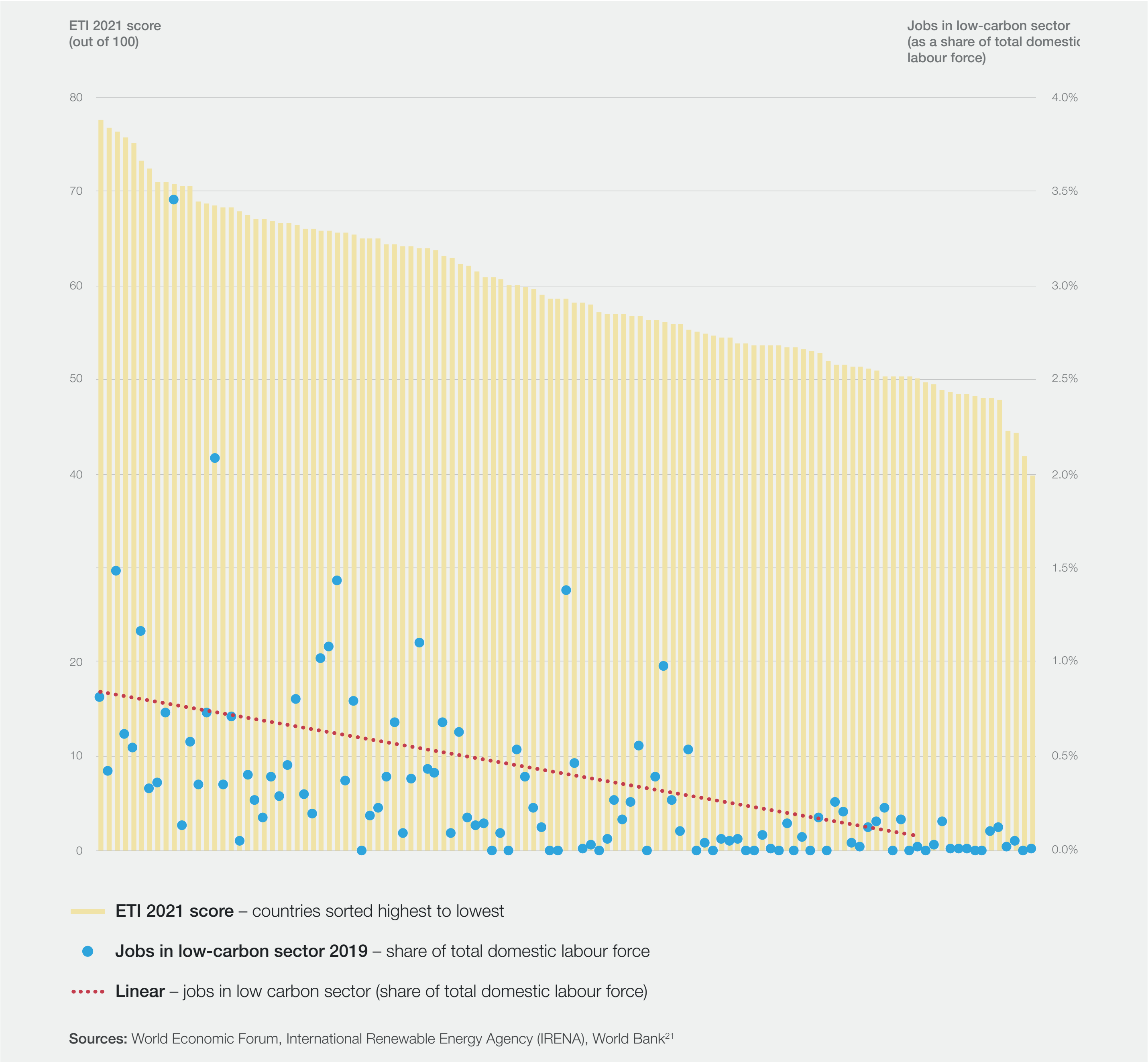


Figure 10: ETI 2021 scores and percentage of jobs in low-carbon sectors.

the need for efficient pricing of the externalities of fossil fuel consumption and fiscal reforms to design a tax system for a low-carbon future.

ENERGY ACCESS AND SECURITY

Global average scores remain the highest in the energy access and security dimension. More than 70% of countries have improved their scores in this dimension since 2010. Advanced economies and large fuel exporters score highly due to more mature energy infrastructure and domestic reserves. The most considerable improvements in this dimension come from lower-middle-income and low-income countries, notably in Sub-Saharan Africa and emerging and developing Asia (e.g. Ghana, Kenya, Mozambique, Cambodia and Vietnam) that have steadily increased electricity access over the past decade. According to the International Energy Agency (IEA), energy security is defined as "the uninterrupted availability of energy sources at an affordable price." For countries dependent on imported energy supplies, maintaining the diversity of import counterparts is critical. Trends from the ETI indicate positive developments over the past decade, with most countries diversifying both import counterparts and their energy mix. Renewable energy and energy efficiency have a synergistic effect of reducing import dependence while adding diversity to the energy mix, underscoring the security gains from the energy transition.

The number of people without electricity declined to 770 million in 2019 – the lowest on record. However, progress remains uneven, and 75% of the population without access now lives in Sub-Saharan Africa, a share that is rising due to a growing population, according to the IEA. Further, past progress is threatened by COVID-19. The IEA suggests that the number of people without access to electricity in Sub-Saharan Africa is set to increase in 2020, pushing many countries farther away from achieving the goal of universal access by 2030. Beyond energy access, the quality and reliability of electricity are of utmost importance. Figure 12 shows the challenge in the quality of electricity supply, particularly in Sub-Saharan African countries. A reliable power supply is critical for the delivery of public services, including healthcare.[24] Lack of reliable electricity is one of the bottlenecks in rapid COVID-19 testing and vaccination programmes in African countries.[25] In almost all countries, the top 10% income group consumes 20 times more energy than the bottom 10%.26 Energy access programmes need to focus on the quality of energy supply, the diversity of energy services available to households and the distribution of consumption across the country. Addressing inequalities in energy access is an important mechanism to ensure the resilience of the energy transition.

A focus on grid resilience is especially crucial as energy systems transition to a more variable and distributed system. Recent extreme weather events – including wildfires in California and Australia and cold snaps in Texas[29] and Japan[30] – have shown that grid operators also need to be aware of tail-risks and plan for a grid that can bounce back quickly from crises. In the face of extreme weather events, levers for improving grid safety and reliability include: enhancing system flexibility, increasing grid restoration effectiveness, network hardening, effective communication with stakeholders and accurate forecasting of weather and its impact, according to a recent study by Accenture.[31] With an increasing share of electricity in final demand due to the electrification of end-use, the risks from the rising unpredictability and frequency of extreme weather events are compounded, making grids a severe area of vulnerability in the energy transition.

ENVIRONMENTAL SUSTAINABILITY

Encouraging progress has been made in this dimension in recent years, with global average scores reaching an all-time high in ETI 2021 and improvements across all indicators.

Much of the progress can be attributed to reductions in energy intensity – the quantity of energy required per unit of output or product (a primary measure of energy efficiency). Progress in this space can lead to a reduction in carbon emissions. It can also improve the marginal contribution of energy to livelihoods through co-benefits such as better air quality and reduced energy costs for households and businesses.

Figure 13 shows a tale of two intensities. Globally, energy intensity fell by 15% between 2010 and 2018, indicating a decoupling between primary energy use and GDP growth, driven by improved energy efficiency. While reducing the economy's reliance

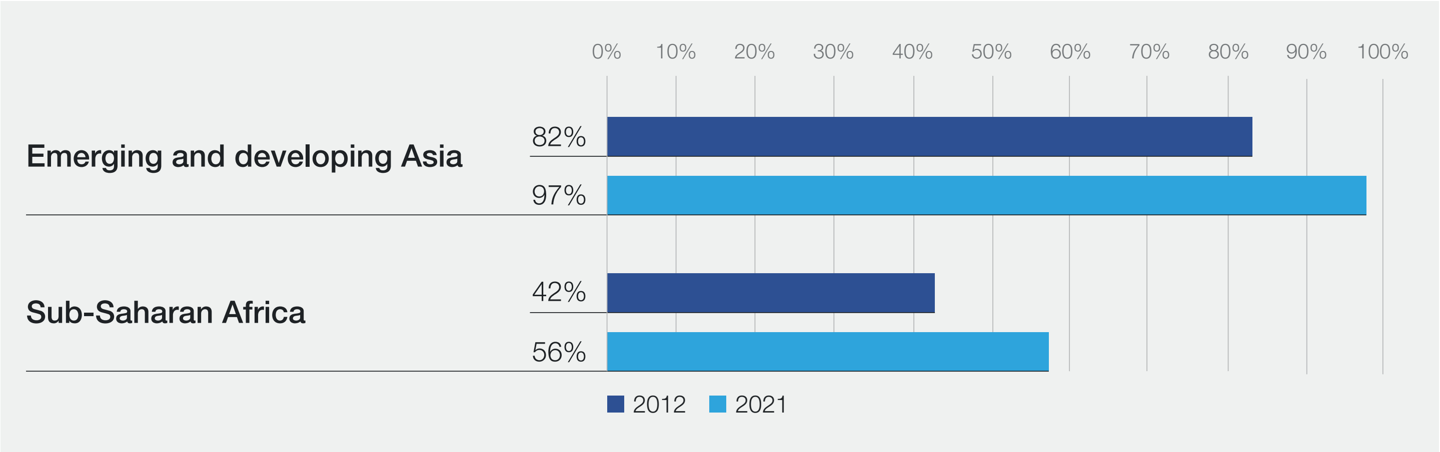


Figure 11: Electrification rates in emerging and developing Asia and Sub-Saharan Africa, 2010 and 2020

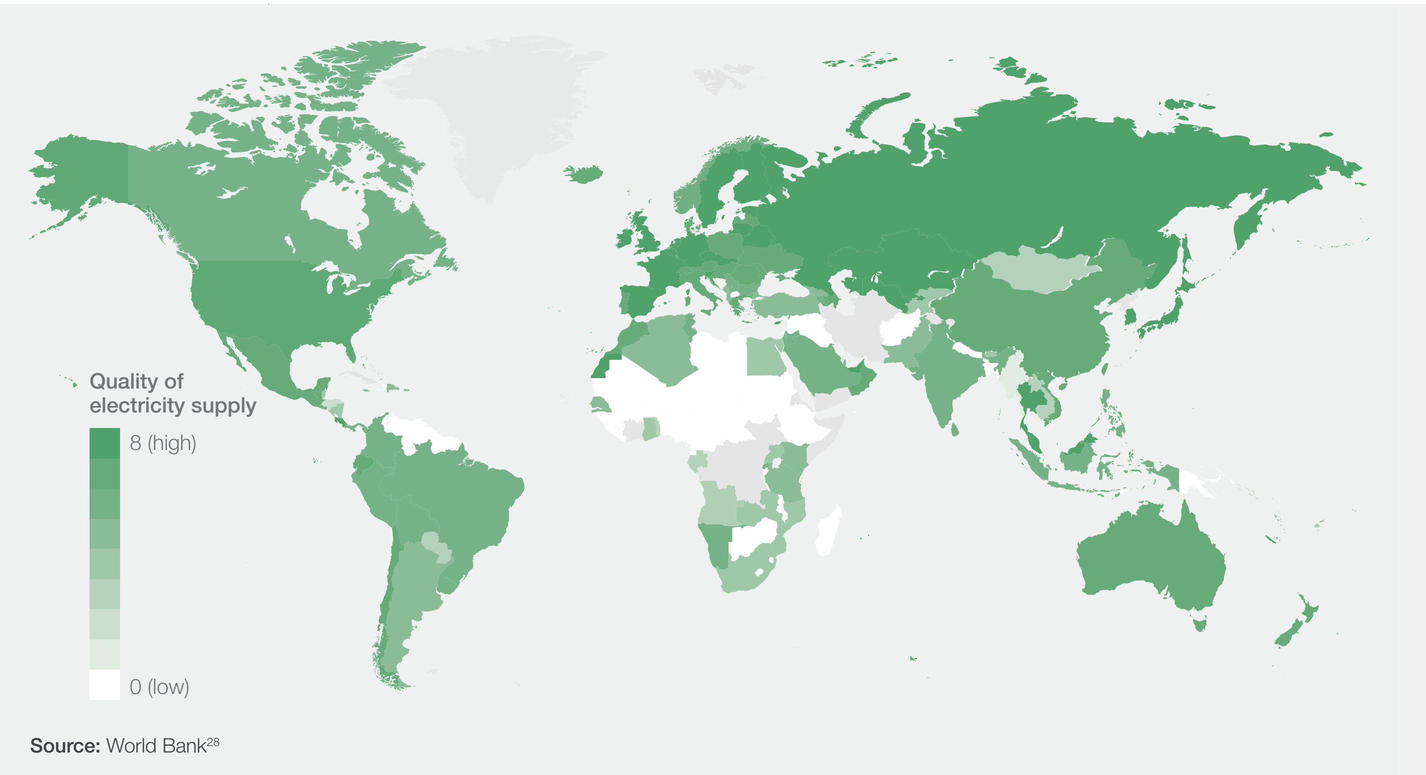


Figure 12 : Quality of electricity supply (2019)

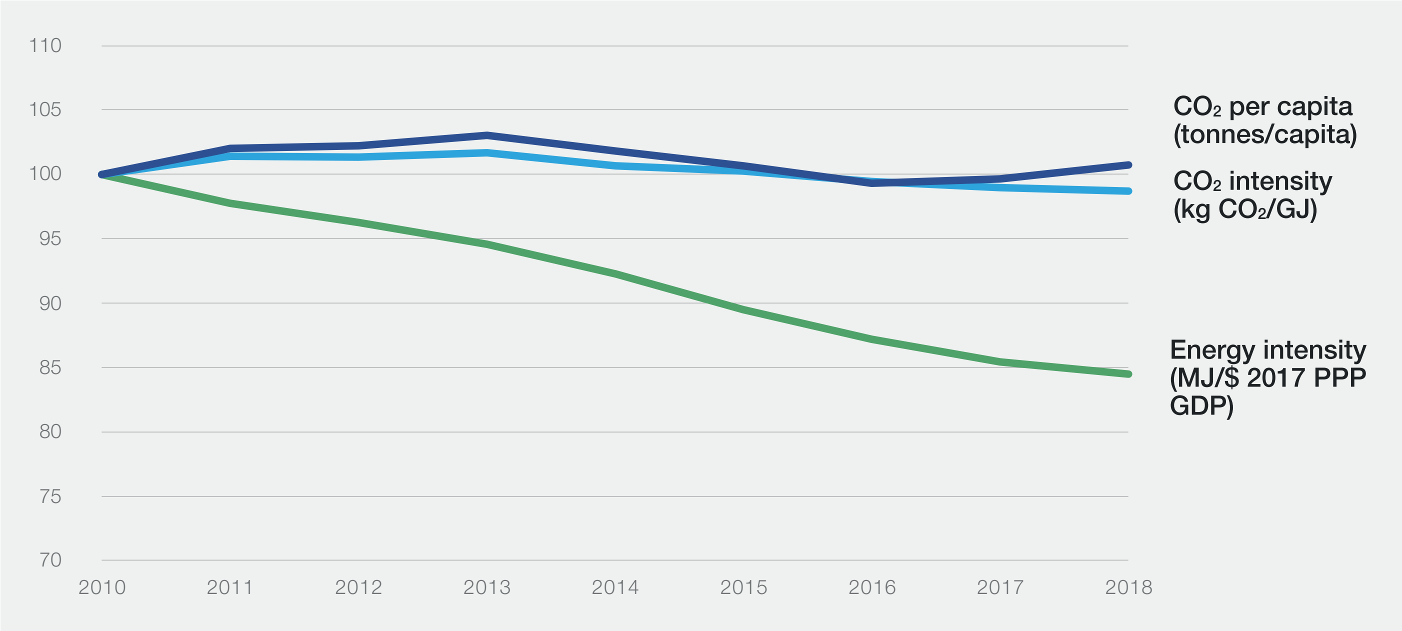


Figure 13: Environmental sustainability indicators – a tale of two intensities (2010 = 100)

on energy is vital, equally important for improvements in environmental sustainability is reducing the carbon intensity of energy use – measured in the ETI as units of CO_2 per unit of energy supply. Globally, the CO_2 intensity of energy use has remained broadly flat since 2010, suggesting a continued dependence on high-carbon energy sources and ongoing inertia from legacy energy infrastructure.

A regional view reveals significant variation (see Figure 14). CO_2 intensity has fallen in advanced economies and much of Europe due to a sustained reduction in the carbon content of energy production. This is mainly a

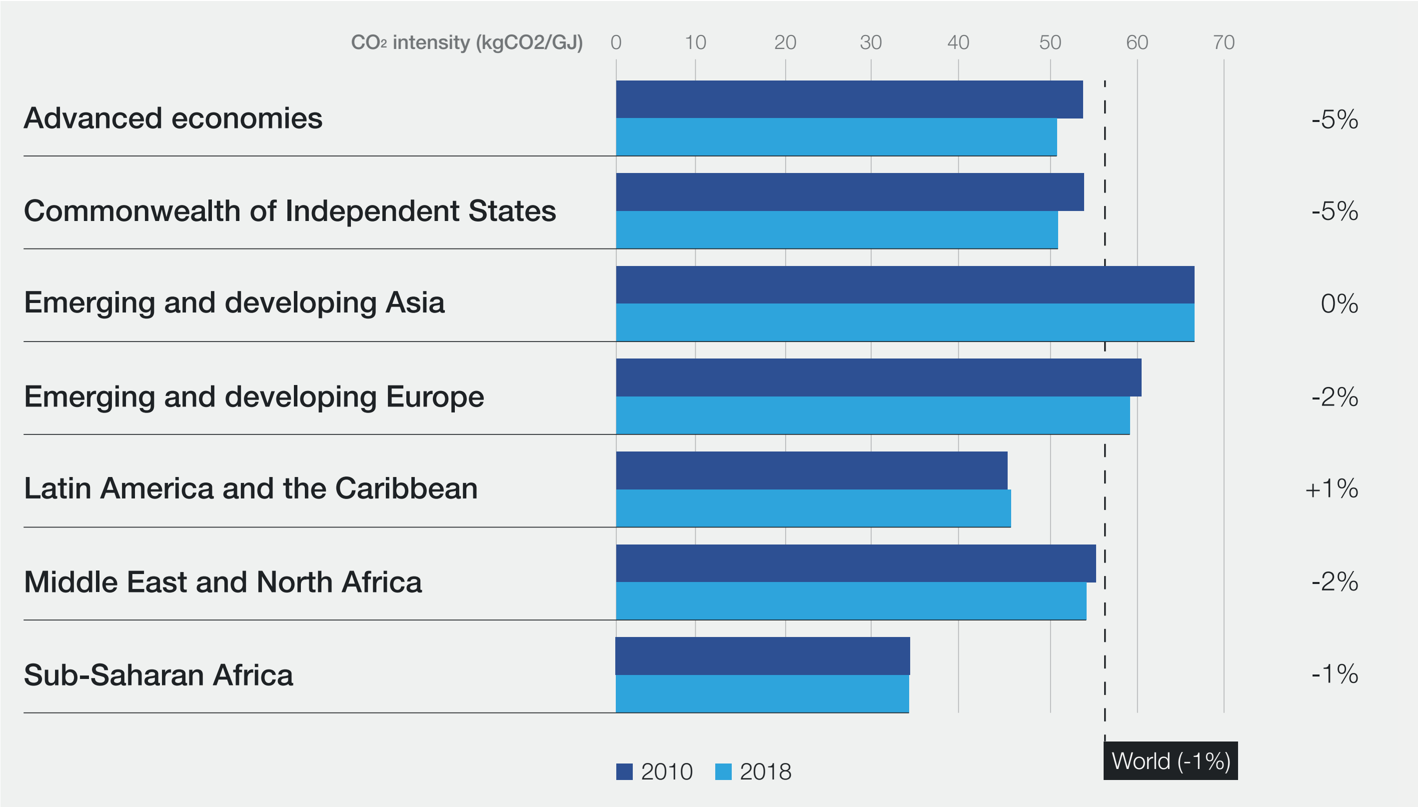


Figure 14: CO_2 intensity by region (kg CO_2 /GJ), 2010 and 2019

result of switching from coal to gas for power generation. However, CO_2 intensity is stagnant or rising in regions where energy demand is growing – in emerging Asia, Latin America and Sub-Saharan Africa. This suggests that CO_2-intensive sources continued to fuel incremental demand over the past decade. Trends in per capita emissions support this conclusion. While absolute emissions in North America and Europe remain structurally higher than the rest of the world, CO_2 per capita is falling. However, CO_2 per capita has risen in regions where energy demand growth is the highest.

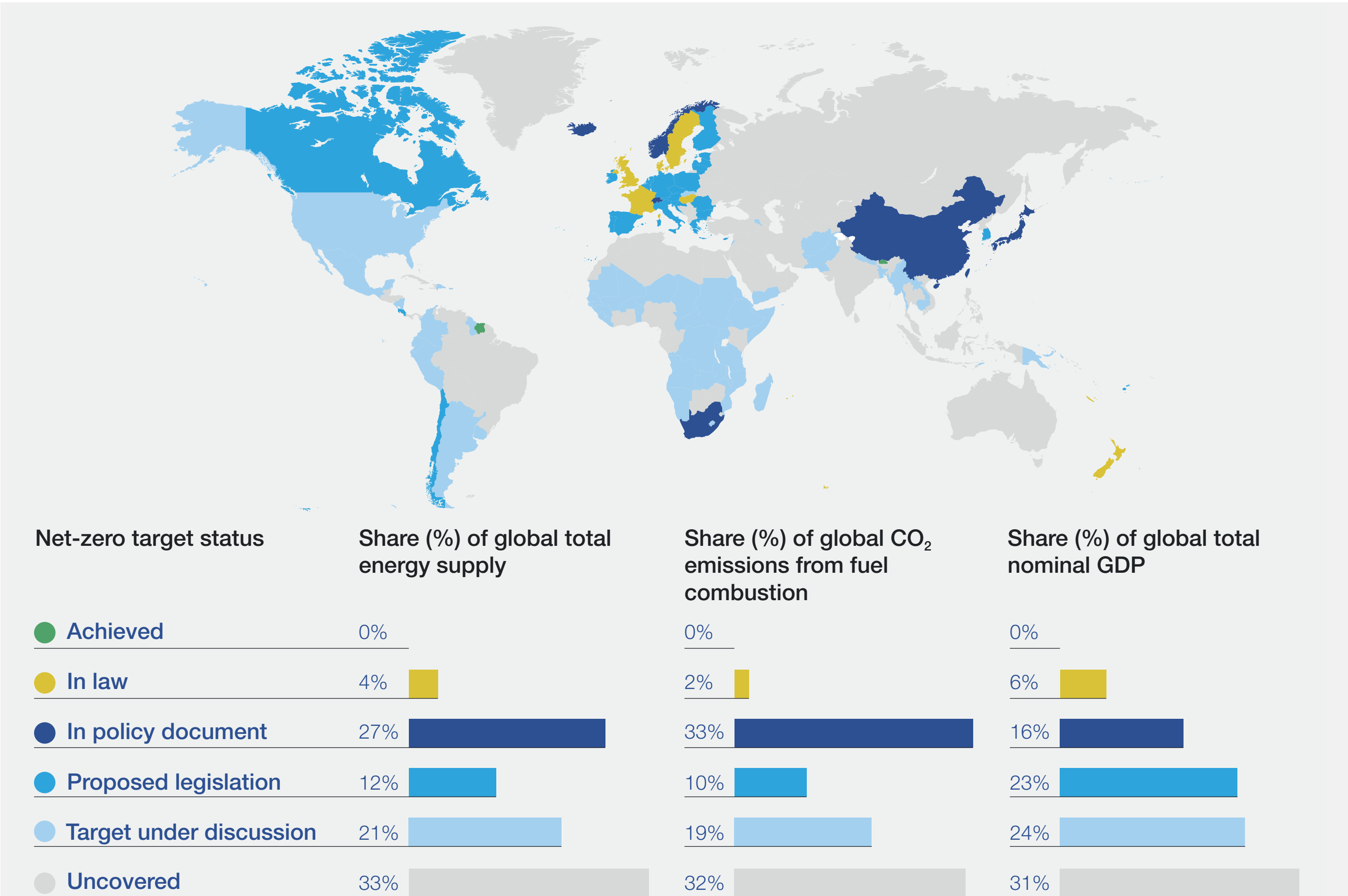
Boosting progress across these lagging variables, including in advanced economies where headway has been made, will be a crucial measure of success over the next decade. Countries should seek to lower the carbon content in energy production across all end-uses. More efforts are needed to transfer technology, provide access to finance, and foster international cooperation to enable developing countries to meet new demand growth with less CO_2 intensity than the pathway taken by developed nations.

Attention also needs to turn to cutting emissions intensity beyond electricity in other sectors such as transport, manufacturing and the built environment. Countries with highly energy-intensive industries, including oil and gas producers, can improve this dimension by reducing emissions intensity. In Canada, for example, the government has set new regulations that require the oil and gas sector to reduce its methane emissions by 40% from 2012 levels by 2025.[33]

TRANSITION READINESS

The energy system's ability to deliver on the imperatives described in the preceding sections depends on the presence of an enabling environment for energy transition, measured in the ETI framework by the transition readiness sub-index. Readiness for energy transition is determined by factors including stability of the policy environment and level of political commitment, investment climate and access to capital, consumer engagement, and development and adoption of new technologies.

While the average transition readiness score reached a high this year (54.7 compared to 53.5 in 2012), progress across dimensions shows a mixed picture. Data since 2012 show marked progress in the dimensions of regulation and political commitment and capital and investment, borne out by increased international commitment to climate action and growing levels of energy transition finance.[34] Progress is slower in other readiness dimensions,



Sources: Energy and Climate Intelligence Unit, International Energy Agency, World Bank

Figure 15: Status of countries' net-zero targets, 2020

including energy system structure, which tracks the transformation of a country's energy demand and sources of supply.

REGULATION AND POLITICAL COMMITMENT

Enhanced political commitment and improved regulatory support for the energy transition are encouraging. Last year saw a proliferation of net-zero announcements and targets. Now around 68% of the world's emissions from fuel combustion are covered by some type of net-zero target.[35] This compares with just 16% a year earlier. One of the most significant announcements came from China, with a policy mandate to achieve net-zero by 2060. However, this ratcheting up of ambition needs to be reflected in legislation, policy and regulation and supported by concrete roadmaps and milestones.[36]

CAPITAL AND INVESTMENT

The capital and investment dimension is another enabler showing a significant improvement over the past decade, primarily supported by improvements in access to credit and investment freedom levels. This lays the foundation for investments in the energy transition. Record flows of finance have been pouring into the energy transition, totalling \$501 billion of global investment in 2020, up from \$458 billion in 2019.[37] However, mature renewable energy technologies account for most of this investment, while other energy transition areas such as mobility, electrified heat, storage, and carbon capture and storage (CCS) account for a small proportion of the total investment.

Figure 16 shows that energy transition investment is concentrated in a handful of economies, with China and the United States (US) accounting for the large share of investments. However, investment outside the top 10 is growing steadily. Countries such as Vietnam, Kenya, Brazil, South Africa, and Chile have shown that a combination of the right enabling

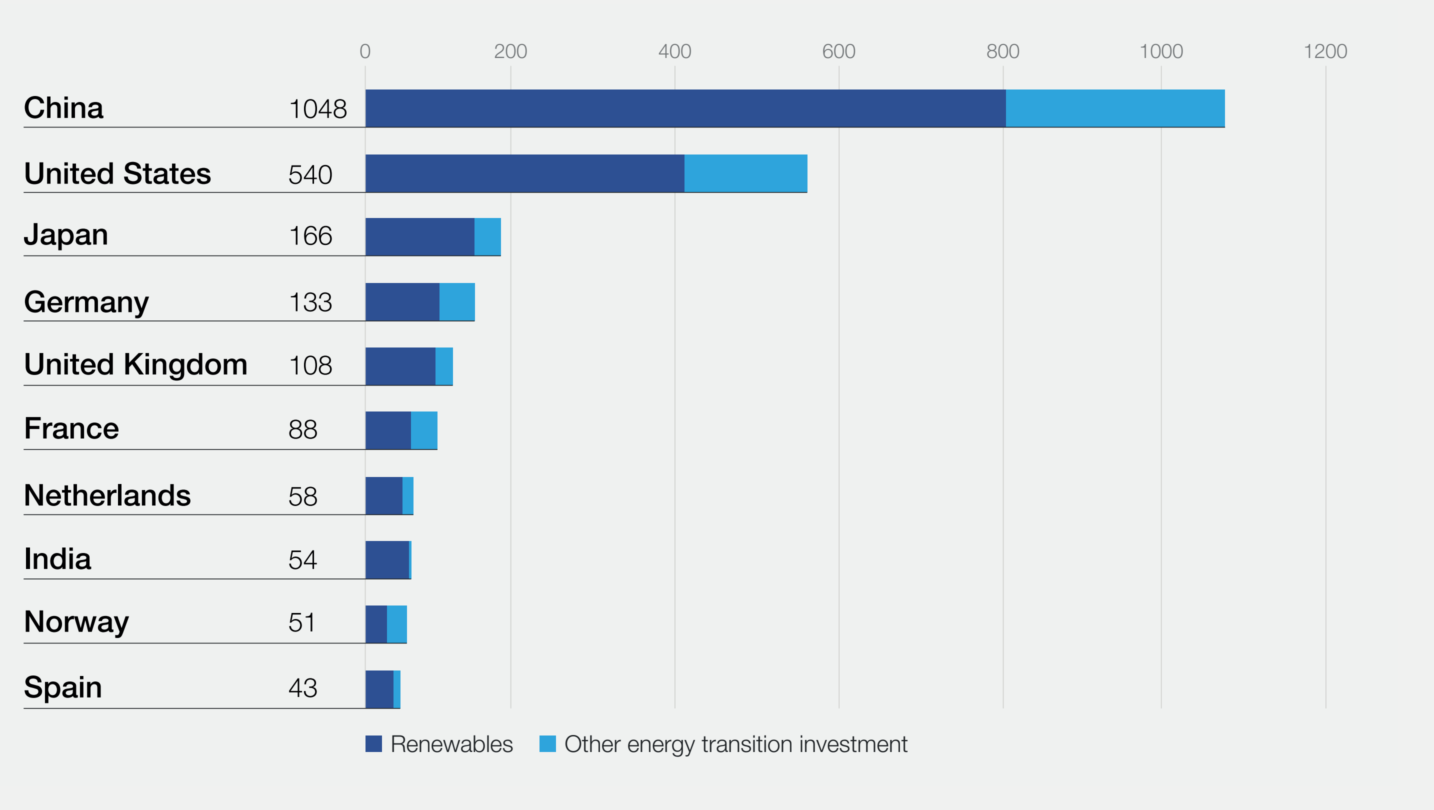


Figure 16: Global energy transition investment, 2016 - 2020 ($ billion)

policies, infrastructure, and better integration into global financial markets can record new investment levels. By enacting measures including deepening national capital markets, developing new risk management solutions and generating healthy returns from low-carbon solutions, countries can create a pipeline of bankable projects that will attract the capital needed to propel their energy transitions.

ENERGY SYSTEM STRUCTURE

In the next decade, political commitment and increased capital will need to translate into structural shifts in the energy mix. Progress has been made in renewable capacity and generation. The share of renewables in the global electricity mix grew from 18% in 2000 to 26% in 2019.[38] Much of this progress has been driven by solar and wind capacity additions. Solar and wind generation are increasing, with solar up 22% and wind up 12% between 2018 and 2019.[39] The latest estimates suggest that renewables have been resilient throughout the pandemic. As the world went into lockdown, the power mix shifted towards renewables due to depressed demand, low operating costs and renewables' priority access to the grid.

Decarbonising the rest of the energy sector is critical over the next decade. Achieving our climate goals will require electrification across other sectors of energy end-use, notably industries, HVAC (heating, ventilation and air conditioning) and transport. This means that renewables will need to meet approximately 80% of global electricity demand growth in the next ten years.

Recent progress in renewables is tempered by the view that coal's share in the electricity mix has been rising, not falling if Europe and the US are excluded. In advanced economies, coal generation appears to be in structural decline due to continued growth in renewables and coal-to-gas switching. In 2019, the most substantial declines in coal-fired power generation were in the EU, which saw coal use decline by 19% or 111 million tonnes, and in the US, coal use fell by 14% or 87 million tonnes. However, coal generation remains high and growing in many parts of the world. For example, in the Asia-Pacific region, coal consumption increased by 1.2% or 69 million tonnes in 2019.[40]

Moreover, while coal's share in the electricity mix globally has been declining, electricity generation from coal in absolute terms has been on an upward trajectory since 2010, despite a slight dip in 2019 (see Figure 18). New coal power plants have long operating lifetimes and can lock in future emissions for decades.

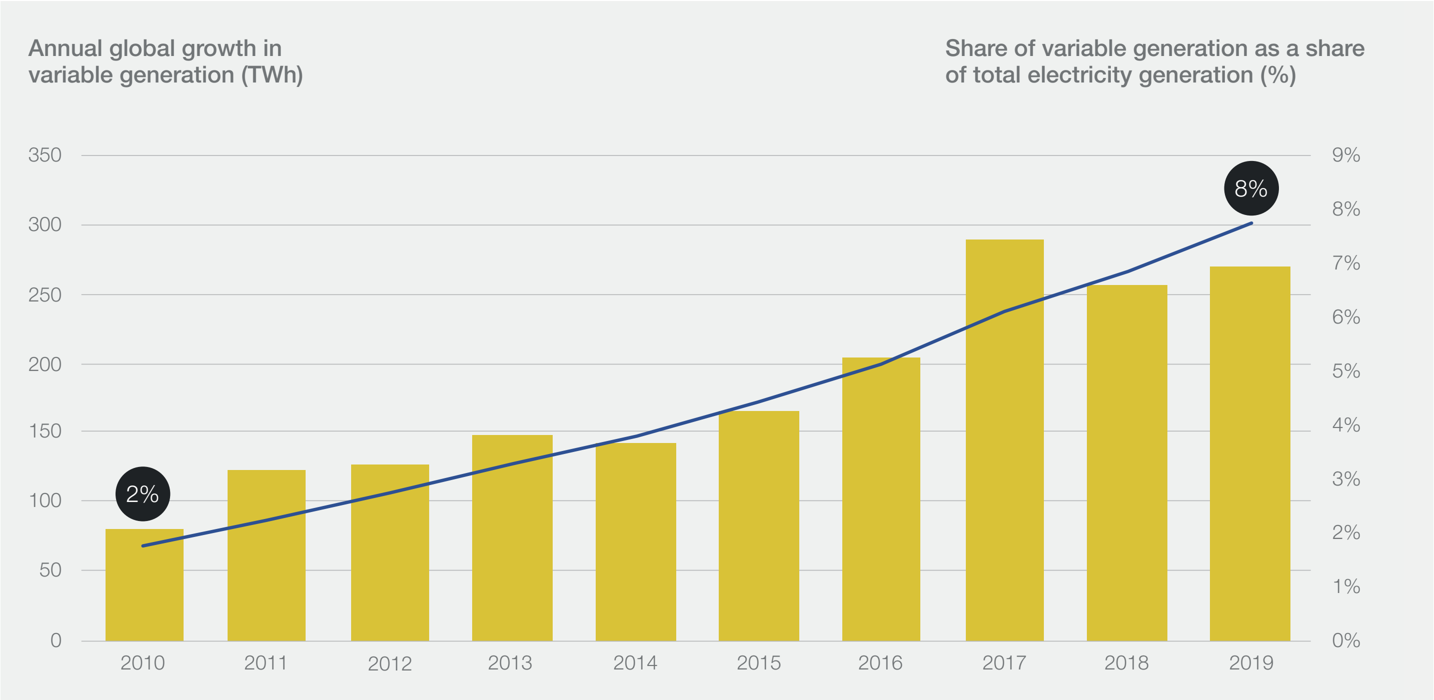


Figure 17: Change in the global variable generation, 2010 - 2019

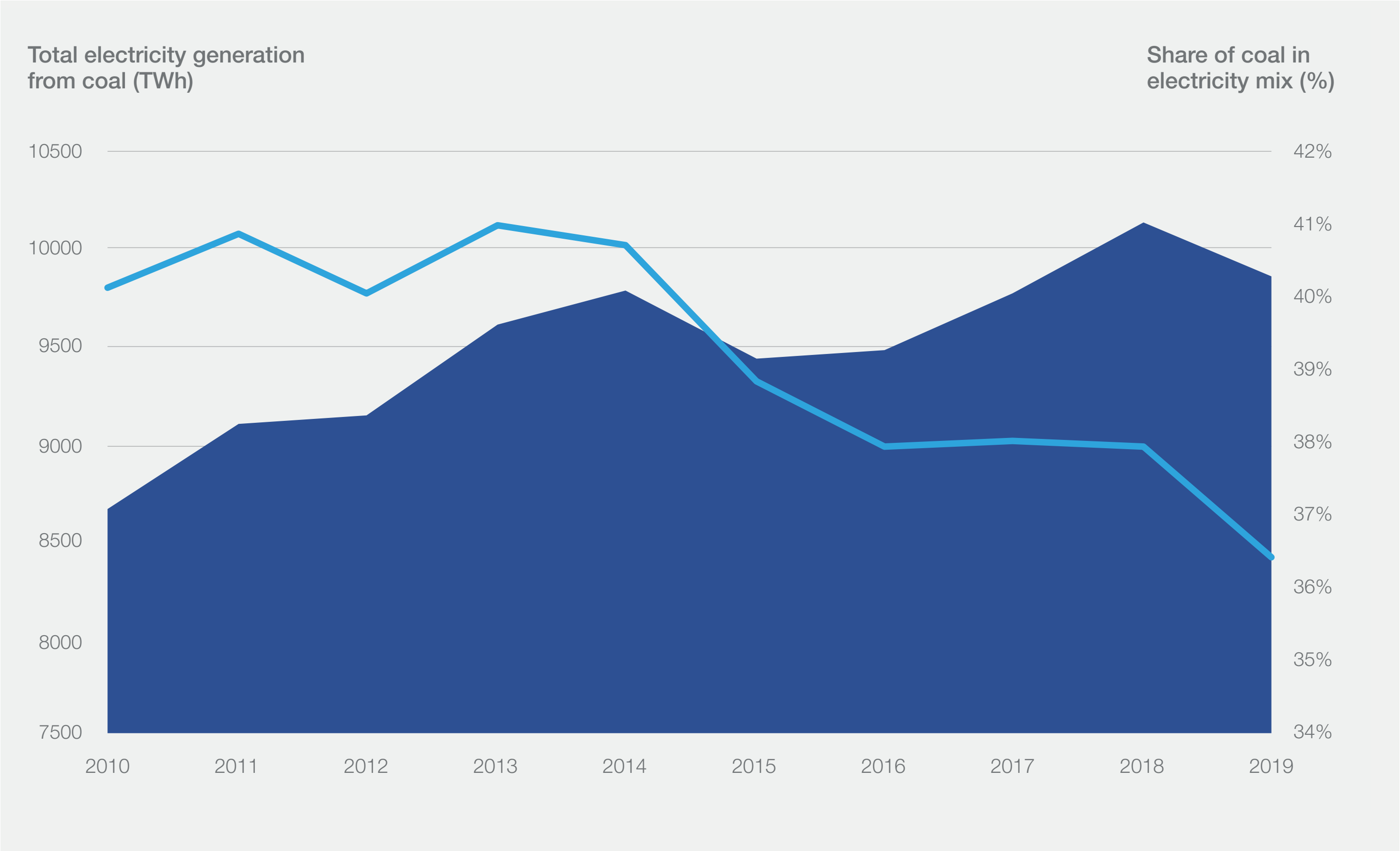


Figure 18 : Global coal generation vs share of generation, 2010 - 2019

Breaking the carbon lock-in will require early retirement of existing assets and revisiting the long-term viability of assets not yet in operation.

BUILDING RESILIENCE TO OVERCOME NEW RISKS

Despite growing momentum, progress in the energy transition requires further acceleration. For this reason, and considering the impact of the COVID-19 pandemic, it is critical to focus on the resilience of the energy transition. As the risk landscape evolves, the transition will fail to deliver the step-change required without building greater resilience.

Resilience is a holistic concept that embraces the enablers of transition readiness and cuts across the following dimensions:

- Societies and policy
- Energy systems and technologies
- Finance

This section looks at how each of these dimensions is impacted by heightened or new risks. We examine the implications for the energy transition. We analyse vital considerations and case studies for those seeking to embed resilience in the energy transition.

SOCIETIES AND POLICY

THE RISK LANDSCAPE As demonstrated by the COVID-19 pandemic, the negative impacts of major socio-economic disruptions fall most challenging on the most marginalised members of society. Climate change is no different. Inequality has been increasing globally, both between and within countries, and climate change

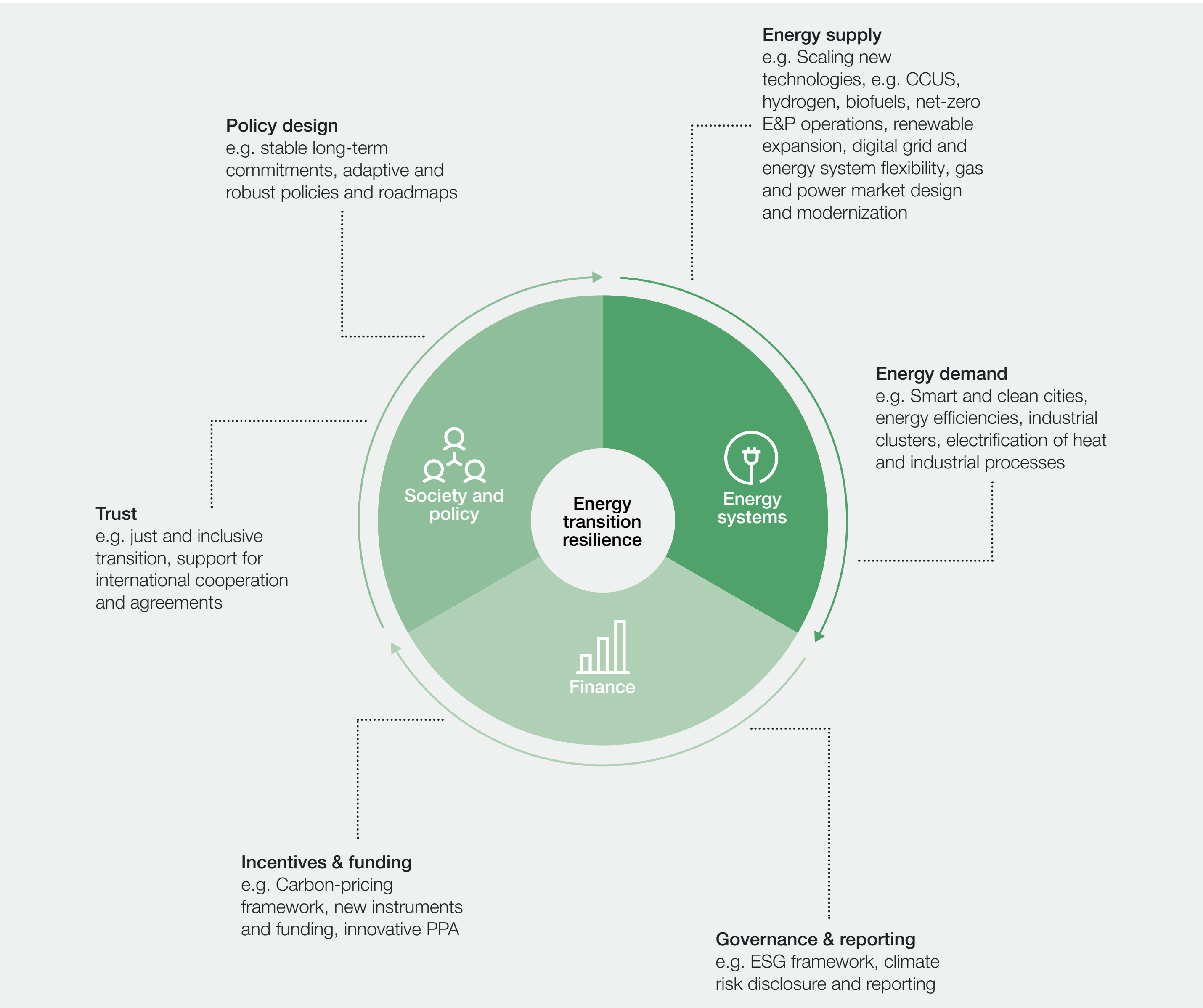


Figure 19: Energy transition resilience dimensions and illustrative mechanisms

is one of the contributing factors.[41] To be resilient, the energy transition will require the active participation of all sections of society. It must be rooted in every country's laws, politics, societies and patterns of consumer behaviour.

COSTS. The energy transition will not come without costs. Carbon taxes, removal of fossil fuel subsidies and levies on electricity bills could all add to the cost of electricity and fuels, leading to affordability challenges for some. Significant infrastructure investments will be required. The pandemic-related recovery packages drafted by governments worldwide provide a one-off opportunity to fund some of these investments. However, Vivid Economics and the Climate Action Tracker research suggests that recovery measures announced to date across the G20 may have a regressive environmental impact.[42]

WORKERS. An additional challenge comes from the potential impact of the transition on existing workforces. While it is estimated that renewable energy could employ more than 100 million people in the energy sector by 2050—boosting global GDP by 2.5%—these gains are not evenly distributed. Some countries and communities, especially those that rely heavily on fossil fuels, will lose out as a result.

CONSUMER BEHAVIOUR. Household consumption – through, heating, lighting, cooking and commuting – accounts for around two-thirds of global greenhouse gas (GHG) emissions.[43] Changes in behaviour – especially on energy efficiency, transportation, diet and responsible consumption – are proving increasingly challenging to lock in, given the varying consumer preferences and abilities to act that we see across different countries.

INTERNATIONAL COOPERATION. The energy transition requires collective commitment and international cooperation, but trust in the ability of countries to collaborate for the common good has been steadily eroded. This was highlighted by the COVID-19 crisis when many countries became more inwardly focused in their approaches. Examples of vaccine nationalism,[44] ranging from conditional subsidies to export controls, demonstrated the tension between international cooperation and competition when near-term national interests are at stake. International cooperation is also needed to create viable carbon markets. The effects of carbon taxes on trade and competitiveness require cooperation between governments and between companies and governments to ensure efficient and fair carbon pricing across the global economy.[45]

However, the acceleration of climate action and the shifting of trade flows away from fossil fuels to cleaner technologies could disrupt existing geopolitical alliances and reshape global power dynamics. An awkward transition is inherently more uncertain than one underpinned by stability and agreed to rules of engagement.

CONSIDERATIONS TO BUILD A RESILIENT TRANSITION

JUST TRANSITION. A prerequisite for resilience is to build a just transition – one that addresses environmental sustainability and provides decent work, enhances social inclusion and helps eradicate poverty.[46] Policymakers should prioritise policies and incentives to support economies, workforces and broader society as countries shift to low-carbon energy systems. This may take the form of fiscal transfers, expanded welfare and social protection, and labour market schemes such as reskilling and training to support affected communities. The EU's Just Transition Mechanism[47] is one example of how governments are looking to support affected communities and businesses and encourage them to take an active role in preparing for the new jobs and opportunities that will arise from the energy transition.

SYSTEM VALUE FRAMEWORK. Building resilience must also start with business leaders and policymakers concurrently evaluating the economic, environmental, social and energy system outcomes of potential energy solutions. One example of a framework to guide this approach is the system value framework developed by the World Economic Forum in partnership with Accenture and others. This quantitative approach shifts the political and commercial focus beyond cost to include value creation and provides a common agenda for stakeholder decision-making.

ENERGY SYSTEMS AND TECHNOLOGIES

THE RISK LANDSCAPE

The shifts within and across the energy supply chain, alongside the greater need for flexibility across increasingly diversified energy sources, will present new challenges and requirements for change.

MARKET REFORMS. A recent analysis of the European electricity market, completed by the World Economic Forum, shows that Europe could reach 60% annual penetration of wind and solar by 2030. At such levels, power market reforms increased demand-side participation, and significant changes to how the network operates will be needed as the grid transforms towards variable generation.

CYBERSECURITY. In the power sector, energy companies are increasingly digitalising their operations to optimise the end-to-end value chain. More digitalisation means higher exposure to cyber-attacks. The number of identified groups targeting the energy sector has risen from 87 in early 2015 to 155 by the end of 2019.[68] Grid infrastructure, nuclear plants, gas pipelines, and safety systems for oil production operations have all been the target of cyber-attacks in the past five years.

RARE MINERALS. The production of minerals such as graphite, lithium and cobalt could increase by nearly 500% by 2050[69] to meet the growing demand for clean energy technologies. These materials are generally produced in developing countries and sometimes in challenging environmental and social conditions. The scramble to acquire these minerals has resulted in a high concentration of resources in the hands of a few countries, increasing potential risks to timely supply.

DEEP DECARBONISATION. For industries that require higher energy density to function, such as heavy industries or heavy transportation, progress to significantly reduce carbon emissions has been slower to date. For example, despite the Paris Agreement taking effect in 2016, there was no emissions-related commitment from the shipping industry until 2018, when the International Maritime Organization (IMO) committed to a 50% reduction in emissions by 2050 (compared to 2008).[70]

INNOVATION RISK. Low-carbon technologies – including hydrogen and carbon capture, utilisation and storage (CCUS) – provide a potential path forward within the fossil fuel industry. The ability to scale each of the technologies depends on collaboration across sectors (and policymakers and financial institutions). No sector alone can fund and take on the risk of scaling these technologies. The increasing investment into industrial clusters, where these solutions can be scaled up, suggests a path ahead and speaks to the types of partnership required for success.

CONSIDERATIONS TO BUILD A RESILIENT TRANSITION OF ENERGY SYSTEMS AND TECHNOLOGIES

Building resilience in the transformation of our energy systems and technologies will require increased flexibility, greater collaboration among and across stakeholders, and a behaviour change.

REGIONAL INTERCONNECTIONS AND INTEROPERABLE MARKETS. Cross-border, connected infrastructure can provide flexibility in demand/supply balancing. In 2020, 38% of the EU's electricity was supplied from renewables, making renewables a higher source of Europe's energy mix than fossil fuels.[71] Interconnections and increased interoperability of market design across Europe's national electricity markets have been central in enabling the continent to achieve this high share of wind and solar penetration while maintaining grid resilience and flexibility.

ENTSO-E – the European Network of Transmission System Operators for Electricity that represents 42 electricity transmission system operators (TSOs) from 35 countries across Europe – is tasked with continuously coordinating and evolving the EU's electricity grid system operations as the continent accelerates its clean energy transition and prepares for more distributed and variable resources added to the electricity network.

OPTIMISE NON-BUILD SOLUTIONS. An estimated 185 GW of electricity could be freed up by system flexibility and digitally-enabled intelligent demand response – roughly equivalent to the installed capacity of Australia and Italy combined. This would prevent the need for around $270 billion of investment in new electricity infrastructure – funding that could be redirected towards transition-linked opportunities instead.[72]

WEATHER-PROOF INFRASTRUCTURE. The energy transition journey is not entirely predictable. As experienced in Texas with the February 2021 winter storm, increasingly volatile climate events can lead to exceptional demand in combination with supply failures. Following diversions of funding for repairs and maintenance could starve investment in cleaner energy sources and lead to questions regarding short-term versus long-term priorities. Therefore, the resilience of the transition may require legacy energy assets to play a critical bridging role as the overall system transitions.

LOW-INTENSITY OIL AND GAS. Reducing the carbon intensity of the oil and gas industry core operations is needed to achieve shorter-term objectives while providing the platform for longer-term, more structural shifts. The largest share of the improvement of the potential emission between now and 2050 will be due to actions that improve the performance of current core energy supply and demand assets.

SCALE-UP THROUGH COLLABORATION. New models of cross-industry collaboration can create the necessary solutions to support investment in low-carbon technologies and extend the possibility frontier for the transition. The Northern Lights project,[73] part

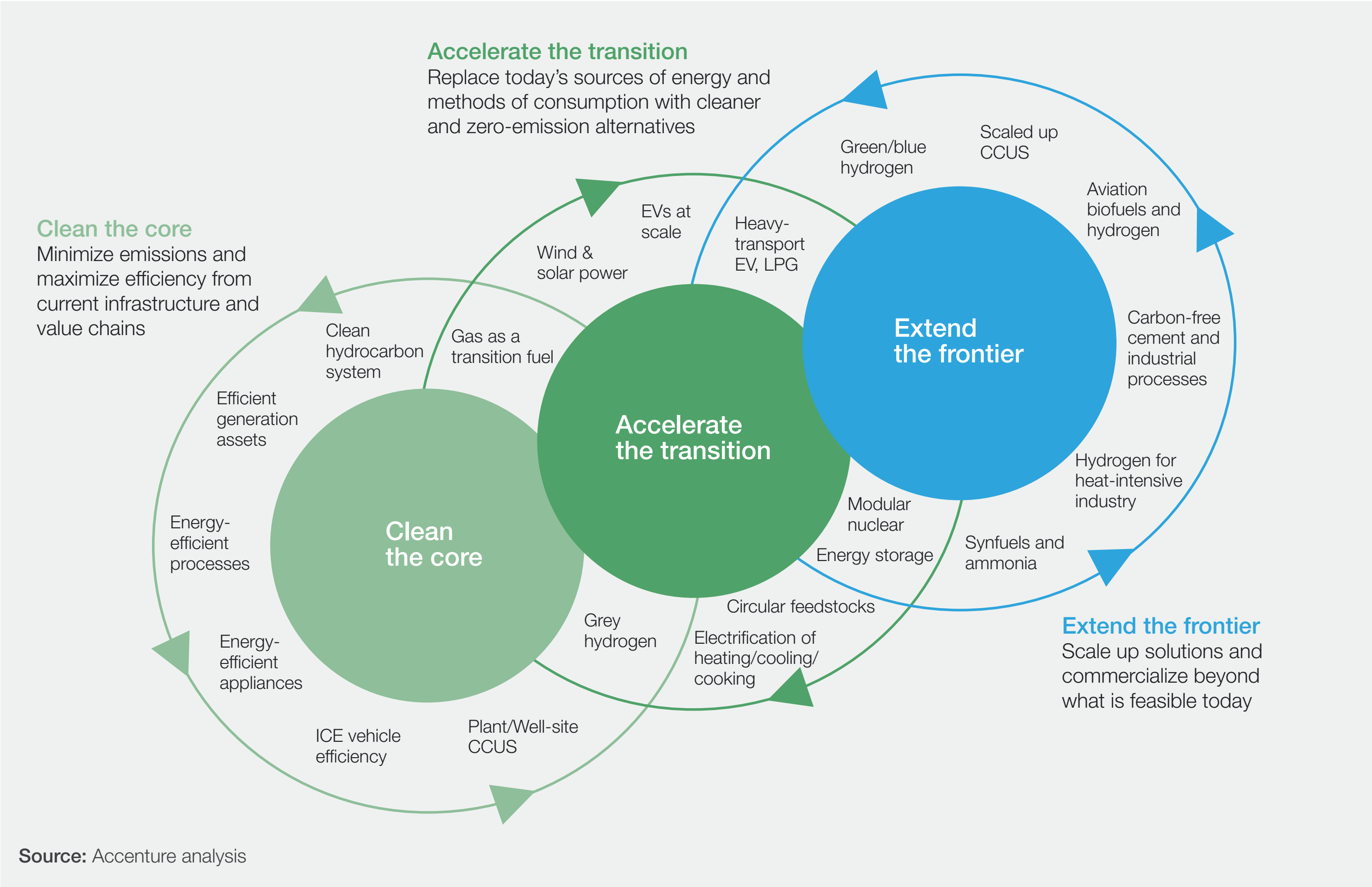


Figure 20: Three sets of actions to achieve the decarbonisation transition

of the Norwegian full-scale carbon capture and sequestration project, collaborates between Equinor, Shell and Total in partnership with heavy industries in the Oslofjord region. Northern Lights captures CO2 from the production of cement and waste-to-energy, transports it and stores it offshore under the North Sea.

Public-private sector collaboration and international cooperation will be crucial in the scaling up of hydrogen. Chile, for example, has set an ambition to become a leading green hydrogen exporter, with at least 5 GW of electrolysis capacity by 2025. Its National Green Hydrogen Strategy[74] identified cross-sector collaboration and international cooperation—especially in common standard-setting and infrastructure planning – as crucial pillars for success. The imperative is to kick-start domestic production through public-private sector collaboration, particularly in areas such as ammonia, oil refining and mining.

FOCUS ON CITIES. Urban areas account for two-thirds of global final energy demand and 70% of global GHG emissions.[75] Today, 55% of the world's population lives in urban areas, which is expected to grow to 68% by 2050. Consequently, cities are a primary focus for the energy transition.

Building resilience into the transition of urban energy demand requires both technological and behavioural change. Best-practice examples include electrified mass-transit systems, intelligent power, intelligent meters, and smart buildings that feature automated systems for lighting- and climate control along with micro-generation and solar heating.

FINANCE

The absence of sufficient capital and investment supporting the transition remains one of the more significant risk areas. Hastening progress and rooting the energy transition for the long term will require a critical transformation in how and where investments are allocated.

THE RISK LANDSCAPE

Global investment in clean energy grew from $60 billion in 2004 to an average of $311 billion per year over the past decade.[86] Finance institutions are increasingly aligning their objectives to the Paris Agreement. Asset managers representing more than $9 trillion of assets under management (AUM) have launched the Net Zero Asset Managers Initiative.

They commit to support investing aligned with net-zero emissions by 2050. While welcome, the IPCC estimates that annual investments in clean energy and energy efficiency would need to increase by a factor of six by 2050, compared with 2015 levels, to limit warming to 1.5 ˚C above pre-industrial levels.[87] At the same time, IEA estimates show that investment trends fail to lead to a large enough reallocation of capital to support the energy transition.[88]

BEYOND POWER. Investments are concentrated in the power sector. Even though electrification will play a leading role in the transition, it is imperative to attract clean energy investment into steel and cement, heavy transport and HVAC to achieve our climate objectives.

Part of the reason finance to non-power sectors has lagged is the lack of scale in technologies and the difficulty in abating some industrial emissions. It is also due to the "crowding-out" effect created by headline wind and solar PV opportunities. However, the increase in net-zero commitments in Europe, China and Japan will force countries to put policies in place to support investments that address emissions outside the power sector.

EMERGING MARKETS. Insufficient investments are flowing into emerging markets. Despite making strides, far greater resources are needed in those regions where most of the growth in economies, populations, energy demand and emissions is expected. This year's ETI results continue to highlight the structural gap in carbon-related metrics, with CO2 intensity rising in regions such as emerging Asia and Sub-Saharan Africa, where energy demand is growing. This trend is driven by continued growth in coal power sector emissions.

CARBON LOCK-IN. Capital is still being channelled into energy assets that have long operating lifetimes, locking in future emissions. Breaking the carbon lock-in will require a new approach to investment in fossil fuels and, in some cases, the early decommissioning of existing assets. Limiting global temperature increase to 1.5 ˚C implies that a significant share of existing oil, gas and coal assets and reserves are outside the carbon budget.[89]

CONSIDERATIONS TO BUILD RESILIENT FINANCE TO SUPPORT THE TRANSITION

MORE DIVERSE FINANCE. To date, most of the finance for the energy transition has been attracted by tariffs and premium guarantees awarded by governments directly to project developers or through regulated bodies. Innovation in financial products and arrangements is required to increase the diversity of available finance and stimulate investment in clean energy.

Corporate power purchase agreements (PPAs) are long-term procurement contracts that give project developers and banks revenue certainty to invest in clean energy. The corporate PPA market is growing rapidly, although it is still primarily concentrated in the US and Europe. Recently, however, it has started to gain traction globally, in particular with large power consumers.

GREEN BONDS AND SUSTAINABILITY-LINKED BONDS.

Green debt issuance linked to sustainability has grown from around $1 billion in 2009 to $270 billion in 2020.[90] The Climate Finance Leadership Initiative suggests that sustainability bonds are helpful to fund the transition, particularly in more carbon-intensive sectors.[91] For example, in 2019, the international energy group Enel was the first company[92] to launch sustainability-linked bonds in US and European markets. Enel linked its sustainability strategy to the terms of general corporate debt, using a pricing mechanism that incentivises the achievement of ambitious sustainability targets within a pre-determined timeline. These instruments have since been recognised internationally, including the International Capital Market Association93 and the European Central Bank.[94]

PUBLIC SECTOR ROLE. Governments can also lead in deploying innovative financing solutions, such as "climate auctions" and regulatory standards mandating cuts in emissions. The World Bank's climate auction model, for example, is a performance-based mechanism to stimulate investment in projects that reduce GHGs. This model of climate auction was trailed by the Bank's Pilot Auction Facility, which hosted three auctions between 2015 and 2017, allocating nearly $54 million in climate finance with the potential to decrease over 20 million tons of CO_2e.[95]

Public sector finance will also have to take the lead in developing new technologies whose long R&D cycles are difficult to support on corporate timescales. Public budgets will be needed to support the commercialisation of technologies through subsidies or risk-sharing mechanisms like loan guarantees.

BANKABLE PROJECTS. In emerging economies, the key to increasing capital flows is to improve the bankability of infrastructure projects by allocating the risks fairly across all parties. The Asia Pacific Risk Centre[96] has created a set of bankability guidelines critical to unlocking international finance in emerging markets. These include appropriate covenants and funding structures, the presence of legal and economic recourse, thorough due diligence, a robust right to payment, and well-structured concession rights. Standardising contracts, so they reflect leading international practice on key bankability dimensions can reduce transaction costs, ease due diligence for investors and banks, and shorten investment cycles.

CONCLUSION

Analysis of the Energy Transition Index has shown encouraging progress on the energy transition over the past decade. But more progress is needed. Evolution in environmental sustainability remains uneven and insufficient, while progress on other dimensions such as economic growth has been mixed. Whether caused by COVID-19 or the climate, recent disruptions have challenged the resilience of the energy transition. As energy systems become more variable, distributed and digitalised, new risks threaten the reliability, resilience and affordability of future energy. Understanding how to boost the energy transition's resilience and identify the levers required to do so will become increasingly critical during this decade of action and delivery.

Policymakers, business leaders and consumers all have a part to play in delivering a balanced, resilient transition that continues to speed progress regardless of disruptions and opposition. While there is no single approach, some common key themes are emerging across different geographies:

- Energy transition must be a just transition. This challenge is about more than simply energy system performance. The energy transition is a systemic transformation of entire economies and societies. It follows that transition measures must address equity, jobs, public health, access and affordability. Policymakers and investors must consider all these issues when evaluating and communicating their decisions to gain cooperation from a broad coalition of stakeholders.
- Electrification is necessary but not sufficient. Accelerating electrification and shifting to renewables will be critical to achieving the emission reduction goals of the next decade. But that alone will not be enough. Jump-starting the transition in other areas of the energy system, from heavy-duty transport to hard-to-abate industries such as cement and steel, is now necessary. We need to commercialise and scale up a wide range of emerging clean energy technologies to decarbonise all energy systems fully. We will also need to foster and fund innovation and collaboration across industry sectors.
- Collaboration between public and private sectors is vital to share risks, scale-up funding and de-risk investments made with multi-year and even multi-decade time horizons. This is crucial for emerging markets and new, clean technologies, where the economics are not yet competitive with more-established energy investments.

Looking ahead, two significant opportunities will have profound impacts for the coming decades. First, the unprecedented level of government stimulus to combat the social and economic impacts of COVID-19 could be targeted to build resilience in the energy transition and provide a near-term focus on energy transition. Second, the upcoming COP26 summit in November holds the potential to set the tone and trajectory for coordinated international action on climate change.

Developments in this decade will be crucial in resetting our economies and in our fight against climate change. Policymakers and private sector actors must work together and seize the opportunities to build the foundation for a resilient energy transition – one that ensures not only long-term sustainability but also delivers inclusive growth and long-term prosperity. wn

END NOTES

Megavolt Power in China

China has become the world's largest user of electrical energy and also the largest user of renewable energy, which includes solar energy, wind energy and hydroelectric energy. China however also remains the world's largest user of coal. This is a volatile situation which is currently undergoing change on a phenomenal scale.

COMPILED BY DUDLEY BASSON

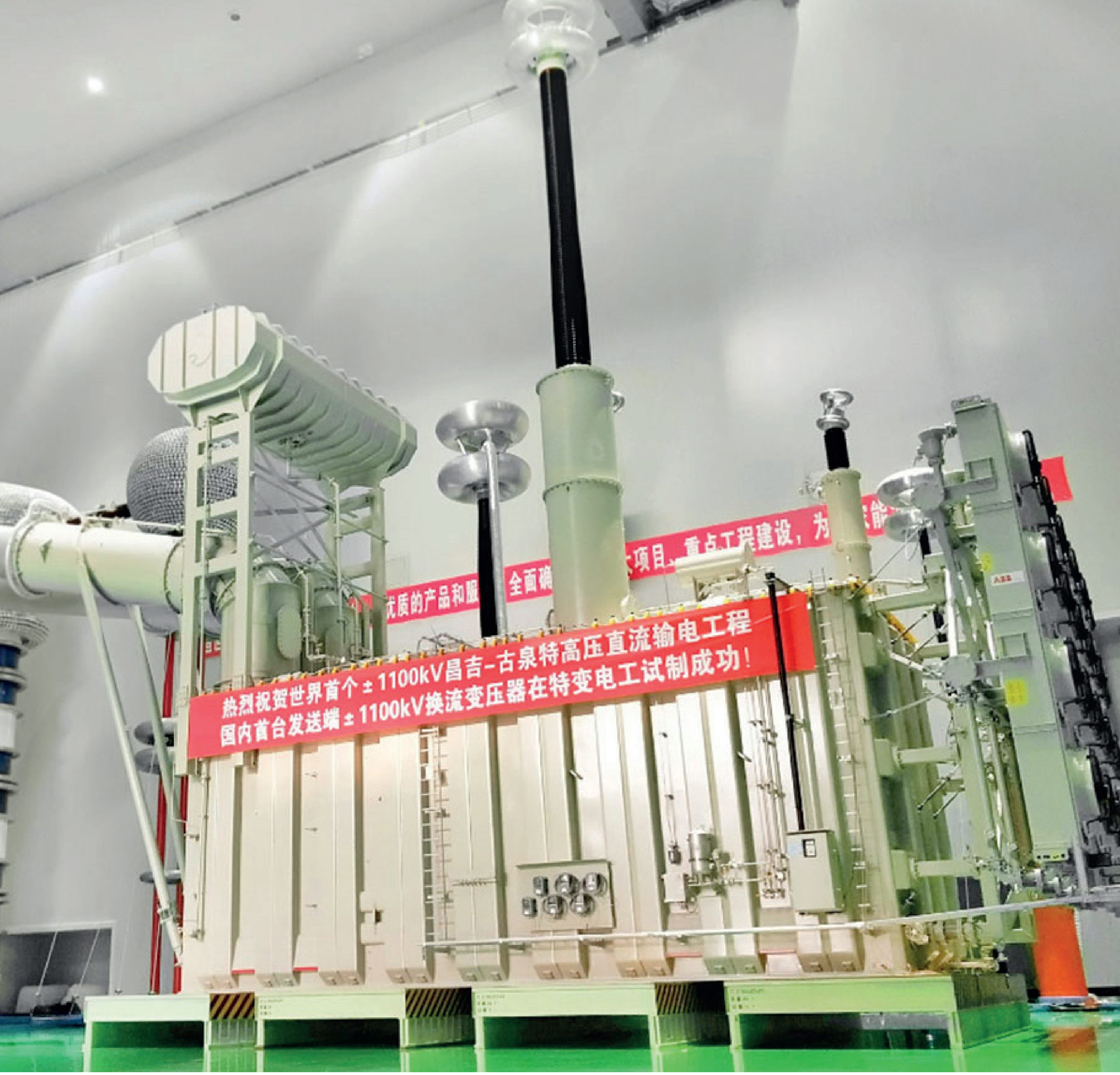
China has abundant resources of wind, solar and coal energy in the west of the country, however the population and industries are concentrated mostly in the east which is some 3000 km away making the cost of energy transport a major consideration in the distribution of power.

Coal is transported by rail to the power stations which are situated close to the coast and consumers, however the wind and solar electrical power must be carried the huge distance by UHV power lines. This has resulted in the most extensive UHV and EHV distribution on the planet.

China's power capacity figures for 2021 are given as:

Coal fired power:	1,09 TW
Non-fossil power:	1,12 TW
Global power projected for 2025:	8,03 TW

Nuclear power contributed 4,9% of China's electricity production in 2019, with 348,1 TWh. As of March 2019, China has 46 nuclear reactors in operation with a capacity of 42,8 GW and 11 under construction which will have a capacity of 10,8 GW. Additional reactors are planned for an additional 36 GW. Most of the nuclear power plants in



China are located near the coast and use seawater for cooling.

WATCH this video on China's energy megaprojects - Mar 2019 (49:04 mins.)

A quick guide to the video contents:

2:00 Gobi Desert. Blasting 38 m of rock coal cover using 1418 tons of explosive in 781 holes at 8 millisecond intervals to uncover a 30 m thick coal seam.

11:30 Power transmission – world's largest UHV network for transmitting power 3324 km from coal fired power stations using air cooling, reducing coal consumption in the east.

17:12 Undersea exploration for oil, gas and methane hydrate (fire ice) using a GPS stabilised ship with 400 ton crane, with load stabilised for ocean swell.

26:10 Hydroelectric dam construction with a 33-month continuous concrete casting.

32:00 Solar Tower array in Gobi Desert. 20 000 mirrors with computer tracking, heating molten salt for steam powered generation.

34:00 CSP 50 MW trough solar plant.

37:10 Wind turbines. Erection of offshore turbine.

41:20 Nuclear Power.

46:20 Nuclear fusion research.

WATCH: For the comprehensive (19 Chapters) Science Direct book on UHV Transmission Technology.

WATCH: The construction of the world's two tallest electricity pylons – 380 m (Taller than the Eiffel tower).

These form part of the 500 kV EHV line between Zhoushan's Jintang and Cezi islands, spanning a distance of 2656 metres. The pylons, completed in 2019, form part of a new power line project between cities of Zhoushan and Ningbo. (20:20 mins.)

UHV CIRCUITS IN CHINA COMPLETED OR UNDER CONSTRUCTION – EHV CIRCUITS (UNDER 765 KV) ARE NOT SHOWN. AS OF 2020, THE OPERATIONAL UHV CIRCUITS ARE:

NAME	TYPE	VOLTAGE KV	DISTANCE KM	POWER MW	YEAR COMPLETED
Jindongnan–Nanyang-Jingmen	AC	1 000	654	5 000	Jan 2009
Yunnan - Guangdon	DC	±800	1 438	5 000	Jun 2010
Xiangjiaba–Shanghai	DC	±800	1 907	6 400	Jul 2010
Jinping – Southern Jiangsu	DC	±800	2 059	7 200	Dec 2012
Huainan–Zhejiang Shanghai	AC	1 000	2×649	8 000	Sep 2013
Nuozadu - Guangdong	DC	±800	1 413	5 000	May 2015
Hami – Zhengzhou	DC	±800	2 210	8 000	Jan 2014
Xiluodu - Zhejiang West	DC	±800	1 680	8 000	Jul 2014
Zhejiang North - Fuzhou	AC	1 000	2×603	6 800	Dec 2014
Huainan–Nanjing–Shanghai	AC	1 000	2×780		Nov 2016
Xilingol League - Shandong	AC	1 000	2×730	9 000	Jul 2016
Lingzhou - Shaoxing	DC	±800	1 720	8 000	Sep 2016
Inner Mongolia West - Tianjin	AC	1 000	2×608	5 000	Dec 2016
Jiuquan–Hunan	DC	±800	2 383	8 000	Jun 2017
Shanxi North–Jiangsu	DC	±800	1 119	8 000	Jul 2017
Xilingol League - Shengli	AC	1 000	2x236.8		Aug 2017
Yuheng–Weifang	AC	1 000	2×1050		Aug 2017
Xilingol League–Jiangsu	DC	±800	1 620	10 000	Oct 2017
Zhalute–Qingzhou	DC	±800	1 234	10 000	Dec 2017
Shanghaimiao–Linyi	DC	±800	1 238	10 000	Dec 2017
Dianxi-Guangdong	DC	±800	1 959	5 000	Dec 2017
Zhundong–Wannan	DC	±1 100	3 324	12 000	Sep 2019
Shijiazhuang–Xiong'an	AC	1 000	2×222.6		Jun 2019
Weifang-Linyi-Zaozhuang-Heze-Shijiazhuang	AC	1 000	2×823.6		Jan 2020
Mengxi-Jinzhong	AC	1 000	2x304		Oct 2020
Qinghai-Henan	DC	±800	1 587	8 000	Dec 2020
Wudongde-Guangxi-Guangdong	DC	±800	1 489	8 000	Dec 2020

UHV LINES UNDER-CONSTRUCTION OR IN PREPARATION ARE:

NAME	TYPE	VOLTAGE KV	DISTANCE KM	POWER MW	YEAR STARTED
Zhangbei-Xiong'an	AC	1 000	2×319.9		Apr 2019
Zhumadian-Nanyang	AC	1 000	190		Mar 2019
Nanyang-Jingmen-Changsha	AC	1 000			In prep
Shanbei-Hubei	DC	±800	1 137	8 000	Feb 2020
Yazhong-Jiangxi	DC	±800	1 711	8 000	Sep 2019
Baihetan-Jiangsu	DC	±800	2 172	8 000	in prep
Baihetan-Zhejiang	DC	±800	2 193	8 000	Dec 2020
Baihetan-Zhejiang	DC	±800	2 193	8 000	In prep

The Baihetan dam, currently under construction on the Jinsha River straddling the border of Sichuan and Yunnan provinces, with an output of 16 GW, is set to become the world's second-largest hydropower station after the Three Gorges Dam once it is fully completed in 2022.

WATCH: a video of daredevil power line workers (11,05 mins.)

WATCH: a comment on China's overcapacity and underutilisation of renewable energy – Jun 2016.

READ : An excellent technical paper on UHV transmission.

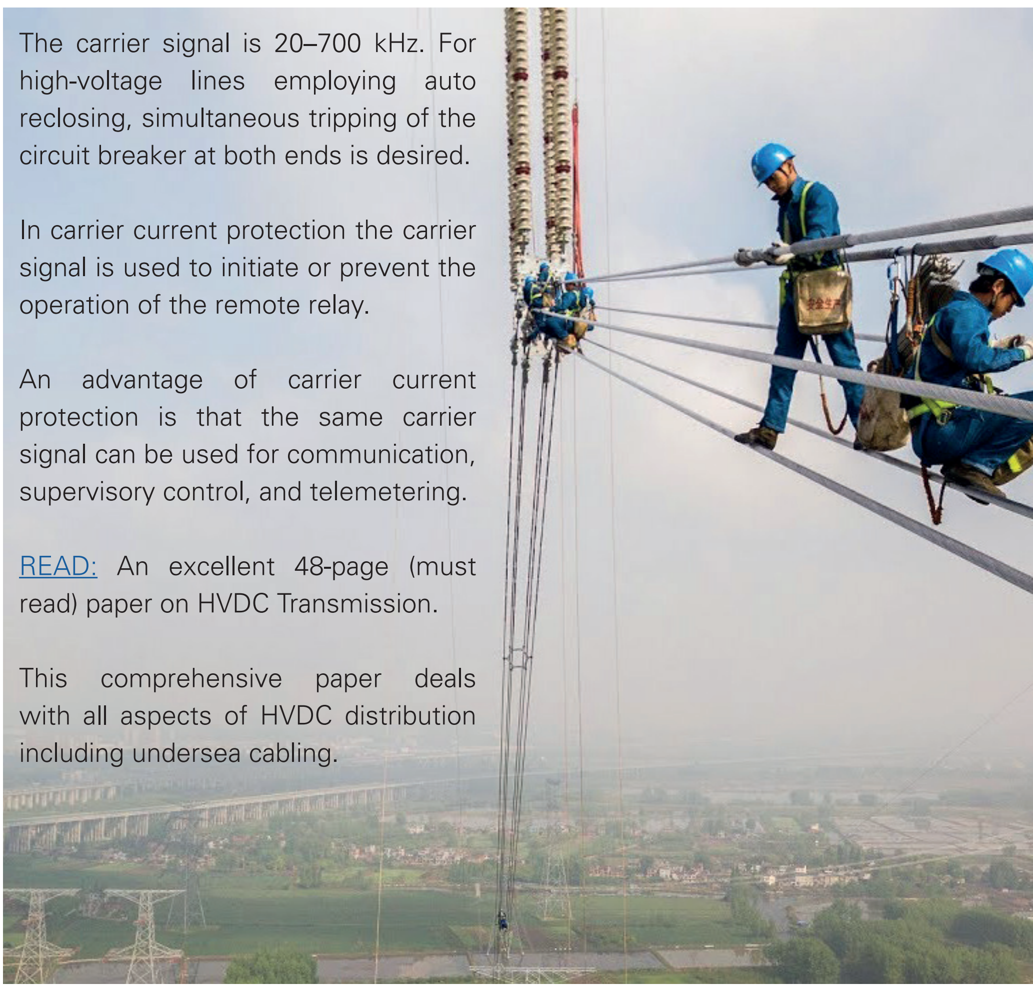
HIGH OR LOW VOLTAGE?

Symbols for voltage levels are not internationally standardised, varying between countries and also as applied to alternating current and ripple free direct current. The values given here are typical for alternating current in western countries.

READ: For further information.

EHV and UHV power transmission lines are widely protected by carrier current protection. Using this method, a high-frequency carrier channel directly coupled to the power line is employed.

ELV	Extra Low Voltage	Less than 50 V
LV	Low Voltage	50 V – 1000 V
MV	Medium Voltage	1 kV – 100 kV
HV	High Voltage	100 kV – 345 kV
EHV	Extra High Voltage	345 kV – 765 kV
UHV	Ultra High Voltage	Above 765 kV



The carrier signal is 20–700 kHz. For high-voltage lines employing auto reclosing, simultaneous tripping of the circuit breaker at both ends is desired.

In carrier current protection the carrier signal is used to initiate or prevent the operation of the remote relay.

An advantage of carrier current protection is that the same carrier signal can be used for communication, supervisory control, and telemetering.

READ: An excellent 48-page (must read) paper on HVDC Transmission.

This comprehensive paper deals with all aspects of HVDC distribution including undersea cabling.

Construction of the $5,9 bn UHV DC (1,1 MV 12 GW 10,9 kA) Changji-Guquan (Zhundong–Wannan) power line was completed in 2019.

This 3 324 km line will allow more renewables to be developed in Qinghai and Gansu provinces and deliver the electricity all the way to Henan province in central China where it will reduce coal generated power and pollution in populated areas. This project is expected to reduce the annual coal consumption by power plants in east China by 38 million tons per year.

THE THYRISTOR BREAKTHROUGH

The thyristor is the most prominent single device that has made modern high voltage DC power possible. The more senior amongst us will not find thyristors mentioned in their early text books. This is a transistor type device with latching properties. The thyristor was proposed by Shockley in 1950 and developed by GE engineers, which appeared in 1956.

A thyristor is a solid-state semiconductor device with four layers of alternating P- and N-type materials. It acts exclusively as a bistable switch, conducting when the gate receives a current trigger, and continuing to conduct until the voltage across the device is reversed biased, or until the voltage is removed. Thyristors are particularly useful, as a relatively small device can handle large voltages and currents.

Huge banks of water cooled thyristors can be seen in valve halls, suspended above floor level to protect them from seismic activity. Thyristors are used for both rectifying from AC to DC and inverting from DC to AC. Twelve-pulse thyristor circuits are commonly used.

The standard six pulse rectifier causes a harmonic Fourier spectrum consisting of the 5th, 7th, 11th, 13th, 17th, 19th, 23rd… harmonics. The 12-pulse converter requires two

3-phase sources which are spaced apart from each other by 30 or 150 electrical degrees.

One of the first EHVDC power lines to use thyristors from its inception was the Cahora Bassa system supplying 1,92 GW from Moçambique to South Africa. This 533 kV, 1420 km line was constructed from 1974 to 1979. The thyristors are grouped into eight 133 kV six-pulse bridges. The original thyristors were mounted outdoors and were oil immersed for both insulation and cooling. The power line runs through inaccessible terrain, so it is mostly built as two monopolar lines 1 kilometre apart. In case of a single line failure, transmission with reduced power is possible via the surviving pole and return through the earth.

The Cahora Bassa system has had an eventful history.

READ: For more information on thyristors

READ: For sample thyristor circuits and wave forms.

An early means of producing high voltage DC was developed in 1889 by Swiss electrical pioneer René Thury (1860-1938). This was an electro mechanical method consisting of a series of DC generators which

Suspended twelve-pulse ABB thyristors in the valve hall at Haywards in the New Zealand HVDC Inter-Island scheme (The two transformer bushings can be seen on the right) added the voltages of the machines together, which became known as the Thury system. The generators were connected in series to match the loads which were also connected in series.

Thury made huge contributions to electrical engineering.

- 1889 first station at 6 kV supplying Genoa from Gorzente River hydro turbines.
- 1897 in La Chaux-de-Fonds (14 kV)
- 1899 between St-Maurice and Lausanne (22 kV 3,7 MW)
- 1906 Lyon-Moutiers project (final capacity: 20 MW 125 kV 230 km)
- 1911 Metropolitan Electric Supply Company, London, 100 A, 5 kV generators.

An interesting feature which can be added to overhead power lines is the wrapping of fibre optic cables to the conductors and ground wires. This has been in use since the 1980s and the wrapping is done at the time of installation.

READ the following link for description of a Siemens 1,1 MV transformer. (Nov 2017)

WATCH: Siemens 1,1 MV converter transformer (5,06 mins.) Nov 2018

The most distinguishing features of an EHV or UHV converter transformer are its gigantic bushings. The purpose of these is to connect the EHV windings inside the transformer to the outside world. The usual terminal box simply will not do. The bushings are a matter of highly technical and specialised design. The bushings are required to project into the power/valve hall and the cooling system will remain outside. The UHV converter transformer is usually of a single-phase two-winding design with a single-phase four-limb core configuration where the central two (or three) limbs are fitted with windings and two side limbs free of windings act as the magnetic flux loop. The windings on the two main limbs are electrically connected in parallel.

Pulsed thyristor operation cannot produce smooth sinusoidal output – the wave form will be stepped resulting in a series of harmonics.

The DC side of the converter will require an inductive reactor for limiting fault currents, preventing resonance in the DC circuit and reducing harmonic currents. A separate harmonic filter will also be required on the AC side of the converter. Active harmonic filters can be a supplement to passive filters due to their superior performance. They can be installed on the DC side or on the AC side of the converter.

Fibre optic wrapping in progress - Image by JayareUK

1,1 MV 587,1 MVA Siemens single phase 800-ton converter transformer

ABB (ASEA Brown Boveri) UHV single phase converter transformer

WATCH: The video describing a 1,1 MV UHVDC transformer by ABB - Dec 2017 (1:12 mins.)

WATCH: The video for the transport of an ABB UHVDC transformer from Ludvika, Sweden to Porto Velho, Brazil. Jun 2012 (3,05 mins.)

For power lines with voltages of 33 kV and higher, suspension insulators are used.

A suspension insulator consists of a number of porcelain or glass discs connected to each other by metal links in the form of a string. The line conductor is suspended at the bottom end of the suspension string which, at the top, is secured to a cross-arm of the tower. Each disc in a suspension insulator string is designed for a voltage of 11 kV or 12 kV. The number of discs in a string depends on the working voltage, which in the case of

Photo: State Grid Corp. of China

This Beijing dispatch centre controls most of China's UHV lines and monitors renewable energy use.

READ: China's ambitious plan to build the world's largest super grid

State Power Investment Corporation (SPIC), one of the five large utilities in China announced its plans to develop around 300 projects in 2020, with a total value of $14,5bn. A major 90% of investments will be allocated to clean energy and new technology projects such as solar, charging stations and hydrogen. This investment plan also includes 3 GW of solar capacities to be realized in 2020.

The growing use of High Voltage Direct Current (HVDC) globally is due to the many advantages of DC transmission systems over AC transmission, including enabling transmission over long distances, higher transmission capacity and efficiency. Moreover, HVDC systems can be a great enabler in the transition to a low carbon electrical power system.

UHV is very large. The number may need to be increased depending on local pollution levels.

The suspension strings are fitted with arcing horns, top and bottom for protecting the line from lightning strikes and surge voltages. The cross-arm of the tower above the insulators also provides protection from lightning strikes.

The massive construction of UHV projects in China has reinstated confidence among the developers of under-construction wind and solar energy farms, as well as attracting interests of investors in generation projects and other related social investments. The UHV projects are also expected to have positive implications on operational renewable projects as the energy curtailments will go down in future.

Power converter facilities in Shanghai Fengxian Converter Station, Jan. 21, 2021. Photo: Wu Huiyuan/Sixth Tone

READ: ABB Review Special Report – 60 years of HVDC

The 1,1 MV 12 GW UHV DC Changji-Guquan power line was completed in 2019.
This 3324 km line has set new world records in terms of voltage level, transmission capacity and distance.

Station in Zhejiang province imports hydropower from Sichuan province as direct current and converts it to alternating current (photo credit: IEEE Spectrum)

Note the 4 rows of 6 converter transformers needed to handle the 800 kV DC power from Sichuan, 1653 km away. The long transformer bushings are fully inserted into the thyristor valve halls where the DC power is inverted to AC for input to the transformers. The UHV DC pylons can be seen in the foreground and the 3-phase AC pylons in the background. The pulsed thyristor power conversion requires considerable reduction of harmonics and resonances.

The numerous Sichuan Hydroelectric power stations produce some 31 GW.

The technological development in solid-state devices, converter topologies and control techniques will continue to improve the attractiveness of DC transmission systems. Regardless of whether AC or DC, there will always be a need to transform the voltage to the optimum level for transmission and distribution, based on the distance and power transmitted.

The cost, efficiency and reliability of modern transformers means that the grid of the future is most likely to be a hybrid AC/DC system with more DC being deployed and embedded in AC systems. There is already research on DC transmission, not only at the EHV and UHV, levels but also MV and LV levels. At LV levels the need for AC remains essential however for the widespread use of distribution transformers and the ubiquitous use of single and 3-phase induction motors, lighting and appliances. wn

A CENTURY OF CIRCUIT BREAKERS - WHERE TO NOW?

It is around 100 years since the first patents were filed for Westinghouse's humble circuit breaker concept in the USA. This was followed soon after by Heinemann Electric; both companies were cited in the USA at the time.

Westinghouse filed for the TM, thermal magnetic principle and Heinemann somewhat later for the HM, hydraulic magnetic principle.

BY | KEVIN FLACK | MSAIEE (RET)

After the patents lapsed, these companies and others produced valuable protection equipment from the early days of electrification. The circuit breaker held some advantages over the only other technology of the time, the mighty fuse. They addressed this need for decades, with the only fundamental changes being the modernisation of their ranges as the industrial landscape changed as machinery and primarily as plastic development occurred.

In South Africa, these devices were eventually made locally by Fuchs Electrical Industries and Murray Manufacturing, later to become Heinemann Electric.* Both product lines existed alongside the front sizing 57mm long and 25.4 mm wide; the sizing was based on the US non-metric system. The mounting of the Fuchs product used the same US system and the Heinemann a virtual copy but substantially bigger in line with their longer products.

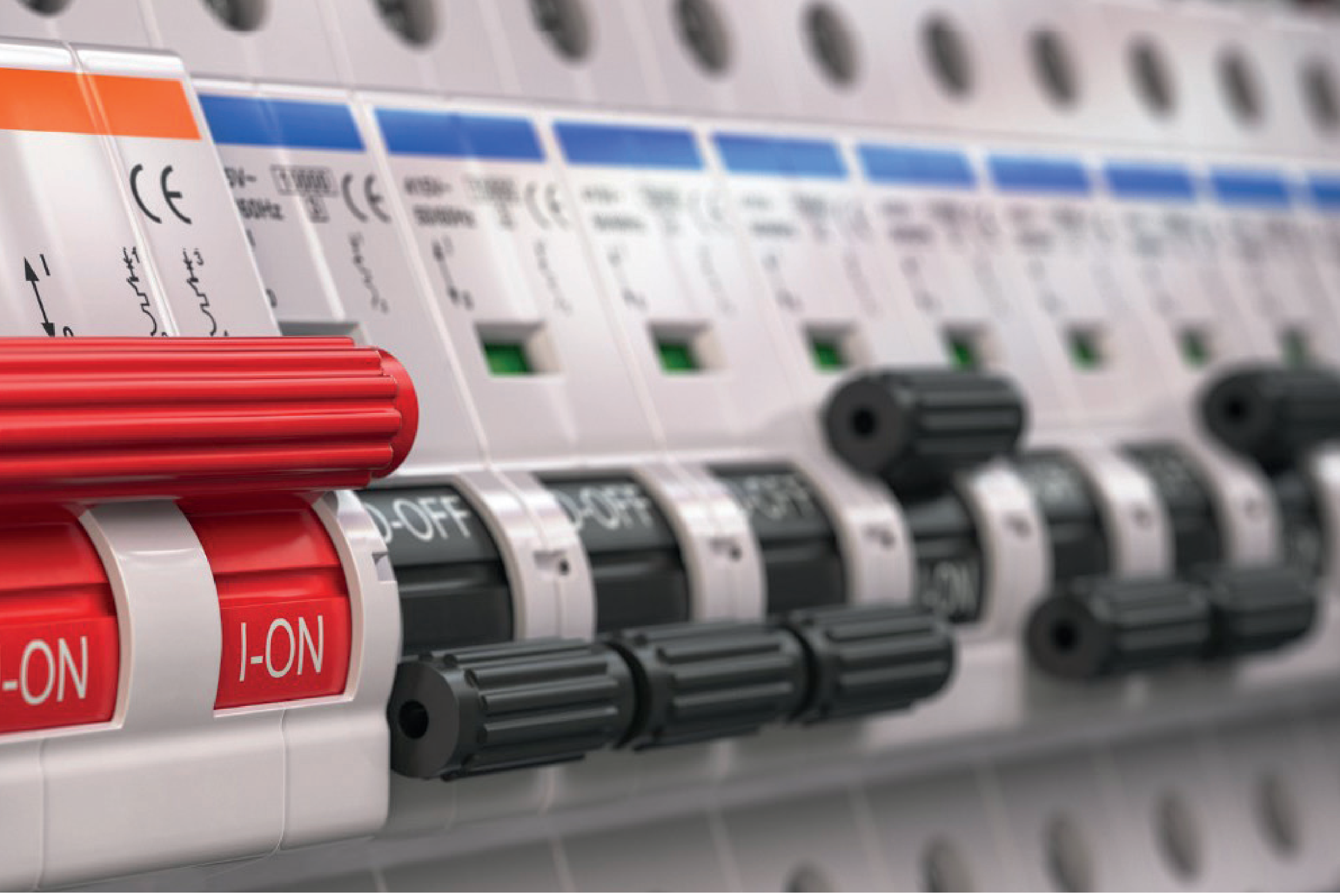
The standardised European DIN rail, smaller profile (metricated) arriving on the market around the mid-1960s. These also are readily identified by the light grey colour vs the older black standard. The significant difference between these two local players would again be the technology employed. However, the bimetal principles did have some problems at the low Amp levels, so many TM manufacturers did dabble in the HM technology from time to time.

Over time, the main challenges were developing distribution products to cope with the dramatic increase society placed during worldwide growth. Particular types were developed for use in equipment when needed.* Some of the manufacturers specialised in these products exclusively.

This existed for a long time before there was some development into electronic technology. When the tube was invented, this was not applied as costing and sizes are not supported in their ideal. The earth leakage breaker was also introduced once electronics became available, this being one of the circuit breaker milestones to date.

The rapid growth in the electronic circuit breaker has been most dominant in the MCCB front as the cost impact was more easily absorbed. There are many options offered with electronic designs with as can be seen with the cell phone with a host of additional features far beyond the original scope of design.

The electronic design can offer an accuracy never imagined in these early patents for sure. They can add to the primary curves options such as phase fail, phase loss, over/under voltage/ current, communication outputs, remote controls, and maybe many more. Limitation really by market demand and size of your purse!



THE FUTURE?

I am sure there are many meetings held in the boardrooms around the planet where the dusty old crystal ball is consulted in the way forward for circuit breaker manufacturers.

As unquestionably, as technology has impacted all our lives, it must eventually reach the electrical industry too?

There have been patents already filed that make use of semiconductor materials to switch current ON/OFF. This is so close to the electronics and controls of today as to drive a shiver through many a board member for sure.

The primary current problem with this new technology must be the relatively large short circuit currents that require control. The energy levels are massive in comparison to the power consumed. All three of the older technologies employ somewhat similar and relatively simple mechanicals. This is somewhat independent of the inverse tripping techniques in any event.

Whether this new-fangled system will follow on is to be seen? Voltages are also an issue to some extent but probably far easier to overcome.

Here is something to note: quite a large portion of the electrical load occurs at some low level, e.g. 12V and lately 5V. Primary electronic use demands DC as well!

One can already see that the humble wall socket can provide the 5VDC for local connection as an inbuilt USB socket.

Just as there was confusion in the early years which would survive AC or DC and the famous Beta/VHS saga society stands again at the electrical crossroads.

There is no doubt that there will be significant changes in the coming years, mainly on the domestic side, where more intelligent controls can be deployed.

Maybe these domestic panel boards will be multi-voltage controlled with innovative type control all in instant comms with the all-powerful cell phone of the future?

There is wi-fi/cell phone controlled MCB's entering the domestic market, and even on the local front, there is much activity in this direction.

I certainly do not have complete insight into what the humble circuit breaker will evolve to in the next 50-100 years, but they will be significantly different from today's units!

Exciting times for our grandchildren! wn

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DATE	TITLE
07/06/2021	Technical Report Writing
08/06/2021	Enlit Africa - The Digital Event
08/06/2021	An Optimisation-Driven Declarative Framework & Its Power Applications
08/06/2021	Photovoltaic Solar Systems
09/06/2021	Incident Investigation and Root Cause Analysis
09/06/2021	5G Webinar Series - 5G Applications
10/06/2021	Lightning Protection: right and wrong
10/06/2021	Earth and Lightning Protection for Engineers
17/06/2021	OHS Act
17/06/2021	Cable Jointing, Termination and Testing
22/06/2021	SAIEE Railway Chapter Webinar
22/06/2021	Design Thinking and Innovation for Engineering Professionals
23/06/2021	5G Webinar Series - Conclusion
29/06/2021	Fundamentals of Power Distribution
29/06/2021	Rosatom - Smart Utilities
30/06/2021	Run your project as a Business

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