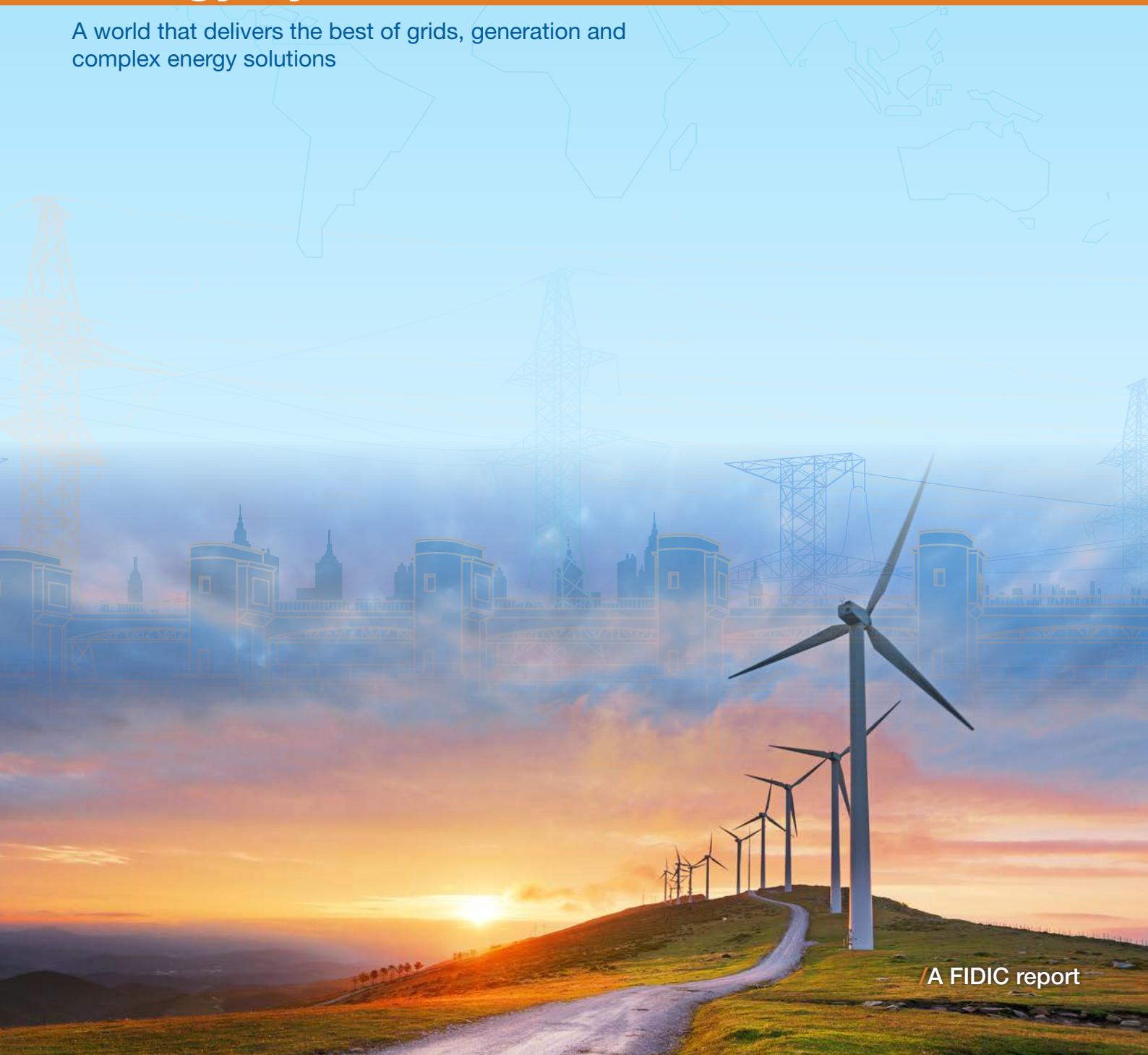


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State of the World

Developing tomorrow's sustainable energy systems

A world that delivers the best of grids, generation and complex energy solutions



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In 2023, FIDIC celebrates its 110-year anniversary and this milestone is one to celebrate but it is also a reminder that, whilst history is important, we also need to continue to look forward.

Change is constant and if we don't embrace change and challenge historical assumptions, the chance of meeting targets such as the SDGs and net zero are likely to fail. This State of the World report embraces such questions and asks whether the development of energy systems today is compatible with the goals and aspirations we wish to achieve.

To do this, we look at one of the main decisions that probably influences current developed markets - the 'war of currents' - and consider how this transformed the energy markets and systems we have developed to date. These developments have created a system where most of the electricity is generated at scale in remote areas and distributes to populations via significant power grid infrastructure.

In this report, FIDIC, the International Federation of Consulting Engineers, underscores its pivotal position in the realm of sustainable infrastructure and engineering solutions. FIDIC takes a staunch stance on the role of infrastructure in advancing global sustainability, emphasising the importance of aligning projects with the UN sustainable development goals (SDGs). The organisation advocates for an approach that engages engineers in the earliest stages of project conception, with a heightened focus on societal and community impact.

FIDIC maintains that, for the successful achievement of the SDGs, it is imperative that policy frameworks be customised to each nation's unique aspirations and requirements. This report exemplifies FIDIC's dedication to thought leadership in engineering practices that catalyse sustainability and deliver lasting value to societies and economies worldwide.

Yet, whilst significant scale generation such as combined cycle gas turbine (CCGT) plants, nuclear, wind farms and even solar will continue, there is also a shift to systems that are regional, communal, local and/or even personal. To meet the UN SDGs and their ambition to supply universal and affordable energy, no single solution will have all the answers.

So, we ask the question, do such historical decisions and their influence on energy markets still hold true all these years later?

The report explores this question by considering what the SDGs strive to achieve across the multiple goals that relate to energy systems, fairness, climate change and resilience and what are the key considerations for energy systems and grid infrastructure now.

This includes the greater involvement of communities, ensuring that there is sufficient capacity for developments such as electric vehicles, the storage of energy so balancing and the effect of renewables can be better accounted for, affordability - and the list goes on.

We consider how systems such as DC that historically lost the 'current wars' race may actually now have some resurgence due to the increased emphasis on renewables, smaller community grid systems and even long-distance high-voltage power networks.

Finally, it is also important to consider government policy in the delivery of energy systems. While the SDGs provide an overarching medium-term target, it is left to regional and national policymakers to design the tools and policies that encourage the right market signals for investors and those in the infrastructure sector.

In this report we will look at several mechanisms that have been utilised so that various regional and national governments can learn from best practice and the design of policy instruments to drive change.

The reality is that it will be a mix of energy systems that produces the outcome we require, providing a much-needed boost in the race against climate change whilst also providing the sort of resilience for communities and governments that we discussed in FIDIC's 2022 report *Building sustainable communities in a post-Covid world*¹.

To achieve this, the SDGs are a good start but there are many areas of the globe that are facing differing challenges. Some face the renewal of old infrastructure and the potential of having to integrate and mix systems to provide an optional and financeable outcome.

Other areas of the global face the decision of whether they should develop new energy systems infrastructure at scale to provide the economic growth and development that communities desire. Beyond this, there is also the challenge of serving and supply the most remote communities and individuals. For these, large distributed systems are likely not to provide value for money or a solution that is affordable.

This FIDIC report presents key recommendations aimed at guiding the development of modern power systems in alignment with the SDGs. It emphasises a client-centric approach, advocating for the procurement of solutions explicitly linked to the SDGs to ensure sustainable outcomes. Additionally, it underscores the importance of early engagement of engineers in project conception and feasibility to address the complexity of modern power projects effectively. The report also highlights the need for a more community-focused infrastructure sector, extending its influence beyond initial public or private clients to address societal needs.

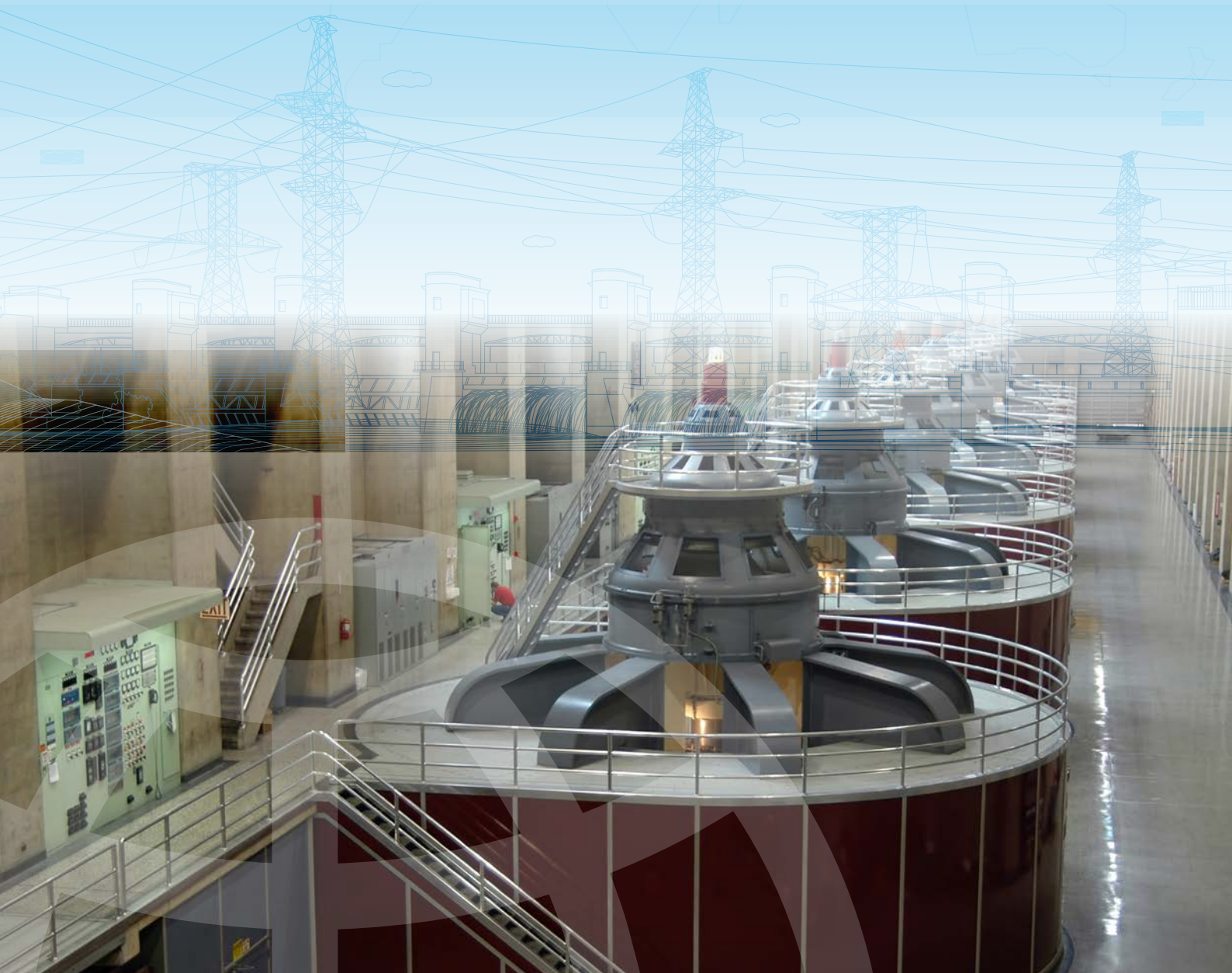
Furthermore, it emphasises the importance of tailored policy frameworks that adapt to each country's unique goals, whether they involve improving existing infrastructure or fostering new infrastructure in developing regions. These recommendations collectively aim to drive sustainable, efficient and socially impactful power systems that support the broader objectives of the SDGs.

The challenge is vast. If we want to achieve the SDGs and net zero, it will be vital to get the right mix of technologies and infrastructure correct. For this we will need to align policy and engineering expertise to ensure that opportunities are not wastes, that the finances are available and solutions deployed and designed appropriately.



/Executive summary

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It is with great enthusiasm that we present this comprehensive report on the evolution and continued need to develop energy systems to meet goals such as the SDGs and net zero. As stewards of innovation, FIDIC, the International Federation of Consulting Engineers, takes pride in shining a light on the compelling story of the development of today's infrastructure - but what about tomorrow's infrastructure?

This leads to the wider question of do such historical decisions and their influence on energy markets still hold true all these years later? Energy markets have developed to "provide energy" as demand for it grew, but now they are transitioning to a position of not only providing energy but doing it in a way that is greener, engages society and increasingly more locally.

Energy systems and grid development - the way forward?

In today's dynamic energy landscape, the significance of integrating renewable energy sources has taken centre stage. The imperatives of environmental sustainability and the urgent need to mitigate climate change have led to a remarkable shift towards harnessing energy from sources like solar, wind and hydroelectric power.

The unique nature of renewables, however, characterised by variability and intermittency, presents both challenges and opportunities. For example:

- Electricity systems have to balance as storage options were limited which can create issues with intermittent sources.
- Having the capacity to install or enable enough connections for more dispersed generation technologies and for high load end use such as the fast charging of electric vehicles.
- There is increasing use of interconnectors to provide flexibility against intermittency.
- Customers are becoming more aware of energy use and deploying demand management solutions which can potentially provide data for 'true' demand management.

The above demonstrates the pivotal role of power grids in facilitating the seamless integration of energy into our daily lives. Power grids, often likened to intricate circulatory systems, must evolve to become agile and adaptable to the ebb and flow of renewable generation.

This poses a number of questions:

- Are we adapting fast enough?
- Can the systems that have been developed over the past 150 years adapt to the goals we now wish to achieve?
- If we are developing new systems where they don't exist across the globe, is the old model of large capacity, limited site distribution still relevant?

As we steer towards a future powered by cleaner and greener sources, the role of power grids as enablers of sustainable energy transition becomes a linchpin and their evolution serves as a bridge between our energy aspirations and the reality of a renewable-powered world.

Amidst the dynamic landscape of renewable energy integration and the evolving role of power grids, various technologies from history are making a comeback in various forms, from windmills to solar collectors. So, what about grids and local solutions?

DC systems, once overshadowed by the prevalence of alternating current networks, have experienced a renaissance owing to their unique attributes.

The inherent advantage of DC systems lies in their ability to seamlessly integrate with various renewable energy sources, such as solar panels and battery storage systems, which inherently produce DC electricity. This intrinsic compatibility reduces the need for conversion processes, minimising energy losses and enhancing overall system efficiency. Furthermore, they can offer enhanced controllability, allowing for more precise management of power flow and distribution, thereby optimising the integration of intermittent renewables into the grid.

So, as we embark on the journey to a greener, sustainable, resilient, demand management, local and society-based energy model, it is important to go back to the wider question of do historical decisions, such as AC/DC, centralised generation and distance transmission still hold true all these years later?

In short, no. As we have seen through this report there are multiple ways in which a more diverse set of energy systems can not only provide efficiency, sustainability benefits and resilience, but also that in some instances for new networks they may even be the preferred solution.

Ultimately engineers will need to assess the complex set of requirements and deliverables needed to meet targets such as the SDGs and net zero, be it AC or DC. It is by balancing the complex set of requirements outlined in this report - and by implementing recommendations that enable innovation, policy development, sustainability and SDG linkages and community engagement - that progress can be made.

This report therefore provides the following overarching recommendations, which in each of the relevant sections also contains further sub-recommendations on the way forward.



Clients should procure solutions with specific links to the SDGs outlined: The SDGs play a vital role in the development of sustainability, economies and society. These goals are by no means simple to achieve and if solutions are to be procured to create the best outcomes to align to these goals, all projects should have a clear statement of intent as to the aims they are trying to achieve under the SDGs.



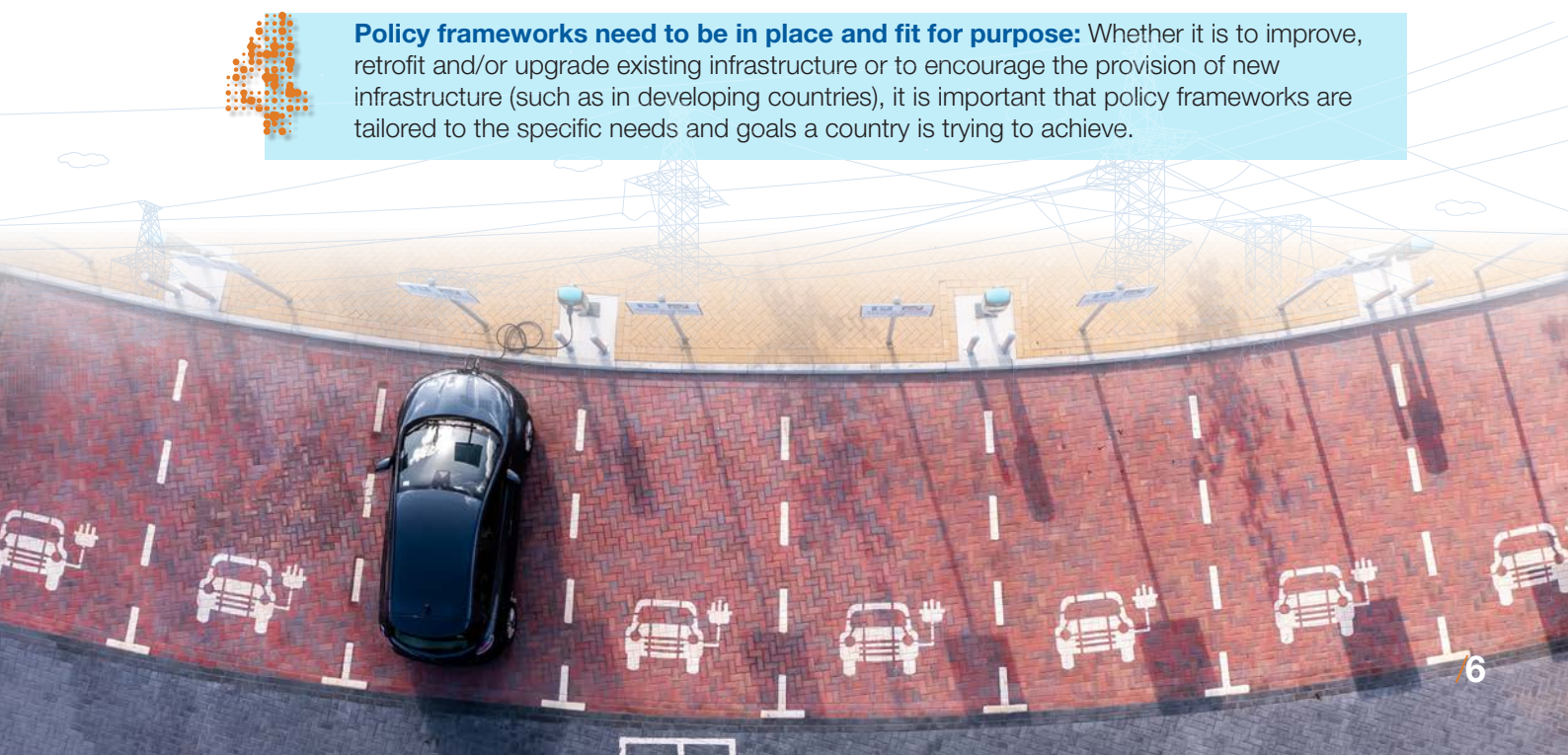
Modern power systems involve a complex delivery of multiple types of projects: As such it is important that engineers are engaged in project conception and feasibility at the earliest possible stage so that complex areas of assessment can be undertaken.



Society and communities matter: If we are to achieve the SDGs, the infrastructure sector is going to have to become more society and customer focused. We will no longer just be serving the initial public or private sector client.



Policy frameworks need to be in place and fit for purpose: Whether it is to improve, retrofit and/or upgrade existing infrastructure or to encourage the provision of new infrastructure (such as in developing countries), it is important that policy frameworks are tailored to the specific needs and goals a country is trying to achieve.



/The historical development of electricity systems and moving forward

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/The historical development of electricity systems and moving forward



The late 19th century witnessed a transformative phase as visionaries like Thomas Edison and Nikola Tesla pioneered the field of electricity distribution. Edison's experimentation with direct current systems marked a significant leap, enabling the illumination of urban landscapes and catalysing the dawn of a new era. DC systems, however, had inherent limitations, particularly in transmitting electricity over longer distances. This gave rise to the ascendancy of alternating current systems, championed by Tesla, which brought about a revolution in electricity distribution.



AC (alternating current): AC, or alternating current, is an electric current that frequently changes direction. It is characterised by the periodic reversal of the direction of the electric charge flow. AC power is commonly used in homes and businesses for electricity distribution because it can be easily transformed to various voltage levels, making it suitable for a wide range of applications.



DC (direct current): DC, or direct current, is an electric current that flows consistently in a single direction. It does not reverse its flow like AC. DC power sources provide a constant and steady voltage, which is often used in batteries, electronic devices and certain specialised industrial applications.

How AC became the dominant technology for power networks

In the late 19th century when electricity was in its infancy, direct current (DC) systems were championed by inventors like Thomas Edison. These early systems supplied power to localised areas, mainly for lighting. Edison's Edison Electric Illuminating Company, founded in 1882, was among the pioneers in using DC for electrical distribution. However, a fierce competition known as the 'War of Currents' emerged between proponents of DC and alternating current (AC) systems.

Basic characteristics: DC is fundamentally characterised by the flow of electric charge in a continuous, unidirectional manner. It maintains a constant polarity and voltage level, which means that electrons flow steadily from the negative (-) to the positive (+) pole. This contrasts with AC, where the direction of electron flow oscillates periodically, reversing direction many times per second (e.g., 50 or 60 times per second in common AC systems).

DC in early grids: Early DC systems demonstrated their suitability for relatively short-distance distribution, primarily within urban areas. However, they faced significant limitations when it came to long-distance transmission. One of the main challenges was maintaining consistent voltage levels over extended transmission lines. Due to these limitations, DC systems were often confined to small geographic areas, limiting their potential for broader electrical networks.

Transition to AC: The adoption of AC for large-scale power generation and distribution marked a significant turning point in the history of electricity. AC's key advantage was its capacity for efficient voltage transformation using transformers, enabling power to be transmitted at high voltages, minimising losses over long distances. The work of inventors like Nikola Tesla, who championed AC systems, contributed to their widespread acceptance. By the early 20th century, AC had become the dominant choice for power grids worldwide.

The transition from DC to AC dominance was driven by the need for more efficient long-distance transmission, as well as the ability to transform voltage levels easily, factors that ultimately made AC the preferred choice for large-scale power generation and distribution. This shift set the stage for the development of modern electrical grids and the expansion of electrical services to a global scale.

Comparison with alternating current (AC) and its limitations

AC advantages: The widespread adoption of alternating current (AC) over direct current (DC) in electrical systems was primarily driven by several key advantages. AC's ability to undergo voltage transformation using transformers revolutionised long-distance power transmission. This feature allowed for power generation at one voltage level, efficient transmission at higher voltages and localised distribution at lower voltages, greatly

/The historical development of electricity systems and moving forward



reducing energy losses during transportation. AC also offered the flexibility to generate electricity at different frequencies, typically 50 or 60Hz, which suited various applications.

Limitations of early DC: Early DC systems faced notable limitations that hindered their ability to compete with AC. One of the most significant drawbacks was the difficulty of voltage conversion. DC voltage levels were challenging to change, making it inefficient for long-distance transmission. As a result, DC systems suffered considerable power losses over extended transmission lines. Additionally, DC systems struggled with voltage regulation, making them less adaptable to varying electrical loads, which was crucial for accommodating the fluctuating demands of growing urban areas.

Efficiency considerations: AC systems held a clear advantage in terms of overall efficiency. They excelled in power generation, transmission and distribution across a wide range of distances. AC's ability to undergo efficient voltage transformation through transformers was a game-changer, enabling electricity to be transported economically over extended networks. This efficient long-distance transmission was pivotal for supplying electricity to urban centres and industries located far from power generation sources. The energy losses in AC transmission lines were significantly lower compared to early DC systems, making AC the preferred choice for large-scale power distribution networks. These efficiency considerations played a pivotal role in the widespread adoption of AC over DC in electrical grids worldwide.

The ensuing 'War of Currents' became a defining moment in the historical narrative. Edison's unwavering faith in DC systems clashed with Tesla's audacious championing of AC. In the end, AC emerged victorious, becoming the linchpin of modern electricity distribution. Its extraordinary versatility, readily amenable to voltage transformation, revolutionised long-distance electricity transmission.

Why is this historical perspective so important when considering the development of energy systems today as we strive for net zero? The simple answer is that the use of AC and its unique ability to seamlessly adapt to different voltage levels (which facilitated efficient long-distance transmission) meant that, to date, energy markets have developed around a model of large generation at a limited number of sites which then transmit the energy to regions, cities and localities. In short, this decision was probably one of the greatest driving factors in how our energy needs and provision developed over the past century. The dominance of AC systems not only transformed the way electricity was distributed, but also laid the foundational infrastructure that underpins the modern world's power networks.

The wider question is, do such historical decisions and their influence on energy markets still hold true all these years later? Energy markets have developed to "provide energy" as demand for it grew, but now they are transitioning to a position of not only providing energy but doing it in a way that is greener, engages society and increasingly more locally.



/Energy systems and the SDGs - paving the way to a greener future

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The intricate link between the application of energy systems and the realisation of the sustainable development goals unveils a narrative of transformative potential and harmonious progress. As the world grapples with multifaceted challenges ranging from energy access and environmental sustainability to technological innovation, the deployment of more effective energy systems emerges as a strategic enabler that intricately weaves through the fabric of the SDGs listed below.

SDG 7: *Ensure access to affordable, reliable, sustainable and modern energy for all.*

Like all the SDGs there are a number of targets² within the goals which are the bases for judging their success. For SDG7, the one relevant for this report, they include:

- By 2030, ensure universal access to affordable, reliable and modern energy services.
- By 2030, increase substantially the share of renewable energy in the global energy mix.
- By 2030, double the global rate of improvement in energy efficiency.
- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology and promote investment in energy infrastructure and clean energy technology.
- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing states and land-locked developing countries, in accordance with their respective programmes of support.

As can be seen from the above, this entails affordable and renewable generation, modern energy services, energy efficiency and an emphasis on developing energy systems in locations that are land locked or remote in nature, thus creating the potential for a spectrum of solutions from the national, regional, local and even down to personal energy systems.

The essence of SDG 7 is magnified through the lens of DC systems. The capacity of DC transmission to efficiently bridge remote energy sources with energy-deficient regions aligns with the goal of universal energy access. By facilitating the integration of renewable energy sources, DC systems forge a sustainable path toward affordable and clean energy for all.

SDG 9: *Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.*

The relevant targets within SDG 9³ are:

- Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human wellbeing, with a focus on affordable and equitable access for all.
- Increase the access of small-scale industrial and other enterprises, particularly in developing countries, to financial services, including affordable credit and their integration into value chains and markets.
- By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.
- Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing states.
- Support domestic technology development and research and innovation in developing countries, including by ensuring a conducive policy environment for, amongst other things, industrial diversification and value addition to commodities.

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At the heart of SDG 9 lies the ambition to build resilient infrastructure and foster innovation. This is envisaged to support economic and social development and importantly to allow such access to all. This is by no means a small task and infrastructure development, especially in energy systems, will play a key role to not only unlocking the potential for innovation and growth but also for the development of other community benefits such as schools and hospitals.

To deliver on this goal, however, we refer back to that single question that is driving the issue for the development of these systems - does the existing model still hold true? To deliver on the SDG, if we are going to ensure access for all the previous model of large, distributed energy, will not be appropriate or cost effective in every instance. As such, energy systems will have to consider smaller, more distributed solutions that still have the resilience to provide base, peak energy requirements and deal with increasing demand management.

SDG 11: *Make cities and human settlements inclusive, safe, resilient and sustainable.*

The relevant targets within SDG 11 ⁴ are:

- By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.
- By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.
- By 2030, enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
- By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.



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- By 2030, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.
- Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilising local materials.

The urban landscape, a centrepiece of SDG 11, mentions several areas that are relevant to energy systems, namely the provision of sustainable cities and reducing their impact on the environment, supporting urban growth, the mitigation of climate change, safe public spaces and the provision of infrastructure such as transport systems, which are increasingly requiring the integration of energy systems to power not just road lights and signs but also to charge electric vehicles.

This SDG in particular poses a challenge for urban areas with historical existing systems. If we consider that the requirements have sufficiently changed from the development of the past century, so too will the direction of solutions that are required. This will mean innovating, retrofitting or replacing existing systems in a way that was not envisaged when they were first built.

This SDG also mentioned the impact of natural disasters and the role of mitigation and resilience, but this will be dealt with in this report as part of SDG 13.

Through efficient energy distribution and reduced losses, DC technology supports the development of smart cities that emphasise sustainability, energy efficiency and improved quality of life for urban dwellers.

SDG 13: *Take urgent action to combat climate change and its impacts.*

The targets with SDG 13 ⁵:

- Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
- Integrate climate change measures into national policies, strategies and planning.
- Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.
- Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilising jointly \$100bn annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalise the Green Climate Fund through its capitalisation as soon as possible.
- Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing states, including focusing on women, youth and local and marginalised communities.

The urgent call for climate action is increasingly resonating with communities across the globe. As can be seen from the targets in SDG 13, education and awareness is a key part of meeting the SDGs. Within this, however, is also an important part about resilience.

As we have seen in 2022 with recent wildfires and flooding events across the globe, it is increasingly important not only to prevent climate change but to build resilience into systems so they can cope with natural disasters or climate-related events. This will be no different for energy systems.

Considering the discussion so far in this report, we considered the current energy system model in many countries of a large scale, limited site, large generation, distributed model. This has its benefits such as efficiencies, location, security and economies of scale but, as has been demonstrated by disasters such as the tsunami which hit Fukushima, it also has its vulnerabilities, as if you remove a large generator or significant

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transmission capacity, the energy systems strain and ultimately fail. This is where a distributed generation model with local supply and demand management can provide an extra degree of resilience.

As can be seen from the above, in the delivery of the SDGs there will need to be significant changes in how we approach and deliver energy systems. These systems will need to embrace both national and local delivery, providing efficient energy distribution and reduced losses, supporting technology in the development of smart cities that emphasise sustainability, energy efficiency and improved quality of life for all.

Along this journey there will be challenges to efficiently bridge remote energy sources with energy-deficient regions and align with the goal of universal energy access.

There are a number of areas where the SDGs will not only influence but the deliverability of the goals will be reliant on not only existing infrastructure but also on how we develop new infrastructure. Given the targets above, there are two areas of the SDGs that are worth exploring further as they are key to universal delivery and important for engagement with society as a whole. These are:

- The delivery of infrastructure in remote areas.
- The delivery of new infrastructure for economic development, in this case grid systems.

Delivery of systems to remote areas

As we strive to provide access to electrical grids to all of society, there will inevitably be countries, regions or localities where populations are remote and so large-scale solutions may not be possible. As has been discussed throughout this report, this does not mean that solutions don't exist but that the solutions implemented may take a different form from the traditional grid energy systems model.

Challenges in remote area electrification

- **Geographic Isolation:** Remote areas are often characterised by their geographic isolation, making them challenging to connect to centralised power grids. They might be situated in rugged terrain, islands or distant rural regions where grid extension is economically and logistically prohibitive.
- **Low population density:** Remote areas typically have low population densities, which means that the cost of grid infrastructure per household or business is much higher than in urban or densely-populated regions.
- **Lack of infrastructure:** In many cases, remote areas lack the necessary infrastructure for electricity distribution, including roads, substations and transmission lines.

Off-grid and mini-grid solutions

- **Off-grid systems:** Off-grid solutions, such as standalone solar home systems or small wind turbines, are well-suited for remote areas. These systems generate electricity locally and can provide power to individual homes, schools or health clinics. They are modular and scalable, making them adaptable to varying energy needs.
- **Mini-grids:** Mini-grids are localised electricity distribution networks that serve a cluster of consumers in a remote area. They are often powered by renewable energy sources like solar, wind or hydropower. Mini-grids offer a balance between individual off-grid systems and large-scale grid extensions, providing reliable power to communities.

Renewable energy integration

- **Solar power:** Solar photovoltaic (PV) systems are particularly suitable for remote areas with abundant sunlight. Solar panels can be installed on rooftops or be ground-mounted and excess energy can be stored in batteries for use during the night or cloudy periods.
- **Wind energy:** In regions with consistent wind patterns, small wind turbines can generate electricity. These turbines are designed to capture wind energy efficiently, even at low wind speeds.

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- **Hydropower:** In areas with access to water resources, micro-hydropower systems can be established to harness the energy from flowing water. These systems can provide reliable and continuous power.

Energy storage solutions

- **Battery storage:** Energy storage solutions, such as lithium-ion batteries, are essential for ensuring a stable power supply in remote areas. They store excess energy generated during periods of high renewable output and release it when energy generation is low.
- **Hydrogen storage:** In some cases, hydrogen can be produced through renewable energy sources and stored for later use, providing an additional energy storage option.

Local community engagement

- **Community ownership:** Engaging local communities in the planning and ownership of renewable energy systems is vital. Community-owned energy projects empower residents and promote sustainability.
- **Capacity building:** Training and capacity-building programmes can be implemented to equip community members with the skills to maintain and operate renewable energy systems.

Government and NGO initiatives

- **Financial support:** Governments and non-governmental organisations (NGOs) often provide financial incentives and subsidies to encourage the deployment of renewable energy solutions in remote areas.
- **Policy frameworks:** Governments can establish supportive policies and regulations that promote renewable energy adoption and remove barriers to entry.

Technological advancements

- **Energy efficiency:** Advances in energy-efficient appliances and equipment can reduce energy consumption in remote areas, making renewable energy systems more effective.
- **Remote monitoring and maintenance:** Remote monitoring technologies enable real-time monitoring of renewable energy systems, allowing for proactive maintenance and issue resolution.



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Delivery of energy systems to remote areas is essential to bridge the energy access gap, improve living conditions and promote economic development in underserved regions. It requires a multifaceted approach that combines appropriate technology selection, community involvement, policy support and innovative financing mechanisms.

Delivery of new energy and grid systems for continued economic development

Whilst remote areas pose one challenge and solutions will play a role in creating growth, there is a need - and indeed society as a whole will expect - that new solutions put in place, be it from scratch or as part of an existing system, will need to generate economic growth. It is very unlikely that the delivery of such systems will be accepted or financed if they do not generate some tangible economic or societal benefit. Below, this report explores some of the challenges we may face.

Infrastructure as an economic driver

- The establishment of new grid systems, especially in regions with limited or outdated electricity infrastructure, can serve as a catalyst for economic development. A reliable and robust electrical grid is a fundamental prerequisite for various industries and businesses to thrive.

Increased industrial productivity

- Access to a stable and ample electricity supply encourages the growth of industries, including manufacturing, mining and agriculture. These sectors greatly depend on electricity to power machinery, equipment and processes, leading to increased productivity and output.

Business expansion and investment

- A well-developed grid infrastructure attracts investment and encourages businesses to expand their operations. Companies are more likely to invest in areas where they can rely on consistent and affordable electricity to meet their operational needs.

Job creation

- As industries grow and new businesses establish themselves, job opportunities multiply. The employment generated directly and indirectly by these economic activities contributes to a higher standard of living for local residents.

Energy access for rural areas

- Extending grid systems to rural and underserved areas is crucial for equitable economic development. Access to electricity enables rural communities to engage in income-generating activities such as agribusiness, food processing and small-scale manufacturing.

Supporting small and medium-sized enterprises (SMEs)

- Grid access is particularly vital for SMEs, which form the backbone of many economies. These enterprises often lack the financial resources for alternative energy solutions and depend on the grid for their day-to-day operations.

Stimulating technological innovation

- The presence of a reliable grid can stimulate innovation in technology and automation. Industries can implement advanced technologies and digital solutions to enhance efficiency, reduce waste and stay competitive.

Energy systems and the SDGs - paving the way to a greener future



Attracting foreign investment

- Developing a modern electrical grid can make a region more attractive to foreign investors. Foreign direct investment can bring capital, technology and expertise, further boosting economic development.

Energy intensive industries

- Certain industries, such as data centres, require a stable and high-capacity electrical supply. Establishing new grid systems or upgrading existing ones ensures that these energy-intensive industries have the necessary infrastructure to operate.

Government and public-private partnerships

- Governments often play a pivotal role in funding and facilitating the development of new grid systems. Public-private partnerships (PPPs) can be instrumental in mobilising resources and expertise for grid expansion projects.

Environmental considerations

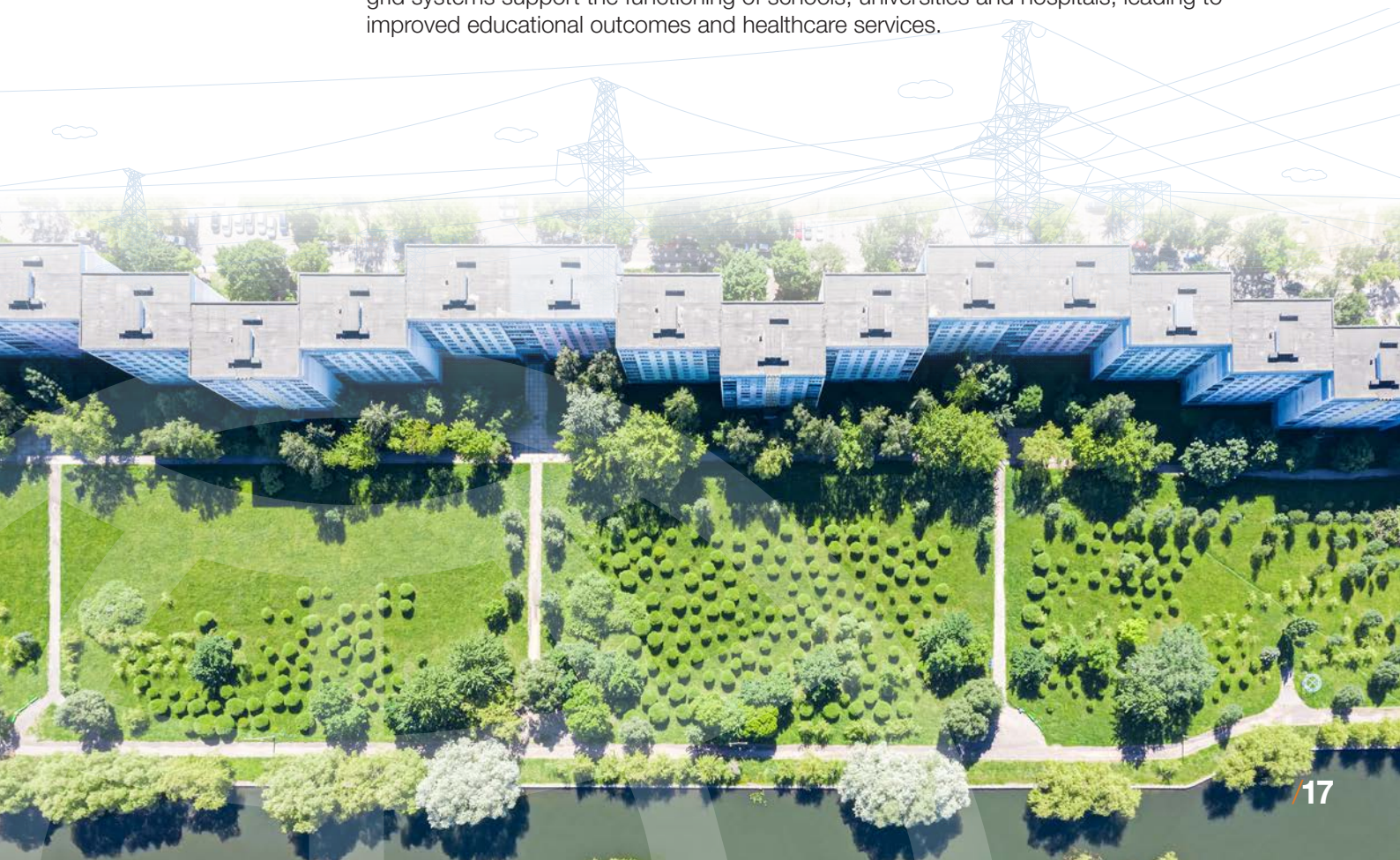
- Modern grid systems can incorporate renewable energy sources and advanced technologies for efficient energy distribution. This aligns with sustainability goals and reduces the environmental impact of economic development.

Resilience and disaster recovery

- A well-designed and modern grid system can enhance resilience against natural disasters and provide faster disaster recovery. This is critical for regions prone to extreme weather events.

Education and healthcare

- Access to electricity is essential for educational institutions and healthcare facilities. New grid systems support the functioning of schools, universities and hospitals, leading to improved educational outcomes and healthcare services.



Energy systems and the SDGs

- paving the way to a greener future

The delivery of new grid systems is a fundamental driver of economic development. It fosters industrial growth, attracts investment, creates jobs, supports SMEs and enhances overall living standards. Collaborative efforts involving governments, the private sector and communities are essential to successfully deliver these grid systems for sustainable economic progress.

By facilitating the integration of renewable energy sources, tomorrow's energy systems forge a sustainable path toward affordable and clean energy for all. This journey may involve new innovations it may also involve a resurgence of some technologies such as a return or the increased use of DC systems. If we are to gain the best outcomes, the result will come from no single solution.

By aiming to achieve the spirit of the SDGs it will be possible to bring together a union of multiple systems that deliver the promise of a cleaner, more equitable and resilient future.

Recommendation 1

Clients should procure solutions with specific links to the SDGs outlined: The SDGs play a vital role in the development of sustainability, economies and society. These goals are by no means simple to achieve and if solutions are to be procured to create the best outcomes to align to these goals, all projects should have a clear statement of intent as to the aims they are trying to achieve under the SDGs.



/Key considerations in modern energy system and grid development

/SOW2023



Key considerations in modern energy system and grid development



In today's rapidly evolving energy landscape, modern grid development and renewable energy integration are at the forefront of addressing global energy challenges. The key considerations in this context encompass a range of critical factors:

Enhanced efficiency and reduced energy losses

- **High-efficiency equipment:** Modern power grids prioritise the use of high-efficiency equipment and components throughout the generation, transmission and distribution process. For example, advanced transformers and power converters are designed to minimise energy losses, especially during long-distance electricity transmission.
- **Smart grid technologies:** Smart grids are equipped with sensors, communication networks and control systems that enable real-time monitoring and optimisation of electricity flow. These technologies help identify and rectify inefficiencies promptly, reducing energy losses.
- **Voltage regulation:** Maintaining proper voltage levels is crucial for reducing energy wastage. Modern grids employ voltage regulation techniques that ensure electricity is delivered at the right voltage, minimising losses due to over-voltage or under-voltage conditions.
- **Distributed energy resources (DERs):** Integrating DERs, such as rooftop solar panels and small-scale wind turbines, allows for localised electricity generation. This minimises the need for long-distance power transmission and decreases energy losses associated with transporting electricity over extensive networks.
- **High-voltage direct current (HVDC) transmission:** HVDC transmission is highly efficient for long-distance power transfer. It operates at higher voltages and lower currents, reducing energy losses during transmission compared to traditional alternating current (AC) systems.
- **Loss reduction strategies:** Grid operators employ strategies like demand-side management, load forecasting and load shedding to optimise electricity distribution. By intelligently managing electricity supply and demand, energy losses can be minimised.
- **Energy storage:** Energy storage systems, such as batteries and pumped hydro storage, play a vital role in reducing energy losses. They store excess energy during periods of low demand and release it when needed, minimising curtailment and transmission losses.
- **Grid modernisation:** Replacing aging infrastructure with newer, more efficient components and systems, is a key part of enhancing grid efficiency. Upgrades to substations, transformers and transmission lines improve the overall performance of the grid.
- **Data analytics:** Advanced data analytics and machine learning are used to analyse vast amounts of data generated by smart grids. These tools help identify areas of inefficiency, predict maintenance needs and optimise grid operations.
- **Renewable integration:** While integrating renewables into the grid, careful planning ensures that energy generated from these sources is efficiently captured and transmitted. Grid operators use forecasting tools to predict renewable energy generation and adjust grid operations, accordingly, minimising energy losses.

Enhancing efficiency and reducing energy losses are essential components of modern grid development, especially in the context of renewable energy integration. By employing high-efficiency equipment, smart grid technologies, voltage regulation, DERs, HVDC transmission and other strategies, today's grids can significantly reduce energy wastage, leading to a more sustainable and cost-effective electricity supply system.

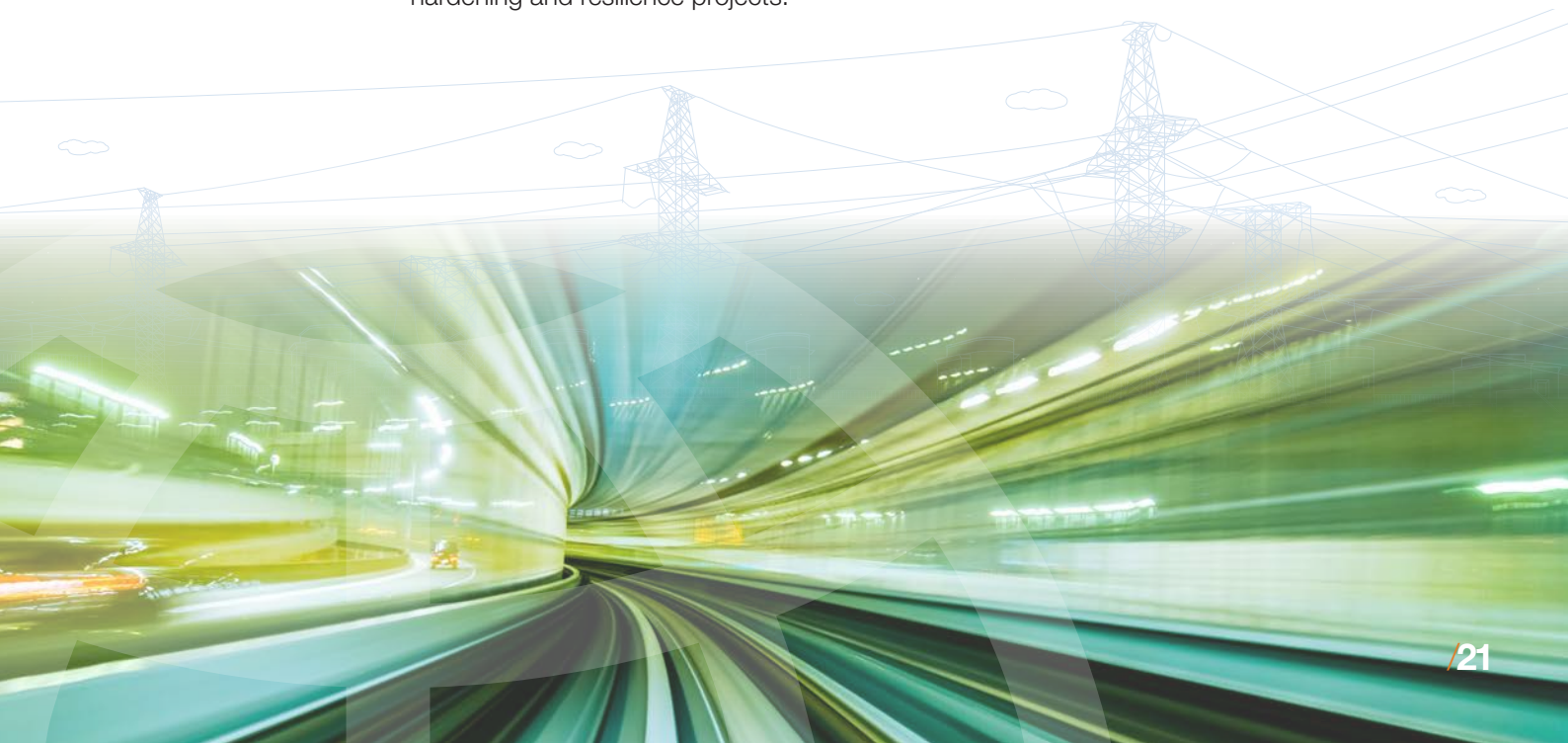
In both developed and developing nations, it will be important that such infrastructure is able to increasingly deal with greater power demands as economies transition away from fossil fuels. As such, any inefficiency and losses will be multiplied as economies increasingly rely on electricity generated from renewable energy sources.

Key considerations in modern energy system and grid development



Improved stability and reliability

- **Grid resilience:** With the integration of renewable energy sources, the grid faces increased variability in power generation. To enhance stability, modern grids employ advanced technologies, such as synchro phasors and wide area monitoring systems, to detect and respond to disturbances swiftly. These technologies provide real-time data on grid conditions, enabling operators to take proactive measures to prevent outages.
- **Frequency and voltage control:** Modern grids incorporate sophisticated control systems to manage frequency and voltage levels within narrow tolerances. In renewable-rich environments, grid-connected inverters and smart grid devices help maintain stable frequency and voltage, preventing fluctuations that can disrupt sensitive equipment and appliances.
- **Energy storage solutions:** Energy storage systems, including batteries and pumped hydro storage, play a crucial role in grid stability. They store excess energy during periods of high renewable generation and release it when demand exceeds supply. This balancing act ensures a consistent power supply, reducing the risk of power outages.
- **Demand response programmes:** Grid operators use demand response programmes to engage consumers in managing their electricity usage during peak periods. By incentivising consumers to reduce or shift their electricity consumption, grids can better match supply with demand, enhancing overall stability.
- **Grid modernisation:** Upgrading aging infrastructure is a priority in modern grid development. This includes replacing outdated equipment with state-of-the-art components that can withstand environmental challenges and extreme weather events, thus reducing the likelihood of grid failures.
- **Microgrids:** Microgrids are localised grids that can operate independently or in conjunction with the main grid. They enhance reliability by providing backup power during grid outages. In regions prone to frequent disruptions, microgrids serve as a crucial resilience measure.
- **Grid planning and simulation:** Advanced modelling and simulation tools enable grid operators to assess various scenarios and plan for contingencies. These tools help identify vulnerabilities and optimise grid configurations for maximum reliability.
- **Regulatory frameworks:** Sound regulatory policies are essential for ensuring grid stability. Regulators often require utilities to meet stringent reliability standards and invest in grid hardening and resilience projects.



Key considerations in modern energy system and grid development



Improving grid stability and reliability is paramount in modern grid development, particularly when integrating renewable energy sources. The adoption of advanced technologies, energy storage solutions, demand-side management and grid modernisation measures collectively contribute to a resilient and reliable power system capable of accommodating the growing share of renewables. These efforts are essential for ensuring uninterrupted power supply and mitigating the impacts of grid disturbances. This resilience will also be important as artificial intelligence and technology plays an increasingly important role in the delivery of good and services.

Facilitating seamless integration of renewable energy sources

- **Grid flexibility:** Modern grids are designed to be flexible and adaptable to accommodate the variable nature of renewable energy sources like wind and solar. Grid operators employ technologies such as energy storage systems, demand response programmes and advanced grid management software to balance supply and demand effectively.
- **Advanced forecasting:** Accurate forecasting of renewable energy generation is crucial for grid stability. Weather forecasting tools and predictive analytics help grid operators anticipate fluctuations in renewable energy output, allowing for better resource allocation and grid management.
- **Interconnection:** Grids are increasingly interconnected at regional and national levels to access diverse renewable energy resources. This reduces the impact of intermittent generation by allowing surplus energy in one area to compensate for shortfalls elsewhere, enhancing overall grid reliability.
- **Microgrids:** Microgrids, which are smaller-scale, localised grids, often powered by renewables, provide resilience in the face of grid disruptions. They can operate autonomously or connect to the main grid, ensuring a continuous power supply, especially during extreme weather events or emergencies.
- **Energy storage:** Energy storage technologies, such as batteries and pumped hydro storage, play a pivotal role in integrating renewables. They store excess energy generated during periods of high renewable output and release it during periods of low generation, ensuring a steady power supply.
- **Demand response:** Demand response programmes enable grid operators to communicate with consumers and adjust their electricity usage during peak demand or low renewable generation periods. This helps balance the grid and reduce the need for additional fossil fuel-based generation.
- **Grid-interactive buildings:** Building designs are evolving to incorporate grid-interactive features. Smart buildings can adjust their energy consumption based on real-time grid conditions and optimise energy use when renewable energy generation is at its peak.
- **Electric vehicle (EV) integration:** The growth of electric vehicles presents both a challenge and an opportunity for grid integration. Smart charging infrastructure allows EVs to be charged when renewable energy generation is high, reducing stress on the grid during peak demand.
- **Grid management software:** Advanced software solutions, including supervisory control and data acquisition (SCADA) systems and distribution management systems (DMS), enable grid operators to monitor and control grid assets more efficiently. These tools enhance grid resilience and facilitate renewable energy integration.
- **Regulatory frameworks:** Supportive regulatory policies and incentives encourage the adoption of renewable energy sources. Feed-in tariffs, tax incentives and renewable portfolio standards promote investment in clean energy generation.

Key considerations in modern energy system and grid development



- **Grid expansion:** Expanding and upgrading the grid infrastructure to connect renewable energy generation sites to areas of high demand is a critical step. High-voltage transmission lines and smart grid technologies enable efficient power transfer.

Facilitating the seamless integration of renewable energy sources into modern grid development requires a combination of technological advancements, including grid flexibility, interconnection, energy storage, demand response and supportive regulatory frameworks. These strategies ensure reliable, resilient and sustainable energy systems capable of harnessing the full potential of renewables while minimising their intermittency challenges.

Enabling advanced grid management and control mechanisms

Smart grid technology

- **Digital communication:** Smart grids utilise advanced digital communication systems to enable real-time data exchange between various components of the grid. This includes sensors, meters, substations and control centres. These communication networks provide essential data on energy consumption, production and grid health.
- **Automated control:** Smart grids employ automated control systems that can remotely monitor and manage the distribution of electricity. This automation enables quicker responses to faults, load fluctuations and outages. For example, if a fault is detected, the system can automatically reroute power to minimise disruptions.
- **Demand response:** Advanced grid management includes demand response programmes, where consumers can adjust their electricity usage based on price signals or grid conditions. This helps balance supply and demand more efficiently.

Grid resilience and reliability

- **Self-healing grids:** Advanced grid management incorporates self-healing capabilities. In case of faults or disturbances, the grid can automatically isolate the affected area, restore power to unaffected regions and initiate repairs, reducing downtime and enhancing reliability.
- **Predictive maintenance:** Grid operators use data analytics and predictive maintenance techniques to identify potential issues before they cause failures. This proactive approach minimises disruptions and reduces maintenance costs.

Renewable energy integration

- **Intermittent energy sources:** Advanced grid management addresses the challenges posed by intermittent renewable energy sources, such as solar and wind. Grid operators use forecasting tools to predict renewable energy generation and plan grid operations accordingly.
- **Energy storage:** Energy storage technologies, such as batteries, are integrated into the grid to store excess energy generated during periods of high renewable output. This stored energy can be released when renewable generation is low, ensuring a stable power supply.

Grid flexibility and scalability

- **Microgrids:** Advanced grid management includes the deployment of microgrids, which are smaller, localised grids that can operate independently or connect to the main grid. Microgrids enhance resilience, especially in remote or critical areas.
- **Grid expansion:** Grids must be designed with scalability in mind to accommodate the growth of renewable energy sources and increasing electricity demand. This involves planning for the expansion of transmission and distribution infrastructure.

Key considerations in modern energy system and grid development



Cybersecurity and data protection

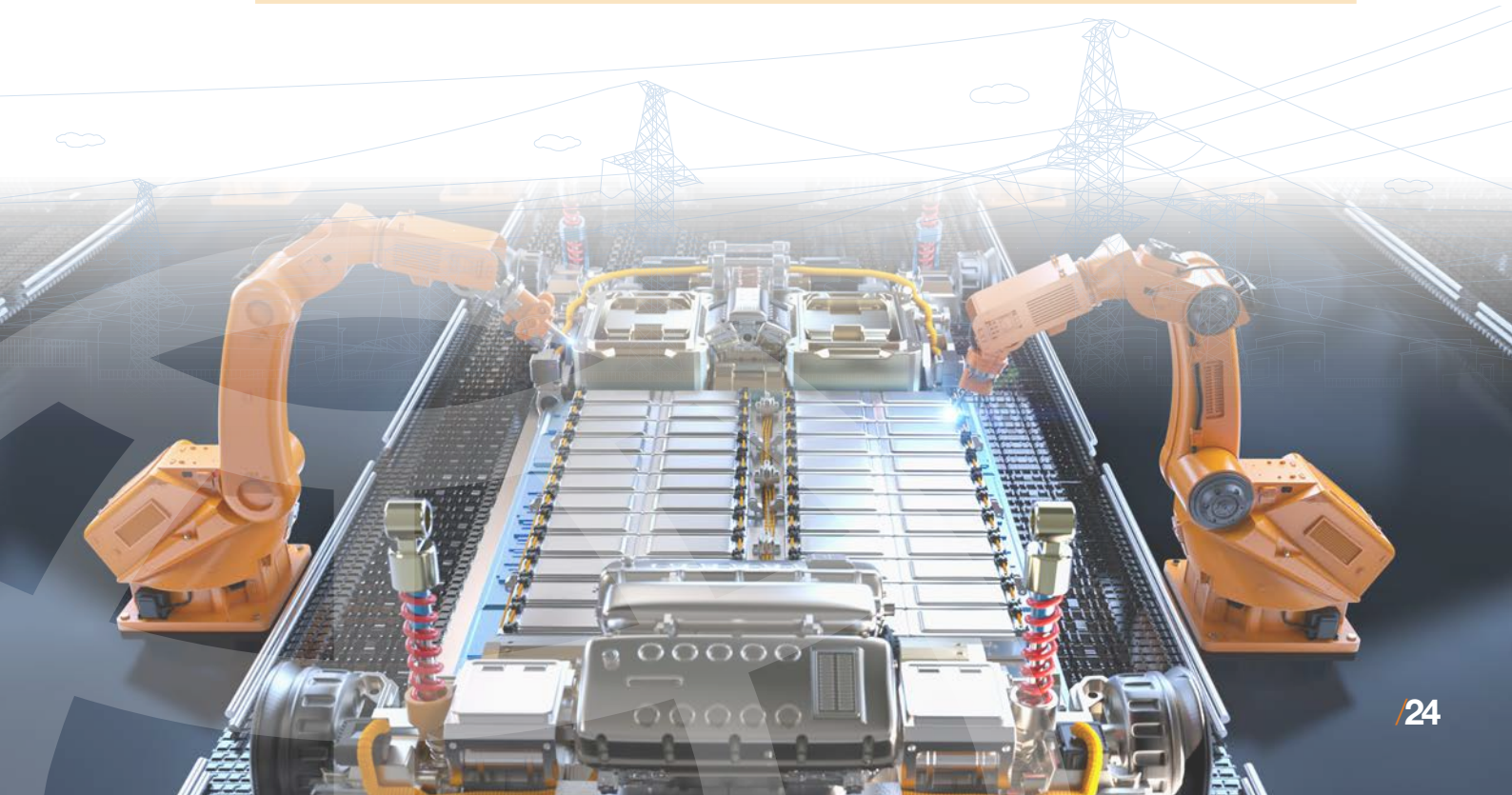
- **Cyber threat mitigation:** As grids become more digital and interconnected, advanced grid management prioritises cybersecurity. Robust measures are implemented to protect against cyber threats that could disrupt grid operations or compromise data integrity.
- **Data privacy:** Grid operators adhere to strict data privacy regulations to safeguard consumer information collected by smart meters and grid sensors. Data encryption and secure storage are essential components of data protection.



Recommendation 2

Modern power systems involve a complex delivery of multiple types of projects: As such it is important that engineers are engaged in project conception and feasibility at the earliest possible stage so that complex areas of assessment can be undertaken, such as:

- **Promote renewable energy integration:** Advocate for policies and incentives that encourage the integration of renewable energy sources, such as solar and wind power. Emphasise the environmental and economic benefits of pairing DC technology with clean energy generation.
- **Interconnector, efficiency standards and certification:** Develop industry-specific efficiency standards and certification processes especially for emerging technologies or technologies such as DC components and systems where they do not already exist.
- **Invest in energy storage:** Encourage investment in energy storage solutions, such as batteries and pumped hydro storage, to complement energy systems and improve resilience.
- **Resilience and disaster preparedness:** Highlight the importance of grid resilience in the face of climate change-related challenges.
- **Lifecycle assessment:** Promote a lifecycle assessment approach when planning and implementing projects. Evaluate the environmental impact of infrastructure construction, operation and decommissioning to minimise resource consumption.





Luigi Pellegrino
Senior BESS
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Fostering the renewable resources penetration with Battery Energy Storage Systems.

In the last decade the number of Renewable Energy Resources (RES) plant installations into the power system increases exponentially thanks to the green energy politics adopted by many countries in the world. This allows on the one hand to reduce the greenhouse gas emission but, on the other hand, introduces some new problems on the electrical power system.

The main two RES technologies, wind and solar, are in fact in part predictable but not fully controllable. This, together with the phase-out of many traditional fossil fuel power plants brings the power system to a critical condition which could lead to a black-out if not properly managed. In fact, in every moment the electrical load of the power system must be balanced with the power production, so the uncertainty of the RES power production must be compensated using the remaining traditional power plants connected to the grid or other flexible resources such as demand response and energy storage.

Power system needs

The new ancillary services requested by the Transmission System Operators (TSOs) in the last years give an idea of the present and near future needs of the power system. These needs tackle the recent critical events which are going to affect more often the power system.

There are three main categories of new ancillary services ^[1]:

- Fast reserve: this service aims to compensate the reduction of the power system inertia that allows to keep the frequency of the grid stable. The goal of this service is to limit the frequency variation. Historically the inertia has been always provided by the fossil fuel plants. RESs power plants are mainly connected through power electronics devices which have not inertia. Anyway, the control of this components can be adapted in order to emulate the inertia behavior of a traditional power plant. The time response of this service is typically lower than few hundreds of milliseconds.
- Mid-term reserve: this service aims to recover the frequency deviation, bringing it back to the nominal value. This kind of services span from seconds to few hours.
- Long-term reserve: this last category facilitates the power flow on the transmission grid, reducing the number of contingencies. The main functionality of this kind of services is the energy shifting from some hours to others of the day/week.

BESSs features

A Battery Energy Storage System (BESS) is an electrochemical energy storage able to store electrical energy in one moment and release it in future.

BESSs applications can span from industrial to grid scale applications. Thanks to their high performance, they can be used for several purposes: energy shifting that makes the RES production predictable and fully controllable, peak curtailment that allows to reduce the power connection of the loads, ancillary services which increase the power quality of the power system.

Due to the modularity of the batteries, the BESS size can be very small (< 1 MW) with a connection to the distribution system or big (> 1 MW) with a connection to the transmission system. The nominal discharge rate, which is the ratio between the nominal power and the nominal energy, of a BESS is typically between 0.25 and 1. Practically, there is not lower bound while the upper bound is limited by the battery.

In the last years the cost of the batteries is decreasing more and more due to the mass production effect for the Electrical Vehicles market ^[2]. Bloomberg expects the volume-weighted average battery pack price of 152 \$/kWh in 2023, with a BESS overall cost above \$300/kWh for a turnkey four-hour duration system ^[3]. This makes BESS more competitive than other energy storage such as pumped hydro power plants.

What is the role of BESSs in the energy transition?

To achieve the challenging target at 2050 of greenhouse gas emission, the RES penetration into the power system must keep growing. In this context BESSs are playing a key role thanks to their modularity, flexibility and competitive cost. Currently BESSs represent a technical and economical solution which allows to facilitate further RES installations keeping a good power quality of the grid.

References

^[1] IRENA_Innovative_ancillary_services_2019.pdf ([click here](#))

^[2] IEA.<https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries> ([click here](#))

^[3] BloombergNEF. <https://about.bnef.com/blog/top-10-energy-storage-trends-in-2023> ([click here](#))

/Society and energy system development

/SOW2023



In FIDIC's 2022 report *Building sustainable communities in a post-Covid world*,⁶ we asked the question of how communities would evolve given the events of Covid and the shift towards more sustainable and resilient requirements.

In addressing this question, the report looked at urbanisation and the development of communities, going beyond the thinking of purely smart or sustainable cities. Whilst some of the latest indications are that people are considering moving out of cities to gain space, it is not known if this will continue. The question is, has the sustainable city concept lost its way?

As such, when considering projects and policies going forward, an assessment is likely to be needed to check if what is being delivered is really more sustainable and in which conditions would probably be useful. It may not be enough for such assessments to rely on the previous assumptions of the last decade, without some degree of stress testing. What can we do to use this change to arrive at a more sustainable world?

FIDIC's 2022 report argued that part of the evolving solution to the meeting of SDGs and net zero targets was the development of the concept of the sustainable city. This concept was not only important for the 'perception' of cities, but also for their development. The rising popularity of buzzwords saw the media, politicians, developers and planners using terms such as 'smart transport', 'living buildings' and 'smart energy'.

Our previous report listed several of these below and the sustainable cities concept was created. The sustainable city was intended to include the following.



There is nothing wrong with the concept of a sustainable city. In fact, cities pose one of the greatest challenges for engineers in terms of sustainability for the following reasons.

1. Access is not always easy.
2. Traffic and travel often delayed.
3. Space is limited.
4. Existing infrastructure is already in place which is either not sustainable or in need of replacement.
5. Communities are complex and potentially transient.

In many ways, many of the items listed above are aimed at improving sustainability, so the concept does hold true, but only to a certain extent and this goes back to the premise of this report and the rationale behind broadening its scope to sustainable communities.

Many of the items were improving environments and sustainability.



Sustainable cities⁷ is to some extent predicated on the idea that the city's sphere of influence continues to increase and that by making its practices sustainable the sustainability of the communities that are consumed within the city's influence also improves. This is a concept we will now explore further, because Covid has posed the question - is the sustainable city actually sustainable?

Numerous challenges threaten the ability of cities to become viable pillars of sustainable development. Unequal access to and inefficient use of public services, as well as financial fragility and the harm inflicted by natural hazards, demand an integrated and coordinated response at the local, national and international levels.

The predominance of small- and medium-sized cities provides an opportunity to invest in green infrastructures, leapfrogging old energy technologies and social development, before social inequities become unsustainable.

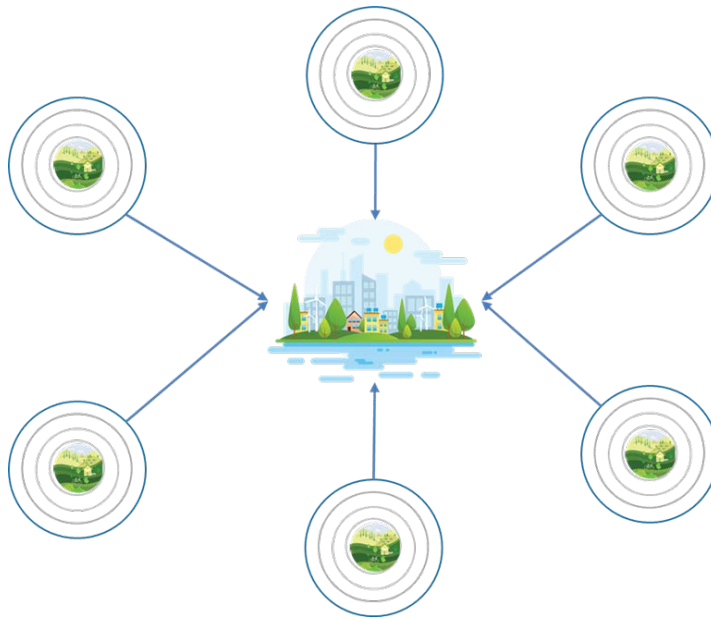
Rural development is critical for an integrated approach to sustainability and for reducing poverty. Ensuring wider and inclusive access to public services can reduce rural/urban inequalities, disaster risk and food insecurity, as well as strengthening networks between cities and peri-urban and rural communities.

The discussion and solution it discussed was the investment and shift from a single sphere of influence to a hub and spoke model and finally to a multi-communal model of development, as discussed below.

The first possibility is that communities could shift further towards a model which is similar to the hub and spoke model operated by airlines across airports over the globe. This would give rise to the following:

- A significant urban centre.
- The development of significant spokes which are well connected to the urban centre via transport links such as high-speed rail and high-speed broadband.
- This would allow travel and working in the centre but also a preference for working in significant and well-connected offices, sites buildings etc in the spokes which are connected.
- The spokes would target those looking for shorter commutes and flexibility in working, open space etc.
- Both would aim to facilitate an improved standard of living for those seeking something different from the urban centre to the spokes.
- Remote/hybrid working (from home) would still be possible but would not be the preferred method for the majority.
- Energy systems would still largely be based on traditional mass generation with distribution, with some local interconnection and generation.
- Transport will continue to be an important factor in the mass movement of people.

We were moving towards a hub and spoke model



The main aspect within this model is that the hub as the urban centre, like cities, is the driving factor. Given changes in the new normal however, sustainable approaches and improvements would focus on creating and improving the spokes.

This is already happening with concepts such as garden cities, but the focus may now be more important than ever following the new normal that evolves out of Covid and the shift towards net zero.

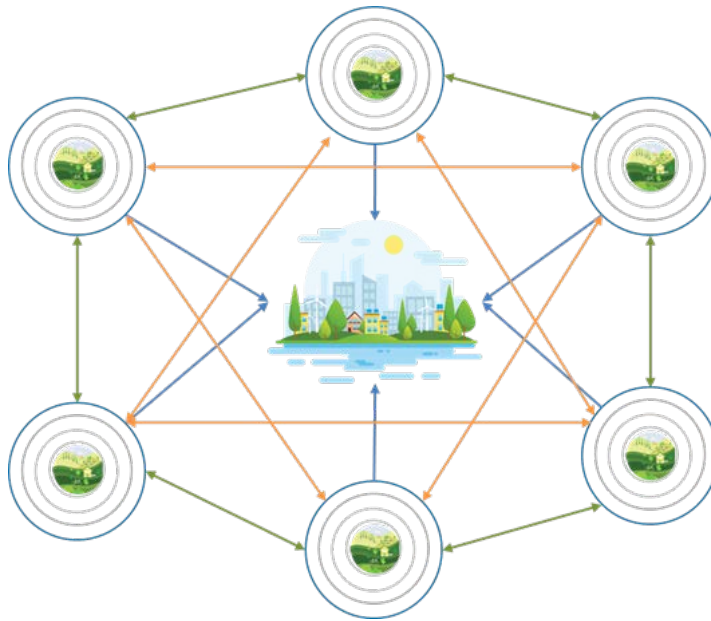
The issue with this model is that Covid has shown that with the advent of remote working and with a shift in individuals' opinions and perceptions towards their work-life balance, commuting, open space and the environment, this model may not be possible going forward.

Are we therefore moving beyond the hub and spoke model to multicommunal spokes where, whilst the urban hub remains important, there is improved and greater links between the spokes? This would mean that:

- Whilst the hub remains important, activity can occur without interaction with it.
- The spokes talk to each other with greater transport links and connectivity, including broadband, to allow them to operate with each other.
- The hub would inevitably have a smaller sphere of influence, possibly resulting in the rise of a greater number of spokes.
- Remote working or working within the sphere of influence of a spoke is more likely.
- Energy systems would over time become more communal, interconnected and devolved providing better demand management.
- Traditional transport systems that are congested would see relief from hybrid working and journeys that simply did not focus on a limited number of spokes.

This kind of model, whilst being more complex, potentially allows for a greater degree of sustainability with resources sourced closer to spokes and interactions occurring between the shortest routes for efficiency, but also allowing for specialisation where resources, capital and labour allow.

Multi-communal spokes



The above, however, would mean that sustainable communities are considered to a far greater extent than the previous urbanisation model. The focus is not only on the centre but the spokes and the connections between them.

To build a truly sustainable society it is important to consider what happens when items fail as well as succeed. If Covid has taught the world anything, it is that the systems and processes we had in place and believed were resilient were proven not to be. At the same time, it also demonstrated the potential for quality of living to improve, pollution to be reduced and the environment to improve as a result of changing the way we live, work and operate.

The reason for repeating this important part of this research is the energy systems we are discussing are very much a part of this debate and this shift in delivery model. A multi-communal model would combine existing infrastructure that has driven the growth of cities and the hub and spoke model into the suburbs, but allow for the integration of local systems, be they DC or AC, to provide not only local resilience, but ultimately improved regional and national resilience in energy systems.

Such community engagement would also help to improve the wellbeing and lives of individuals, where communities can, if they chose to, be exemplars of engineering and energy systems providing services such as local generation, EV innovation, vertical farming and energy storage.

This report therefore wishes to re-emphasise the model above, as it does not only apply to communication and digital systems and/or transport, but the whole host of infrastructure solutions required by today's modern economies and communities.

In our exploration of DC microgrids, Harry Stockman, an esteemed expert in the field, emphasised the multifaceted nature of these systems. He aptly stated: "Frequently, when discussing DC microgrids, we focus primarily on the technological aspects, neglecting the significant social advantages they offer. Beyond their technical capabilities, these DC microgrids have the potential to strengthen community ties, encourage local participation and advocate for fair energy distribution". This insight sheds light on the broader societal implications and benefits of DC microgrids, extending beyond their technological prowess.



Recommendation 3

Society and communities matter: If we are to achieve the SDGs, the infrastructure sector is going to have to become more society and customer focused. We will no longer just be serving the initial public or private sector client. As such we need to:

- **Engage and assist communities in understanding the issues:** Create a comprehensive repository of case studies showcasing successful system implementations and the benefits that were received by the communities themselves.
- **Public awareness and education:** Promote public awareness and education about the advantages of achieving environmental sustainability and energy efficiency goals. Develop educational materials and outreach campaigns targeting various stakeholders.
- **Engage with community-led and personal solutions:** Increasingly community or personal energy systems and demand management will need to be factored into grid systems. As such we need to engage communities now to ensure we are all travelling in the most efficient and effective direction.



/Have energy system requirements re-opened
the AC/DC question?

/SOW2023



Have energy system requirements re-opened the AC/DC question?



The versatile uses of DC systems means that the technology can provide innovative solutions, aligning with the goals of a sustainable future. This symphony encompasses various sectors, each playing a vital role in achieving sustainable development objectives. In the following sections, we will explore potential applications in depth, where such systems seamlessly integrate with the fabric of progress, weaving a compelling narrative as to why the historical AC/DC war of current and the dominance of one may no longer be the best status quo in energy systems.

Factors contributing to the renewed interest in DC systems:

Direct current (DC) has seen a resurgence of interest in recent years due to some of its unique advantages in modern grid infrastructures and energy systems. This section provides an in-depth exploration of DC, its characteristics, historical context and its growing relevance in the evolving energy landscape.

Potential applications and benefits

- **Renewable energy integration:** The resurgence of direct current (DC) systems is closely linked to the growing integration of renewable energy sources into the power grid. Some methods of renewable production, such as solar panels, inherently produce DC electricity. By utilising DC distribution systems, the need for frequent conversions between DC and alternating current (AC) is reduced, resulting in more efficient energy utilisation. This efficiency gain is particularly vital as the world shifts toward cleaner, sustainable energy generation.
- **Efficiency gains:** DC systems offer some efficiency advantages, making them an attractive choice for various applications. One notable advantage is the lower transmission losses associated with DC power transmission over very long and extended distances. DC lines exhibit significantly reduced resistive losses compared to AC lines, making DC especially suitable for high-voltage, long-distance transmission, where minimising energy loss is paramount. Additionally, DC systems eliminate the complexities and losses associated with AC-DC conversions, contributing further to their appeal.

Example - Enhanced efficiency and reduced energy losses:

One of the most compelling promises of DC systems lies in their capacity to enhance the efficiency of energy distribution. Real-world examples affirm this promise. In Europe, the NordLink interconnector, spanning 623 kilometres between Germany and Norway, showcases the prowess of high-voltage direct current (HVDC) technology. This groundbreaking link not only enables efficient exchange of renewable energy between the two nations but also exemplifies the potential of DC systems to span vast distances with minimal energy dissipation.
- **Grid modernisation:** The ongoing transformation of power grids to accommodate bidirectional power flows and incorporate distributed energy resources (DERs) has sparked renewed interest in DC systems. DC's unique characteristics, such as its ability to support bidirectional power flow without complex inverter systems, position it as a promising solution for modern grid requirements. DC systems can efficiently manage the integration of DERs like rooftop solar panels and energy storage devices. Furthermore, DC architectures facilitate enhanced grid control and reliability, both essential elements of grid modernisation efforts.
- **Grid stability enhancements:** DC integration can bolster grid stability, especially with intermittent renewable energy sources. Grid stabilisation devices like synchronous condensers and STATCOMs are being incorporated into existing systems. The DolWin3 offshore grid connection in Germany integrates STATCOM technology to enhance grid stability during the incorporation of offshore wind power, underscoring the significance of these enhancements.

/Have energy system requirements re-opened the AC/DC question?



- **Grid control and protection systems:** Enhancing grid control and protection systems is crucial for managing DC integration. Flexible alternating current transmission systems (FACTS) devices play a pivotal role in regulating voltage and power flow. In Germany, the SuedOstLink project is employing FACTS devices to stabilise the grid during the integration of renewable energy sources. This project showcases how advanced control mechanisms can enhance grid reliability and efficiency.
- **Grid interconnection points:** The establishment of grid interconnection points, equipped with DC/AC converters, is essential. These points facilitate seamless integration into existing systems. A prime example is the Quebec-New England transmission project, connecting the grids of Quebec and New England via HVDC technology. Converter stations were strategically placed to ensure smooth power exchange between the two regions, enhancing grid reliability.

Example - Improved stability and reliability of power systems:

The quest for grid stability and reliability has been an enduring pursuit in the energy sector. DC systems offer a lifeline in this endeavour. In the heart of the United States, the Prairie State Energy Campus exemplifies this facet. This coal-fired power plant employs HVDC technology to transmit electricity over long distances, ensuring a stable power supply to homes and industries alike. The integration of DC systems in such critical infrastructure heralds a new era of grid reliability.



- **High-voltage transmission:** Over the years, high-voltage DC (HVDC) transmission technology has undergone significant evolution. This advancement has paved the way for efficient, long-distance electricity transmission at elevated voltage levels. HVDC lines have proven to be invaluable for interconnecting remote renewable energy sources, such as offshore wind farms with urban centres. Their ability to minimise energy losses over extensive distances positions HVDC as a cornerstone in the integration of renewable energy into the broader power grid. As the demand for clean energy continues to rise, HVDC technologies are central to creating sustainable and interconnected power systems.



Have energy system requirements re-opened the AC/DC question?



- **Community and microgrids:** DC microgrids have garnered attention for their potential to enhance grid resilience and integrate renewable resources at the community level. These microgrids can operate autonomously or connect to larger AC grids, offering flexibility and adaptability to varying local energy needs. In remote or underserved areas, DC microgrids can provide a reliable source of power, improving energy access and supporting community development. Their ability to accommodate renewable energy generation, energy storage and local distribution underscores their significance in modern grid infrastructures.

One significant advantage of combining DC systems with resilient microgrids is the enhanced reliability and resilience they offer. This makes them well-suited for critical applications, especially during grid failures. DC microgrids can seamlessly switch to local power generation, such as solar panels or batteries, ensuring a continuous power supply to essential facilities like hospitals, emergency services and data centres.

Example - Facilitating seamless integration of renewable energy sources:

The proliferation of renewable energy sources, such as wind and solar, demands flexible grid architectures. DC systems offer a seamless solution for



integrating these intermittent resources. Consider Hornsea Project One, the world's largest offshore wind farm situated off the coast of the United Kingdom. It relies on HVDC technology to efficiently transport clean energy to onshore grids. This monumental project underscores how DC systems can serve as the conduits for a sustainable energy future.

- **Decentralised energy generation:** The growing trend of decentralised energy generation, such as rooftop solar panels and residential wind turbines, provides real potential for DC systems. These systems can efficiently handle the direct current produced by renewables, reducing the need for frequent DC to AC conversions. This simplification of the energy flow contributes to enhanced energy efficiency and lower costs for end-users. This approach shifts from traditional centralised power generation to a more distributed and local model, reshaping how we generate, store and consume electricity.
- **Energy storage:** The application of DC coupling in energy storage systems has emerged as a promising avenue for enhancing grid stability and reliability. DC coupling allows for more direct and efficient energy transfer between renewable sources, energy storage devices and the grid. This approach minimises energy conversion losses, optimising the utilisation of stored energy during grid contingencies or peak demand periods.

Example - Enabling advanced grid management and control mechanisms:

In the era of smart grids, the role of advanced management and control mechanisms cannot be overstated. DC systems, with their controllability and adaptability, align seamlessly with the demands of modern grid management. Across the Pacific, Japan's HVDC Interconnection Project is a testament to this synergy. By interconnecting regional grids through HVDC links, Japan enhances its grid's stability and responsiveness. This strategic deployment of DC systems amplifies the precision of energy management.



By leveraging DC for energy storage, grid operators gain a valuable tool for managing variable energy resources, thereby bolstering grid resilience and ensuring a reliable power supply to consumers. As energy storage assumes a pivotal role in modern grids, the role of DC technologies in this context becomes increasingly significant. Modern battery technologies, such as lithium-ion batteries, have revolutionised the storage landscape. These batteries efficiently store surplus DC electricity generated from renewable sources, such as solar and wind, for later use.

- **Smart homes and appliances:** In smart homes, IoT devices and appliances are increasingly being powered by DC systems for improved energy efficiency. DC-powered LED lighting, for instance, consumes less energy than

Have energy system requirements re-opened the AC/DC question?

traditional AC-powered lighting. Additionally, DC-based home automation systems can provide greater control over lighting, security and entertainment systems through smartphone apps and voice commands.

- **Data centres and electronics:** The modern digital age heavily relies on electronic devices and data centres and increasingly these data centres are being linked with or are building directly renewable power provision in the form of solar and other sources. Integrating DC distribution within these environments therefore has the potential to create efficiency gains. An approach simplifies power management within data centres, reduces energy losses and aligns with the broader goal of optimising energy consumption in the rapidly growing digital landscape.

- **Power electronics advancements:** Advances in power electronics have revolutionised the efficiency and controllability of energy systems. Modern power electronic devices play a pivotal role in ensuring the seamless conversion between DC and AC, making hybrid AC/DC grids a practical reality. These advancements enable the integration of DC systems into existing AC-dominant infrastructures with minimal energy losses. Moreover, they enhance grid stability by facilitating precise control and rapid response to dynamic energy demands. Power electronics innovations continue to drive the development and deployment of DC technologies, aligning them with contemporary grid requirements.

Example - Delivery of systems to remote areas:

The remotest corners of our planet yearn for electrification. DC systems, with their ability to span vast distances efficiently, can play a pivotal role in delivering electricity to these underserved regions.

Take, for instance, the One Belt, One Road Initiative in China. It leverages HVDC transmission lines to extend power supply to remote areas, thereby catalysing economic development and improving the quality of life for inhabitants.



- **Standardisation efforts:** International standardisation bodies are actively engaged in formulating comprehensive guidelines and standards for DC systems. These efforts are instrumental in promoting interoperability, safety and reliability in DC applications. Standardisation not only fosters consistency and compatibility across diverse DC technologies, but it also instils confidence in stakeholders including grid operators, investors and policymakers. As DC systems gain prominence in the energy landscape, standardised practices and protocols ensure their seamless integration into existing grid infrastructures, further accelerating their adoption.
- **Cable infrastructure upgrades:** The adaptation of cable infrastructure is a critical aspect of DC integration. Employing high-voltage DC (HVDC) cables for efficient, long-distance energy transmission is common practice. The IFA2 interconnector between the UK and France utilises HVDC cables for underwater transmission. This project highlights the importance of upgrading cable infrastructure to support cross-border power exchange and renewable energy integration.
- **Electrification of transport:** With the rise of electric vehicles (EVs), DC fast-charging infrastructure will continue to expand. DC fast chargers, capable of delivering high-voltage DC directly to EVs, will play a pivotal role in supporting the electrification of transport. This evolution will require a broader deployment of DC infrastructure across urban and highway networks. The electrification of transport is a pivotal aspect of the future of direct current (DC) systems and warrants further elaboration. This dimension encompasses not only passenger vehicles but also a broader spectrum of transportation modes, including public transit, freight and even maritime and aviation sectors.

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- **Passenger vehicles:** The transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs) has gained remarkable momentum. This shift is driven by several factors, including environmental concerns, government incentives and advancements in EV technology. DC systems play a central role in the EV ecosystem, as the majority of EVs operate on DC power. This makes DC fast-charging infrastructure critical for EV adoption. DC fast chargers provide rapid charging, reducing the time needed to recharge an EV significantly.
- **Public transit:** Many urban centres are electrifying their public transit systems, replacing traditional diesel or natural gas buses with electric counterparts. Electric buses operate on DC power and offer several advantages, including reduced noise pollution, lower operating costs and decreased emissions. Moreover, some cities are exploring the concept of electric tramways and trolleybuses, which also rely on DC technology.
- **Freight transport:** The electrification of transportation extends beyond passenger vehicles and public transit. Freight transport, a significant contributor to greenhouse gas emissions, is undergoing transformation. Electric trucks, vans and delivery vehicles are emerging as sustainable alternatives in the logistics sector. DC systems are integral to the operation of electric freight vehicles, offering high torque and efficiency, particularly for last-mile deliveries.

Example - Delivery of new grid systems for continued economic development:



As burgeoning economies seek to power their growth, the development of entirely new grid systems becomes imperative. DC systems emerge as the catalysts for these ambitions. In India, the Green Energy

Corridor Project exemplifies this vision. By deploying HVDC transmission lines, India not only bolsters its renewable energy capacity, but also ushers in new grid infrastructures that stimulate economic progress.



Have energy system requirements re-opened the AC/DC question?



Potential challenges and considerations:

- **Conversion complexity:** It is imperative to acknowledge that while DC is conducive to efficient transmission, end users typically require AC power. Consequently, the deployment of DC systems entails the incorporation of additional conversion equipment at substations to furnish AC power for distribution. The upfront costs and intricacy associated with these conversion stations must be prudently factored into the decision-making process regarding DC deployment.
- **Interoperability with existing grids:** New grid systems must coalesce harmoniously with existing AC grids and infrastructure, thereby obviating interoperability conundrums upon the integration of DC. Strategic placement and engineering of transition points and converter stations are imperative for ensuring seamless compatibility.
- **Safety measures and insulation:** To ensure the safety of personnel and equipment, specific safety measures and insulation techniques are imperative. The Pacific Intertie project in the United States adhered to stringent safety protocols during its HVDC installation. These measures included robust insulation materials and effective grounding techniques to maintain reliable and secure operation.
- **Regulatory dynamics and standardisation:** The realm of grid development frequently intersects with intricate regulatory frameworks and stringent standards. Policymakers wield considerable influence in shaping grid development strategies. Hence, a cogent evaluation of how DC aligns with prevailing regulations and the adaptability of standards to accommodate DC technology is essential.
- **Comprehensive cost-benefit analysis:** To ascertain the judiciousness of utilising DC for nascent grid systems, a comprehensive cost-benefit analysis is indispensable. This endeavour encompasses not solely the initial installation outlays, but also encompasses considerations of maintenance, reliability and long-term efficiency. Projects like the China-Mongolia-Russia HVDC transmission line underscore the imperative of rigorous cost-benefit assessments when contemplating the implementation of DC for new grid systems.
- **Technical limitations of DC integration:** Incorporating DC into existing grid systems requires a nuanced understanding of technical limitations. DC integration often involves infrastructure upgrades and modifications to adapt to DC's requirements. Existing AC-based systems might lack the necessary voltage conversion capabilities for efficient DC transmission. Engineers will play a vital role in assessing the feasibility of these upgrades and their impact on the grid's overall performance.
- **Safety enhancements:** For existing grid systems transitioning to include DC elements, safety enhancements are crucial. Retrofitting safety mechanisms, such as arc fault protection and emergency shutdown systems, becomes necessary. Additionally, ensuring that personnel receive adequate training on working with DC components is essential to maintain safety standards.
- **Semiconductor materials:** Modern DC systems benefit significantly from advancements in semiconductor materials. Silicon carbide and gallium nitride semiconductors are increasingly replacing traditional silicon components in power electronics. These materials offer higher efficiency, reduced heat generation and increased power density.

Example - Data will continue to be increasingly important:

Data centres, which are hubs of digital activity, rely heavily on DC systems for efficient power distribution. For example, Facebook's data centre in Sweden is a facility that uses DC power distribution for increased energy efficiency.



Have energy system requirements re-opened the AC/DC question?



- **Environmental considerations:**

Environmental concerns remain relevant for both new and existing grid systems. DC-specific components, when replaced or upgraded, can raise disposal and recycling challenges. Sustainable practices in manufacturing and decommissioning these components should be integrated into the upgrade process to minimise environmental impact.

- **International standards and regulations:**

Regardless of whether it's a new or existing grid system, adherence to international standards and regulations specific to DC systems is paramount. Compliance ensures that safety and technical aspects align with industry best practices, promoting safe and efficient DC integration.

Example - Energy storage integration:



DC systems are integral to energy storage solutions like batteries. The rise of lithium-ion batteries and their compatibility with DC systems has the potential to play a role in storage solutions. Tesla's Powerwall, for instance,

uses DC-coupled energy storage to optimise the charging and discharging processes, improving overall system efficiency.

The verdict to harness DC for the development of emergent energy systems necessitates an exhaustive scrutiny of its inherent advantages and/or disadvantage in conjunction with the particular needs and limitations of the project. Stakeholders may simultaneously grapple with conversion complexities, interoperability intricacies and regulatory considerations and execute comprehensive cost-benefit analyses to ascertain whether DC stands as the most pragmatic solution for a given grid development undertaking or project for the benefit of society.





Ahmad Makkieh
DC Business
Development Leader
Schneider Electric

DC systems are becoming increasingly important in the energy infrastructure, alongside AC systems.

The energy industry is facing several challenges as it transitions to more sustainable and renewable sources of energy. These challenges include increasing energy efficiency, reducing carbon emissions and ensuring energy security. To address these challenges, the industry is turning to innovative technologies, including direct current (DC) systems. DC systems have the potential to improve energy efficiency, reduce energy losses and easily integrate renewable energy sources into the grid. In this context, the exploration of energy trends and challenges, as well as the role of DC systems in addressing these challenges, will be discussed in more detail.

Energy trends and challenges

The global energy sector is currently experiencing a transformative shift due to various economic, environmental and technological influences. Some of the key trends are outlined below.

- **The shift towards renewable energy:** Nations are increasingly committed to reducing their carbon footprint, leading to a global shift towards renewable energy sources like solar and wind power. The growth of the world's capacity to generate electricity from

renewable technologies is projected to grow at an unprecedented rate which will contribute to the development of a new global energy economy.

- **The surge in electric vehicle adoption:** The transportation sector is currently undergoing a transformative shift towards the widespread adoption of electric vehicles (EVs). Driven by advancements in battery technology and an increasing global consciousness about environmental issues, the pace at which EVs are being embraced is accelerating. This momentum is poised to continue, especially as many countries set targets to phase out the production of fossil fuel-powered vehicles.
- **Decentralisation of energy systems:** Traditional centralised power systems are evolving, making way for more decentralised systems like microgrids. By focusing on localised solutions, communities can demonstrate greater resilience and flexibility in response to diverse energy demands and supply constraints. Moreover, these decentralised approaches not only improve energy efficiency but also reduce energy consumption and facilitate the smooth integration of renewable energy sources into the wider grid.
- **Digitalisation and the internet of things (IoT):** The increasing interconnectivity of devices and appliances through the internet of things (IoT) is revolutionising energy management. The IoT is becoming increasingly important in the energy industry as it provides businesses with a real-time data about their system operations and performance, covering aspects from machine efficiency to supply chain and logistical operations. This synergy is not only enhancing energy efficiency but also reducing consumption and refining the overall energy utilisation.

Challenges in the current energy landscape

The global energy sector is currently experiencing a marked shift towards more eco-friendly methods of energy production and consumption, driven by a surge in renewable energy adoption and a deepening understanding of the environmental consequences of conventional power systems. However, realising an exclusively sustainable energy paradigm is not without its challenges. Key hurdles faced by the energy industry include:

- **Transition to renewable energy sources:** The world is moving towards renewable energy sources such as solar, wind and hydropower. This transition is driven by the need to reduce carbon emissions and mitigate climate change. Although the multiple sources of renewable energy offer myriad possibilities for alleviating the heavy reliance on fossil fuels, there are infrastructure challenges related to generation, transmission and distribution. Additionally, the substantial costs associated with transitioning from fossil fuels to green energy cannot be overlooked. Building, developing and deploying new infrastructure, technology and products to renewable sources require significant financial commitments.
- **Energy efficiency:** Enhancing energy efficiency is a considerable challenge for the energy industry. When measures of energy efficiency are put into practice, they have the potential to decrease energy consumption. This reduction can lead to reduced energy costs and enhanced energy security. Nevertheless, the realisation of such energy efficiency mandates considerable investment, the adoption of new behavioural standards, the integration of new technologies and infrastructure and a supportive policy and regulatory framework.
- **Energy security:** Energy security encompasses more than just uninterrupted access to energy, it also involves ensuring that energy supplies are available at a reasonable price. This topic has always been significant and has recently resurfaced as a top policy priority for many governments due to the global energy crisis sparked by geopolitical conflicts.
- **Integration of renewable sources:** Wind and solar resources are inherently intermittent energy resources due to their reliance on unpredictable weather conditions. While they can generate more energy on sunny or windy days, their output might significantly drop on cloudy or calm days. Such fluctuations can pose challenges to traditional power grids, which are designed for consistent energy input. As many of these grids weren't initially designed to accommodate a large-scale integration of renewable energy, introducing these sources often necessitates updates or reinforcement of the grids to manage the fluctuating energy contributions.

- **Energy conversion:** In the energy conversion process, particularly when transitioning between DC and Alternating Current (AC), there can be substantial energy losses. These losses become more pronounced when the energy passes through several conversion stages. While there have been improvements in the efficiency of converters and inverters, further development is still needed.
- **Aging utility infrastructure:** One of the primary concerns with aging infrastructure is its propensity to cause power outages and other disturbances within the electrical grid. These older systems are often less efficient and less environmentally friendly than their newer counterparts, which results in increased operational costs and higher energy consumption. Moreover, such infrastructure can introduce safety hazards, raising the likelihood of equipment failures or accidents. Modernising these ageing infrastructures will necessitate a significant investment. Determining the right timing and strategy for upgrades can be complicated, particularly in areas with constrained resources.

The role of direct current (DC) systems

In the evolving landscape of energy sector, the challenges associated with integrating renewables sources, enhancing efficiency and modernising infrastructure have become increasingly prominent. A potential solution to these challenges lies in the expanded use of DC systems, which offer promising solutions.

Buildings of the Future: one approach to net zero is with direct current



70% of the world's generated AC power gets converted into DC power

10 to 20% energy savings by eliminating the bulk of AC-to-DC conversion

Compatibility with renewable sources

- **Solar systems:** Solar panels, fundamental to the renewable energy movement, inherently produce DC. By harnessing this natural DC output, we can avoid the energy-inefficient conversion processes, thereby boosting the efficiency and effectiveness of energy systems.
- **Energy storage:** Advanced energy storage systems, such as batteries, typically store energy in DC form. Given the intermittent nature of energy production from renewable sources, it becomes essential to store energy efficiently during periods of peak production and release it during periods of low production. The inherent compatibility of DC with these storage systems facilitates a smoother and more efficient energy storage process.

Efficiency in modern electronic devices

Modern electronic devices are deeply integrated into our daily routines from smartphones and laptops to smart home appliances and industrial equipment. Intrinsicly, these devices operate on DC, even though our household and office outlets predominantly deliver AC. For these devices to utilize this power, AC has to be converted to DC, a

transformation that inevitably incurs energy losses. By directly powering these devices with DC, we can bypass this conversion, achieving enhanced energy efficiency.

The advent of DC microgrids

The concept of microgrids isn't new, but the increasing emphasis on DC microgrids heralds an exciting era in energy distribution. DC microgrids are localised energy systems that distribute power using DC rather than the traditional AC. Employing DC microgrids could provide significant advantages to the challenges faced by the energy sector, particularly concerning grid capacity.

- One of the standout features of DC microgrids is their ability to seamlessly integrate with renewable energy sources.
- Natural disasters, equipment breakdowns or other grid disruptions, can disrupt a central power system, leaving vast areas without power. DC microgrids, as localised systems, have the capacity to operate independently (islanded mode) during such events, guaranteeing an uninterrupted power supply.
- The reduction or elimination of conversion processes, specifically AC/DC conversions, within DC microgrids results in enhanced energy efficiencies.
- Increasing prevalence of electronic devices, electric vehicles and other DC-native technologies show that the demand for DC system is on the rise. DC microgrids are ideally positioned to address this evolving energy demand.
- DC microgrids empower communities through decentralising energy production and distribution. Instead of relying solely on large-scale power plants, communities can produce and manage their own power, leading to more resilient and self-sufficient communities.
- DC microgrids not only facilitate the integration of renewables and minimise energy losses, they also play a pivotal role in reducing greenhouse gas emissions and the overall environmental impact of energy production and distribution.

DC fast-charging in electric vehicles (EVs)

As Electric vehicles (EVs) continue to grow in popularity, there is an increasing demand for infrastructure to support their rapid adoption. One major concern for many potential EV owners is the duration required to recharge the vehicle's battery. This is where DC fast-charging becomes essential. While traditional chargers might take several hours to fully charge an EV battery, depending on its capacity, fast chargers can replenish these batteries to up to 80% in just 30 minutes to an hour. Fast charging stations primarily use DC, in contrast to the AC used in standard home chargers. Since batteries store energy as DC, charging via DC enables more direct power transfer, resulting in quicker charge times. Both manufacturers and governments around the globe are investing heavily in the development of a comprehensive network of fast-charging stations to alleviate range anxiety and promote EVs as a viable option for long-distance travel.

The benefit of utilising DC fast EV charging

- DC fast charging is of utmost importance for individuals who are frequently on the move, especially during long-distance journeys. Charging an electric vehicle quickly not only enhances the travel experience but also results in substantial time savings. Travellers no longer have to wait for long periods at charging stations. This means travellers can promptly continue their journey, making electric road trips both feasible and efficient.
- One of the main concerns expressed by buyers of electric vehicles is 'range anxiety', which refers to the fear of running out of battery power before finding a charging station. The concern can be significantly alleviated by the widespread availability of DC fast-chargers. DC fast-chargers offer the assurance of quickly recharging batteries, which in turn boosts consumer confidence and encourages a greater number of people to switch to electric vehicles.

- Charging electric vehicles is not only convenient but also essential to optimising energy usage. Promoting DC fast-charging during off-peak hours will help in maintaining a balanced load on grids, thereby preventing instances of excessive demand. Moreover, the integration of DC fast-charging technology with renewable energy sources promotes a cleaner and more sustainable pattern of energy consumption. This highlights an environmentally friendly approach to charging electric vehicles.

Considering the evolving energy landscape and its inherent challenges, DC systems have emerged as an effective way to address myriad concerns in the energy sector. The global energy landscape is transitioning swiftly, characterized by a significant move towards renewable energy, the proliferation of electric vehicles, decentralisation of energy systems and the widespread digitalization of energy management. Simultaneously, the sector confronts significant challenges such as the integration of renewable sources, achieving desired energy efficiency levels, ensuring energy security and updating aging infrastructure.

DC systems, present a comprehensive response to these challenges. From the inherent compatibility of DC with renewable sources like solar panels and energy storage systems to the efficiency gains achieved by directly powering modern electronic devices with DC rather than converting from AC to DC. The concept of DC microgrids is particularly promising, offering resilience during disruptions, efficient energy distribution and facilitating a significant reduction in greenhouse gas emissions.

However, for DC systems to realize their full potential, standardization is vital. The lack of universally accepted standards for DC systems can impede their widespread adoption and integration. Variability in standards can result in compatibility issues, increased costs and hinder the proliferation of innovative solutions. CurrentOS Foundation has recognised the urgent need for standardised DC solutions that cater to the global market.

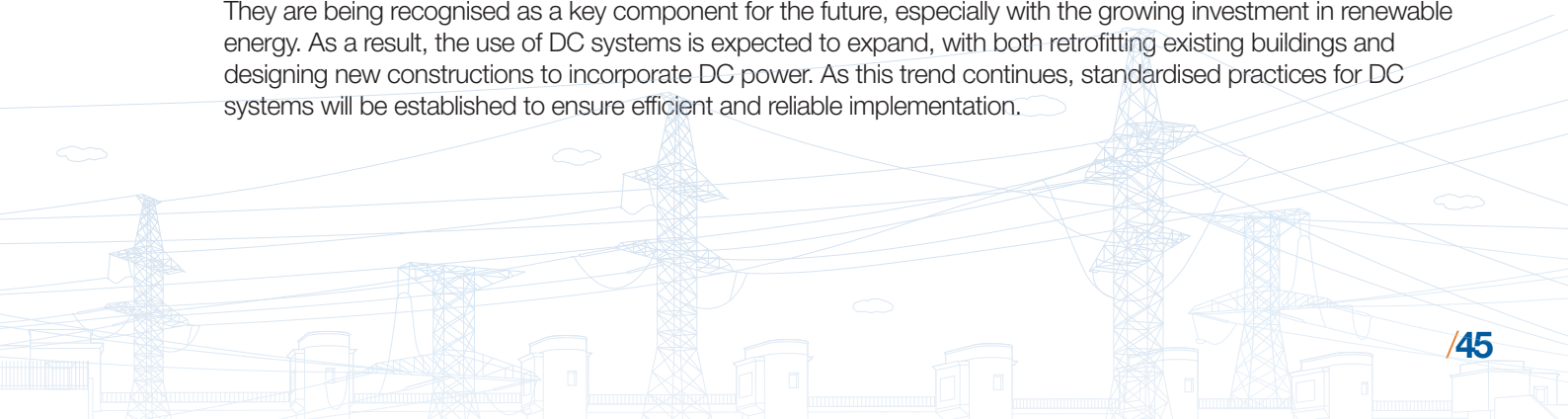
The foundation was established to ensure that a set of rules is available to all manufacturers of DC products, system integrators, design firms and academic institutions. Its primary goal is to establish a unified system specification for DC Systems. To achieve this, the foundation offers its partners a comprehensive and open set of rules, along with clear guidelines on how to manufacture DC products that are compatible with a standardised based DC environment. This initiative aims to foster innovation while ensuring safety and interoperability across the growing field of DC systems technology.

The set of rules offers several key features:

- Enhanced safety on DC distribution- Ensure that the system operates safely.
- Multi-vendor interoperability- this allows products from different manufacturers to work seamlessly together.
- Multi distribution topologies – this supports flexible and scalable grid configurations with multiple distributed sources.
- Simplicity in control, with highly resilient and power-demand flexible prosumer installations.
- Simplicity in design, installation and maintenance streamlines the process of deploying and maintaining DC systems.

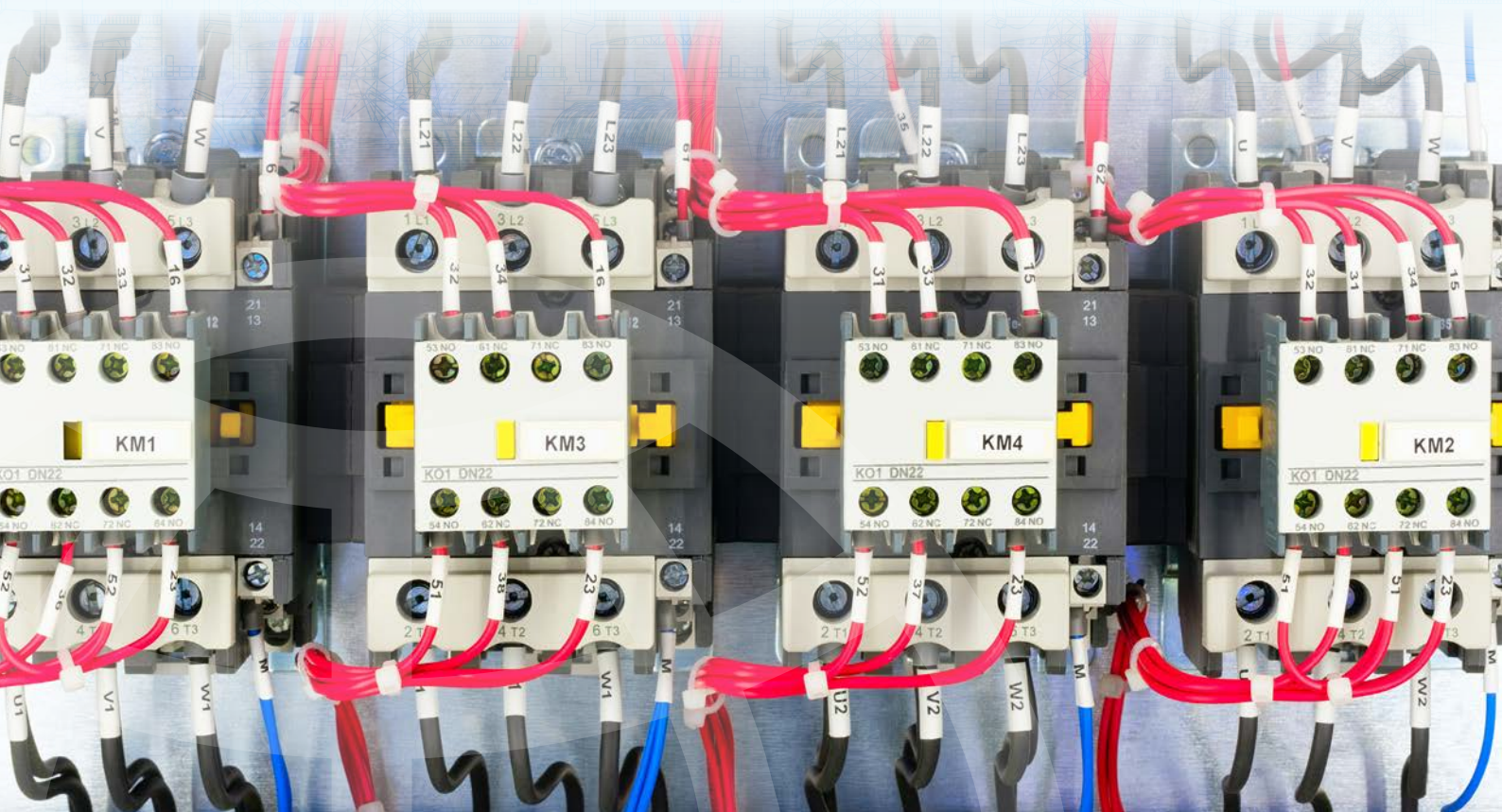
By promoting and advancing the technology and adoption of DC systems, ultimately contributing to a more sustainable and resilient energy future.

In summary, DC systems are becoming increasingly important in the energy infrastructure, alongside AC systems. They are being recognised as a key component for the future, especially with the growing investment in renewable energy. As a result, the use of DC systems is expected to expand, with both retrofitting existing buildings and designing new constructions to incorporate DC power. As this trend continues, standardised practices for DC systems will be established to ensure efficient and reliable implementation.



/Policy and regulatory frameworks supporting energy systems development

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/Policy and regulatory frameworks supporting energy systems development



Within the complex tapestry of modern grid development, the role of policy and regulatory frameworks emerges as a pivotal strand intricately woven into the fabric of progress. In this section of the report, we embark on a comprehensive exploration of the profound influence exerted by policy and regulatory initiatives. This discussion not only explains the regulatory landscape but also illuminates the dynamic interplay between policy, grid development, sustainability and societal value.

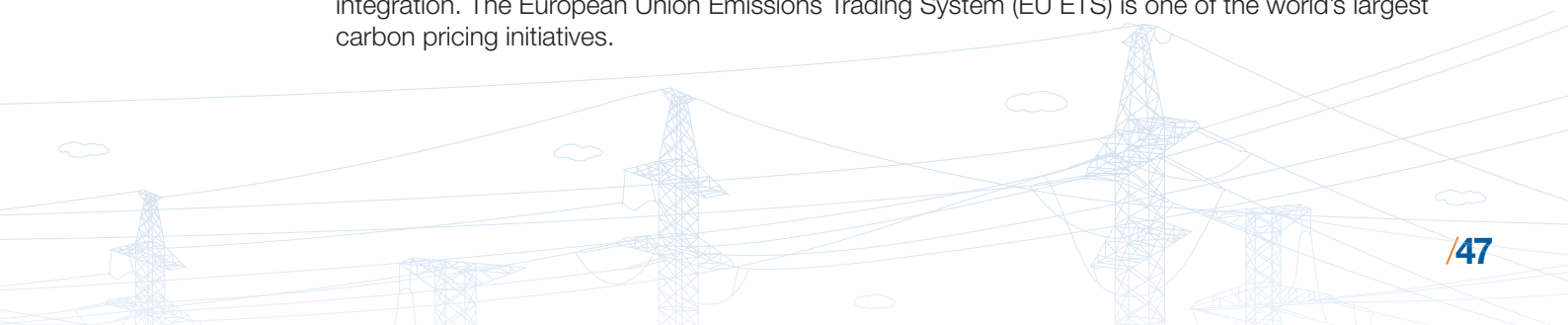
Policy as a catalyst for energy systems and grid development

The development of robust and forward-looking policy frameworks stands as the cornerstone of progress in the energy and grid sectors. Policies crafted at regional, national and international levels articulate the vision, objectives and mandates governing grid development. These policies often encapsulate overarching goals, such as enhancing grid resilience, reducing carbon emissions and promote energy efficiency, all of which resonate with the aspirations of modern grid evolution.

Policymakers must address critical facets, including grid reliability, safety standards and the harmonisation of regulations, sustainability, carbon reduction, resilience, financing and the governance of potentially co-existing energy systems such as DC/AC.

Catalytic policies and initiatives driving grid development – some real-world examples

- **Renewable portfolio standards (RPS):** Several countries and states within the United States have implemented RPS policies that mandate a certain percentage of electricity generation to come from renewable sources. These standards stimulate investment in renewable energy projects and necessitate grid expansion and modernisation to accommodate the distributed nature of renewables. For instance, California's Renewable Portfolio Standard requires 60% of retail sales of electricity to come from renewable sources by 2030.
- **Feed-in tariffs (FiTs):** Feed-in tariffs are policies that guarantee a fixed payment rate for electricity generated from renewable sources. They provide financial incentives for individuals and businesses to invest in renewable energy systems like solar panels. Countries like Germany and Spain have successfully implemented FiTs to promote decentralised energy generation, leading to grid development to handle this distributed generation.
- **Capacity markets:** Some regions have established capacity markets that pay power providers for maintaining a reliable supply of electricity, ensuring grid stability. These mechanisms encourage investments in grid infrastructure, including the development of smart grids, energy storage solutions and grid interconnections. The United Kingdom's capacity market is an example of such a policy.
- **Net metering policies:** Net metering policies enable customers with renewable energy systems, such as rooftop solar panels, to sell excess electricity back to the grid. This encourages investment in distributed energy resources and incentivises grid operators to accommodate bidirectional power flows. States within USA like California have robust net metering programmes.
- **Energy efficiency standards:** Policies that set energy efficiency standards for appliances, buildings and industrial processes indirectly drive grid development. By reducing overall energy consumption, these policies alleviate stress on the grid and delay the need for costly grid expansion. The European Union's Ecodesign Directive and Energy Performance of Buildings Directive are examples of such policies.
- **Carbon pricing mechanisms:** Carbon pricing, such as carbon taxes or cap-and-trade systems, incentivises the reduction of greenhouse gas emissions. As a result, it encourages the transition to cleaner energy sources and promotes grid development to accommodate renewable energy integration. The European Union Emissions Trading System (EU ETS) is one of the world's largest carbon pricing initiatives.



- **Grid modernisation legislation:** Some countries, like the United States, have passed grid modernisation legislation that provides funding and regulatory support for upgrading aging grid infrastructure. For instance, the Grid Modernisation Act of 2019 in the US aims to promote advanced grid technologies, cybersecurity and greater grid resilience.
- **Interconnection standards:** Policies that establish technical and regulatory standards for grid interconnections are crucial for the integration of renewable energy sources. In the US, the Federal Energy Regulatory Commission Order 841 mandates that grid operators allow energy storage resources to participate in wholesale energy markets, driving grid modernisation efforts.

These examples illustrate how a diverse range of policies can act as catalysts for grid development by promoting renewable energy integration, energy efficiency and grid modernisation to meet the evolving needs of the energy landscape.

Regulatory frameworks - the guardians of grid development

Regulatory authorities wield significant influence in shaping the trajectory of grid development. These frameworks prescribe the rules, codes and standards that govern the operation, safety and interoperability of grid components. In the context of DC systems, regulators play a critical role in ensuring compliance with standards and aligning grid development efforts with broader policy objectives.

One key regulatory consideration revolves around ensuring the safe coexistence of DC and AC systems. This entails defining clear rules for the operation, maintenance and control of hybrid AC-DC grids. Regulatory authorities often engage in extensive consultations with industry stakeholders, technical experts and policy advocates to craft nuanced regulations that mitigate potential conflicts and safety risks.

Harmonising policies and regulations

A linchpin in the grid development narrative is the harmonisation of policies and regulations across jurisdictions. Grid infrastructures are often interconnected across regions, requiring seamless cross-border coordination. In the DC resurgence era, harmonisation assumes heightened significance as it ensures the compatibility of DC systems and facilitates the transnational transmission of renewable energy.

A noteworthy example of such harmonisation efforts is the European Union's (EU) drive for a unified energy market. The EU's ambitious Energy Union initiative seeks to harmonise energy policies, regulations and market mechanisms to create a single European electricity grid. This endeavour necessitates harmonising DC/AC standards, grid codes and regulatory frameworks to enable the seamless integration of renewable energy resources and interconnectivity between member states.

Globally, however, to facilitate such a change there will need to be certain standards and practices shared to ensure we get the most out of the potential of both AC and DC in both new and existing infrastructure as we shift towards the SDGs and net zero.

Standardisation efforts and interoperability considerations

The evolving landscape of modern grid development, whether for new systems or the integration of direct current (DC) into existing infrastructures, demands meticulous attention to the crucial facet of standardisation efforts and interoperability considerations. Below, we delve into the intricate interplay between the drive for standardisation and the imperative of ensuring seamless interoperability, emphasising their intrinsic connection to the overarching theme of advancing grid infrastructures in an era where DC is gaining renewed attention.

Standardisation in the context of grid development

The deployment of DC systems, particularly in the context of new grid infrastructures, necessitates the establishment of robust standards that delineate technical specifications, protocols and operational norms. These standards serve as the scaffolding upon which grid components, equipment and technologies are constructed, ensuring that they operate cohesively and reliably. Without standardised guidelines, the landscape of grid development would devolve into a heterogeneous milieu fraught with inconsistencies and operational ambiguities.

One exemplary case of standardisation within the DC realm is the establishment of international standards for high-voltage direct current (HVDC) transmission systems. The International Electrotechnical Commission (IEC) has formulated a comprehensive framework of standards (IEC 61803) that delineates the fundamental parameters for HVDC systems, encompassing aspects such as voltage levels, converter technologies and operational criteria. These standards provide a unified foundation for HVDC projects worldwide, assuring compatibility and promoting cross-border energy transmission.

Interoperability

Interoperability, a pivotal consideration in grid development, encapsulates the capacity of diverse systems, components and technologies to seamlessly collaborate and exchange information. It is key to grid modernisation in grid modernisation, serving as the linchpin that empowers grids to integrate renewable resources, incorporate distributed energy sources and bolster overall resilience. The essence of interoperability lies in its potential to avert fragmentation and discord within the grid landscape, enabling disparate elements to function in concert.

In the DC context, interoperability assumes a paramount role, especially when retrofitting DC into existing AC-dominant systems. Ensuring that DC and AC components can interact harmoniously is imperative to achieve the envisioned grid objectives. Grid developers must tackle the intricacies of converter stations, transition points and communication interfaces to facilitate effective information exchange between DC and AC domains.

The important between standardisation and interoperability

The symbiotic relationship between standardisation and interoperability becomes patently evident. Standards provide the blueprint for interoperable systems, delineating the parameters, interfaces and performance criteria that govern interactions. Conversely, interoperability underscores the practical applicability of standards. While standards set the theoretical framework, interoperability confirms the real-world viability of grid components adhering to these standards.

Consider the deployment of smart grid technologies, where the convergence of DC systems, distributed energy resources and advanced control mechanisms necessitates both standardised protocols and seamless interoperability. Here, standards such as the Common Information Model (CIM) and the IEC 61850 standard for substation automation, bolster interoperability by standardising data models and communication protocols. These standards empower grids to intelligently manage energy flows and respond dynamically to fluctuating demand, epitomising the fusion of standardisation and interoperability in grid development.

Incentivizing DC adoption and investment

Effective policy and regulatory frameworks extend beyond rule setting, they also stimulate investment and innovation. Policymakers often introduce incentives such as tax credits, subsidies and feed-in tariffs to encourage private sector investment in infrastructure. These incentives bolster the business case for adoption, driving the deployment of new projects and the modernisation of existing grid systems.

For instance, in the United States, the Investment Tax Credit (ITC) has played a pivotal role in promoting renewable energy projects, many of which employ DC technology. The ITC offers tax incentives to businesses and homeowners who invest in solar energy systems, incentivising the adoption of DC-based solar panels.

The crucial nexus of policy, regulation and DC adoption

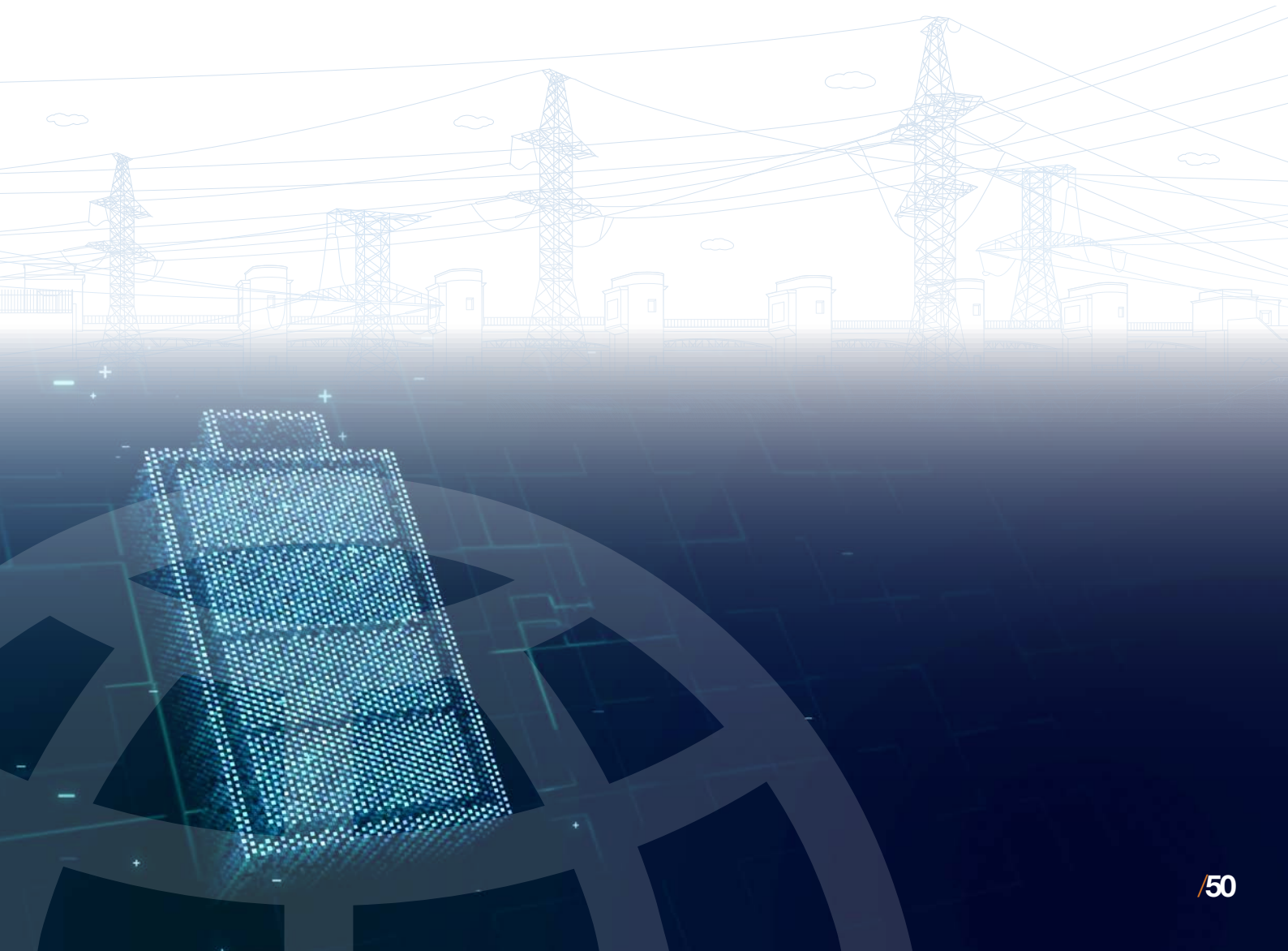
The integration of DC systems into grid infrastructures is not a siloed endeavour but one that unfolds within the intricate tapestry of policy and regulation. The policy and regulatory frameworks crafted by governments and authorities play a dual role as architects of grid development and enablers of DC system adoption. They pave the way for the resilient, efficient and interconnected grid infrastructures of the future, where DC systems are poised to thrive in tandem with evolving energy needs and sustainability imperatives.



Recommendation 4

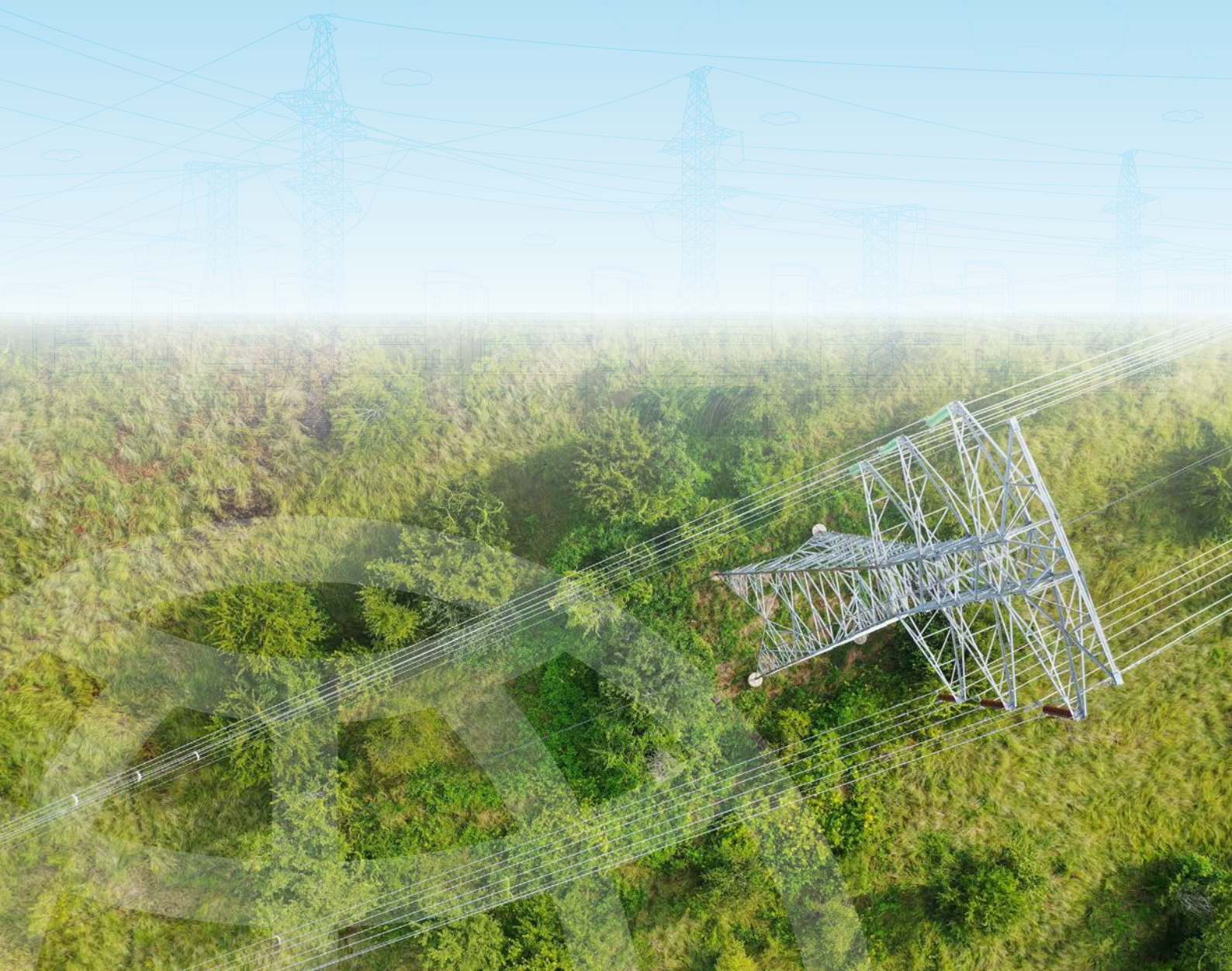
Policy frameworks need to be in place and fit for purpose: Whether it is to improve, retrofit and/or upgrade existing infrastructure, or encourage the provision of new infrastructure (such as in developing countries), it is important that policy frameworks are tailored to the specific needs and goals a country is trying to achieve. These frameworks should:

- **Provide stability:** If policy frameworks change too often, they can create as many issues as they resolve. Policy frameworks should be developed with stability, financial envelopes and five to ten and 15-year timeframes in mind.
- **Learn from other countries:** In this report we have provided examples of various mechanisms to encourage energy system development. No single policy is a silver bullet and all countries can learn from the experiences of others.
- **Collaborative research initiatives:** Encourage collaborative research initiatives between academia, industry and government agencies to aid in knowledge sharing and the utilisation of best practice.
- **Skills and training:** Emphasise the need for workforce development and training programmes to equip professionals with the skills required for developing, procuring, financing, designing, operating and maintaining and decommissioning of infrastructure.



/Appendices

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/Appendix A - The most sustainable road in the Netherlands

The provincial road N470 represents a unique undertaking for the region, bringing together multiple partners. South Holland is ambitiously aiming to manage and maintain its roads, waterways and bridges and locks-in a carbon-neutral fashion. The ambitious objectives set for the region were achieved with the N470 project, which has been hailed as the most sustainable road in the Netherlands. This initiative underscores that such a sustainable venture can be a standard tender, not just a showcase, within the prevailing ecosystem.



The N470 stands out as the region's first road renovated entirely in a CO₂-negative approach, boasting its own energy generation for lighting and traffic signals. Traffic moves more seamlessly and the road has become safer with the incorporation of innovative DC technologies. The short transmission distances eliminate significant energy loss that usually occurs through high-voltage cables and AC conversion, thus reducing energy consumption and Carbon emissions. An environmentally friendly battery stores energy generated during the day, releasing it in the evening when there is no sunlight available.

Furthermore, the N470 proudly claims to be the pioneer in using a self-sustaining energy system. The 'Energy Wall', acting as a noise barrier, also doubles as an energy generator with solar panels situated within the barrier's glass plates. The energy harvested in this manner powers 332 lights and 225 traffic signals along the road. Comprising 100kW solar components, the noise barrier produces an enormous 75 megawatt-hours of electricity annually, akin to supplying green electricity to around 26 households for an entire year.

The features and benefits of the N470 project

- The entire system is powered by a singular cable that runs for 4.7 km.
- This cable utilises DC power, circumventing the challenges tied to transmitting AC power across water channels.
- In the event of a primary grid failure, the system can function in an islanded mode.
- The system operates as an autonomous microgrid with distributed energy sources, maintaining power flow without the need for digital communication (CurrentOS system).
- While the system incorporates energy management features, it avoids the need for data or internet connectivity due to security considerations.
- Renewable energy sources, including photovoltaic panels and energy storage mechanisms, are integrated into the system.
- Emphasising its viability, this is a commercial project, not merely a prototype within the existing ecosystem.



Appendix B - Sustainable parking in the Netherlands



At A.S.R, a leading Dutch insurance firm, a 5,000 m² two-level parking lot has been established that is environmentally conscious with a green outlook. This refurbished facility is equipped with 2,000 solar panels, contributing to the company's CO₂ neutral office initiative. The state-of-the-art bi-directional electric vehicle chargers (V2X) are a defining aspect of this cutting-edge system, enabling a rapid transition to sustainable energy.



Highlights

- The parking lot functions similar to a mini grid, leveraging the capabilities of EV chargers. One fully charged EV can assist in charging other EVs as required (V2V).
- In scenarios where traditional AC power is compromised, the DC grid remains operational, supported by EVs and solar energy. This bolsters the grid's reliability, cementing the role of EVs and solar energy as pivotal to grid stability.
- Features autonomous measurements and controls with inbuilt settings ensuring system automation.
- The autonomous energy system guarantees a continuous energy supply, irrespective of weather conditions. On sunny days, the system makes the best use of solar energy to charge electric vehicles. Should the AC grid fail, EVs still benefit from the solar-powered DC grid.
- Incorporates a bottom-up congestion management strategy.
- Ensures continuous monitoring of DC stray currents.
- Monitors the transition of electrical energy from AC to DC during both charging and discharging.
- Observes DC grid behaviour in response to fluctuating droop rates to maximise energy self-delivery from PV sources.
- Has an EMS (energy management system) and adjustable V-P characteristic settings.

Technical specifications

- The two-level parking lot is engineered to prioritise DC energy use over AC.
- It includes 96 solar panels with a total output of 48kW connected to AMPT string optimisers on DC.
- There are 250 AC EV chargers and three scalable DC bi-directional EV chargers, each with an 11kW capacity.
- An Active Front End (AC/DC converter) capable of producing 50kW.
- A DC distribution cabinet fortified with solid state protection, namely current routers.
- The system features droop rate control, which enables each device to have customised voltage and power settings.

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As with all documents and research produced by FIDIC, the board plays a vital role in ensuring that quality, integrity and direction of such publications and as such we thank the board members for their contribution to this publication.

The secretariat

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Digital Technology on a Path to Net Zero

In 2022 FIDIC produced its Digital disruption and the evolution of the infrastructure sector State of the World report. This report outlined not only the pace of change but also the role of technology as a potential disrupter to industries changing their business model as a result of shifts in technology, data and/or how a combination of how customers/clients and the sector can access and use such information. It is, however, not only important to recognise that change is constant, but also that if we are going to meet challenges such as net zero, it is inevitable. In this latest State of the World report, we explore the practical role technology currently has in the development of infrastructure and also how this will change as we move forward with increased retrofitting, carbon reduction and increasing cooperation.

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Corruption, its effects and the need to take action

As evidenced by international public law and the domestic laws made according to the public policy of nation states, corruption is not and should not be acceptable. This report outlines figures on its effects, considers new relationships between economic, industry and FDI flows and the perceptions of corruption. The report looks at data collected over the last decade across as many countries as possible and asks the question, how has the fight against corruption gone? Are we really combatting it?

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Digital disruption and the evolution of the infrastructure sector

This report explores the pace of this technological change and shows that not only is the pace of change significant, but that many of the technology companies we use today for day-to-day activities in the grand scheme of time are actually very young and company longevity is continuing to decline. This suggests that not only is the pace of change faster, but the companies and people we deal with today may not be the ones we are dealing with in ten years' time. We also discuss the role of technology as a potential disrupter to industries changing their business model as a result of shifts in technology, data and/or how a combination of how customers/clients and the sector can access and use such information. It is then also important to look at the role of technology as an innovator and as something which drives real changes and improvements. What does it mean in terms of big data, artificial intelligence, customer lead data and more devolvement of smart devices?

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State of the World Series - Net Zero - What Next?

Net Zero. It could be argued that we have only just begun, but such ambitions were set decades ago. Yes, to hit a target you first have to create one and to reach that target you have to gain acceptance, political support, industry support and then delivery through all related activity. FIDIC, as the global voice of engineering and infrastructure, asks not only what is next but we also provide the next global target. This target not only helps to achieve our current trajectory but also sets the kind of ambitions the engineering sector and humanity should be proud to achieve. We go beyond Net Zero and ask “what next?” Find out more about what comes next after Net Zero by attending the launch of “Net Zero... so, what next?”, the fifth report in the FIDIC State of the World series.

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State of the World Series - Building sustainable communities in a post-Covid world

The world is gradually learning what it means to be sustainable as we march towards achieving the 2030 UN Sustainable Development Goals and approach net zero, but should we simply be adapting our current way of living or thinking about a new way of life? The Covid pandemic has demonstrated that remote working is not just the digital dream of IT professionals and visionaries, but is and can be real life. Do we need cities? Is urbanisation going to continue? Alternatively, should we be looking at the airline industry and the ‘hub and spoke’ model as the future for communities where most activity can happen locally in a more sustainable way via serviced offices, with only occasional visits to major hubs? The world is changing and this State of the World report asks: “are we changing quick enough to match the way communities want to live not only tomorrow, but today?”

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Tackling the global water crisis - State of the World 2020-2021

Water, it falls from the sky, runs in our rivers, fills our lakes, waters our crops and flows through our infrastructure, yet it is more than a monetary product. Yes, having explored the value of water in our second State of the World report, we explore the flip side of this equation. The environment we live in, the pollution that has historically occurred and minimising such pollution in the future, is becoming more important day by day. The SDGs make this clear, but how can industry stand up and lead the way.

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Endnotes

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