Accelerating the electrification of everything

How to decarbonize buildings, industry, and mobility while boosting the grid.

SIEMENS

Introduction

The energy transition requires the phasing out or replacement of all fossil-fueled loads (e.g., engines, boilers, or furnaces) with non-polluting alternatives. The 'electrification of everything' currently seems one of the most feasible pathways to achieve this, if accompanied by a shift toward zero-carbon generation of the electricity needed to power all these new electric devices.

As our planet experiences more extreme weather events such as wildfires and devastating floods, the need is more pressing than ever to show how we can support and, most importantly, accelerate the decarbonization process in every way possible, and to emphasize that, fundamentally, the necessary solutions and technologies are already available and market-ready.

The international community's stated policies and pledges still lag behind what is necessary to reach the 1.5-degree target[1]. However, we must remain deeply committed to our common goal of net-zero carbon and greenhouse gas emissions by 2050, as set out in the Paris Agreement, and to providing technology solutions that will help to get us there.

We know what to do

While the deep systemic change required by decarbonization may be daunting, it is crucial to remember that there is no time to lose, and in principle, we know what to do. On the path to net zero, many electric-powered technologies are available today, including for instance chargers for electric vehicles, heat pumps for buildings, and electric boilers for some industrial processes. Digitalization is crucial here too.

To be clear, as with every solution proposed for phasing out fossil fuels and reaching net-zero greenhouse gas emissions, widespread electrification alone is no silver bullet, especially as long as the electricity consumed by electric vehicles, for example, still comes from fossil energy sources, such as coal, oil, or natural gas. By way of example, we must ensure that electric vehicles are charged with renewable energy. Electrifying assets now means that their carbon emissions will decline during their life cycle as fossil fuels are phased out of the energy generation mix and renewable sources are ramped up.

"Speeding up grid expansion and renewal will require substantial technology investment over the next decades."

Beware of the bottleneck

Since electricity consumption is already increasing, additional capacity is urgently needed to replace fossil fuels. The demand for electricity will double and peak supply will triple with the electrification push. We will therefore need to expand renewable generation, but also strengthen, expand, and upgrade transmission and distribution grid infrastructure. To illustrate the scale of the challenge, it is instructive to remind ourselves that over the next decade, we will have to add the same capacity over again that it took us a century to build. And time is not working in our favor, as transmission projects have become notoriously hard to build.

The grid infrastructure is at risk of becoming a bottleneck in the energy transition and may even sabotage our quest for decarbonization. Speeding up grid expansion and renewal will require substantial technology investment over the next decades. Crucially, we will also need to leverage smart digital solutions to lower costs, improve grid efficiency and capacity, and gain flexibility to shift loads to periods when there is sufficient renewable energy.

Indeed, digitalization and digital solutions, built on state-of-the-art hardware, must be center stage. Only with digitalization of the existing electrical network in terms of transparency, control, and automation we will be able to move the needle of decentralization in a short time frame. It is essential to focus on digitalization of the existing network as fast as possible, as new electrical networks cannot be delivered quickly. Agility is also key. With fact based long-term planning no longer feasible, we must adopt a more agile approach to planning electrical networks.

If we succeed, however, electrification will yield a host of benefits, including local and global energy autarky, sector coupling, the end of geopolitical fossil fuel dependency, and improved efficiency and reduced loads through digital twins and automation.

This paper will explore how the electrification of everything will impact electricity demand in the future against the backdrop of increasing renewable energy generation, focusing on the electrification of the core sectors of buildings, mobility, and industry. Special consideration will be given to the future-proofing of our grid infrastructure.

Pathways to electrification: **Trends, targets, and challenges**

There is no doubt that net zero emissions electricity and electrification are absolutely central to the shift to a net zero emissions system. There are many uncertainties regarding how we will get there, but the trend is clear. The share of electricity in global final energy consumption is projected to rise. The International Energy Agency (IEA) envisages three scenarios:

- Based on currently stated policies, the share of electricity rises from 20% today to 22% in 2030 and 28% in 2050.
- Assuming the additional national pledges will be fulfilled, the share rises to 24% in 2030 and 39% in 2050.
- In the net zero emissions scenario, which would honor the pathway established in the Paris Agreement, electricity would account for 28% of final energy consumption by 2030 and 52% by 2050.[2]

This projection is predicated on a huge overall surge in global electricity demand. By 2050, electricity demand in the net zero emissions scenario we are aiming for will double and peak demand will triple.

A further trend we are observing is a steady rise in renewable energy generation capacity. In current scenarios – which do not include increased ambitions under a net zero emissions scenario – renewables make up 75 to 80% of newly installed capacity, led by photovoltaics (PV) and wind. This changing demand pattern and the increase of fluctuating PV and wind in the electricity mix will place further strain on overburdened transmission and distribution grids, making grid flexibility – enabled by smart grid solutions – paramount.

Where does the surge in demand come from?

The decarbonization effort in industrial economies has mainly focused on the electrification of transport and industry, as well as buildings. Notably, while industry and transport will be the key triggers for an increase in electricity consumption in the coming decades, fully electrified buildings will not require much additional electricity. This is due to the vastly superior energy intensity and the improved efficiency of electric solutions such as heat pumps.

Critical infrastructure such as harbors, airports, data centers, and the like will require full electrification to become carbon-neutral, leveraging on-site renewable generation – which will hardly ever be feasible as a stand-alone solution. The grid will need to back up and provide most of the additional electricity, and this needs to be factored in.

Decarbonization of the mobility sector with electric passenger cars, electric delivery vans, and e-buses is in full swing, and even electric trucks are predicted to see a breakthrough in the next decade.[3] This will account for a large share of additional generation and peak capacity. Together with industry, transport and mobility will account for the biggest surge in electricity demand.

Electrification of everything only makes sense with a rapid drop in energy emissions

Electrification will not sustain us all the way across all sectors. Some industries, for instance, require high process heat, which cannot yet be generated with electric power. Alternative solutions include biomethane or renewable hydrogen. However, systematic electrification can deliver 80% of the decarbonization journey, even in industry.

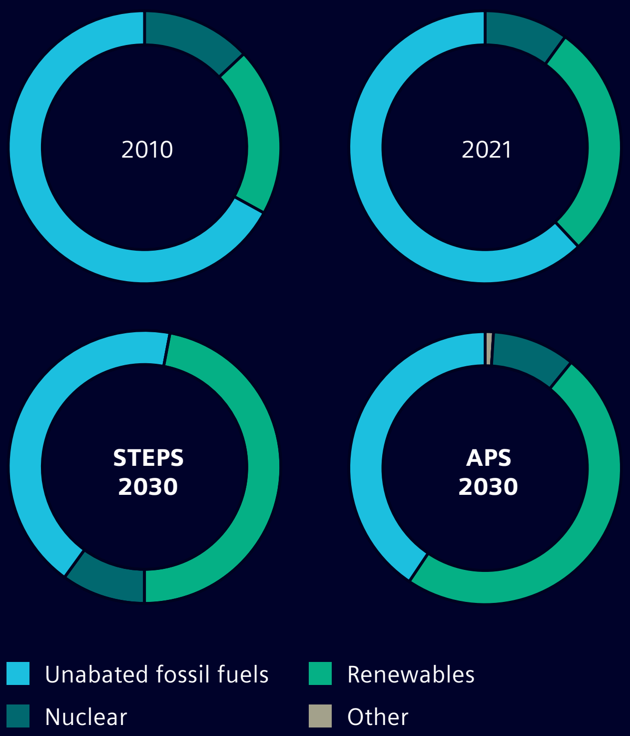
While the long-term pathway is to lead us to net zero in 2050, there are intermediate targets that are crucial to mitigating the climate crisis. Targets we need to achieve by 2030 include:

- A reduction of emissions with a 72% share of low-emissions sources in electricity generation
- A reduction of energy intensity by 33%
- A 2.8-fold increase in investment in clean technologies.

In the IEA's net zero emissions scenario, the electricity sector must be made carbon-neutral by 2035 in advanced economies, and by 2040 in emerging and developing economies. Only with such a rapid drop in emissions in electricity generation can continued emissions reductions through electrification be enabled in the industry, transport, and buildings sectors.[4]

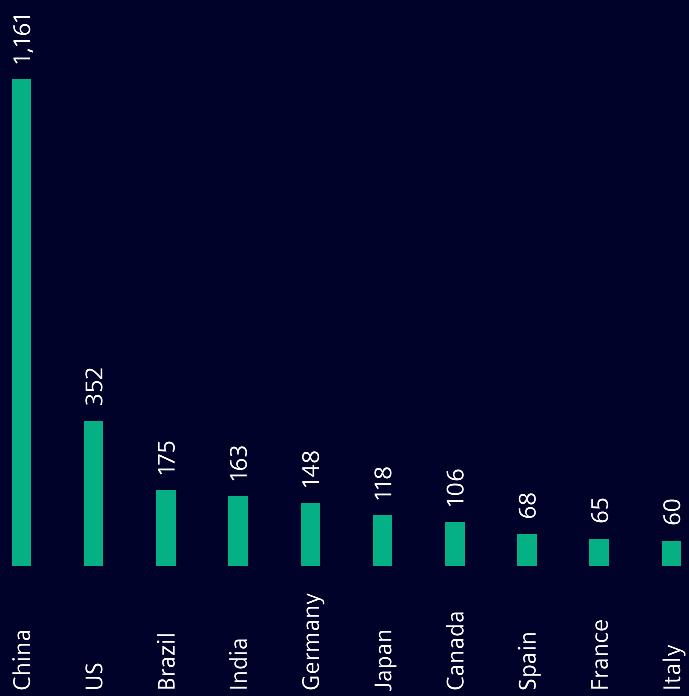
How is the electricity mix changing?

Low-emissions sources of electricity, led by renewables, are poised to overtake fossil fuels by 2030 in the Stated Policies Scenario (STEPS) and Announced Pledges Scenario (APS), ending decades of growth for coal.



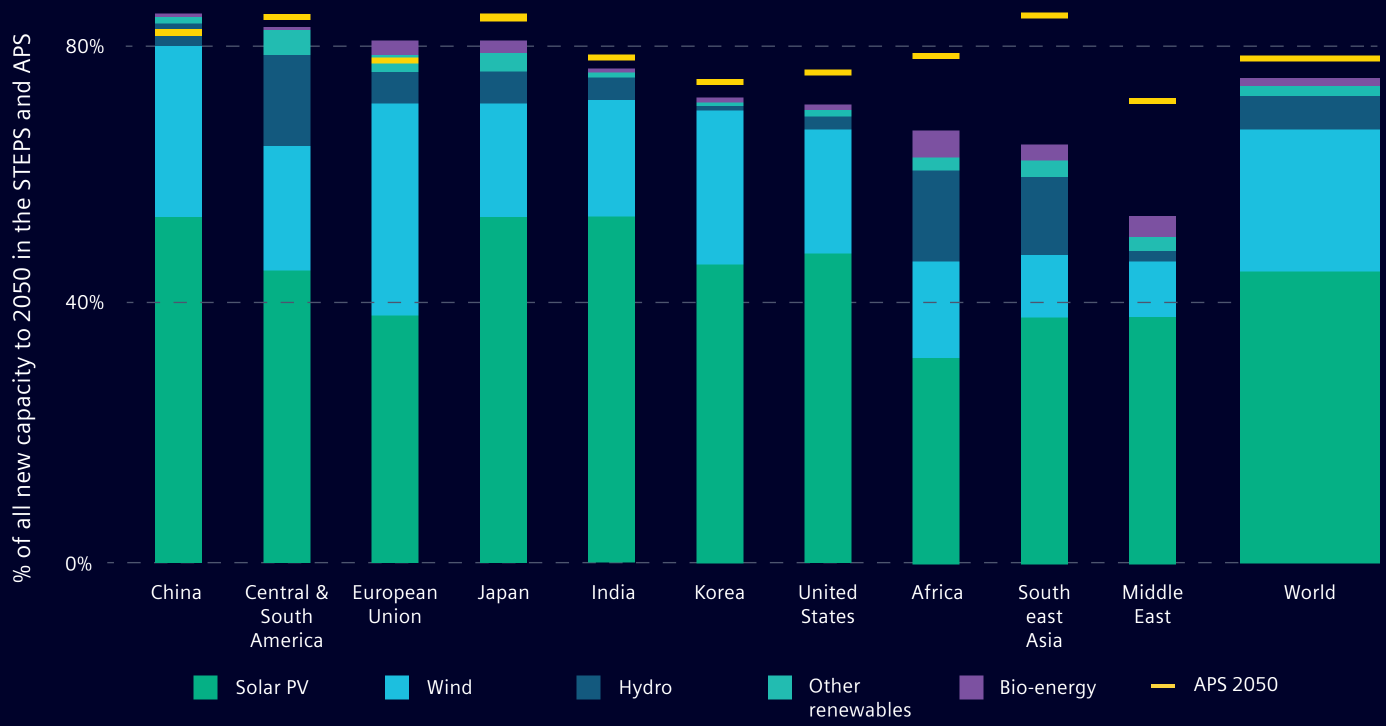
Leading countries in installed renewable energy capacity worldwide in 2022

(in gigawatts)



What new power capacity will be built?

Renewables are set to dominate global capacity additions, accounting for 75-80% of all new capacity to 2050 in the STEPS and APS, led by solar PV and wind.



Electrification of buildings: Efficiency gains will balance out increased electricity demand

Buildings account for 40% of annual global greenhouse gas emissions, a quarter of which is incurred during construction.[5] Considering that two thirds of the buildings that will make up the built environment in 2040 already exist, it will be crucial to decarbonize existing buildings to make sure that their polluting legacy ends as soon as possible.

Electrification is the capstone in a comprehensive future-proofing process that includes energy efficiency upgrades with smart building management solutions, the switch to electric HVAC or district heating and cooling systems, and localized on-site generation or the procurement of 100% renewable energy.

This is another example where electrification and digitalization have to go hand in hand to achieve full decarbonization. Extensive adoption of building automation solutions will improve efficiency and save crucial resources, balancing out the additional energy needs created by electrification.

In the IEA's net zero emissions scenario, electrification and the widespread deployment of efficiency and energy savings could enable the buildings sector to almost halve its emissions by 2030, despite a continued expansion of floor area and a rise in appliance ownership in emerging market and developing economies. In this scenario, the share of homes fitted with high-efficiency heat pumps will rise from 20% today to 30% in 2030 and over 50% in 2050.[6]

Urgency of upgrading buildings not realized

One driver of this scenario is the EU's Energy Performance of Buildings Directive (EPBD), a major legislative instrument for raising the energy performance of buildings in Europe. It sets mandatory emission reduction targets and efficiency standards while promoting incentives for renovation of buildings to meet those benchmarks. In the US, the Inflation Reduction Act of 2022 places a clear emphasis on growth through incentives and has unlocked massive capital flows, including billions of US dollars for home energy efficiency upgrades and improvements to home energy supply.

"Extensive adoption of building automation solutions will improve efficiency and save crucial resources"

While the path ahead and its milestones are clearly marked out, the urgency of upgrading buildings and optimizing their energy efficiency has not yet led to commensurate action everywhere. In order to make this transformation easier and affordable for all, it is important to lower the entry barriers to smart technology for building owners, who face a substantial loss of value over the coming decades unless their assets are upgraded to meet new efficiency standards.

If they are to succeed, any refurbishment and electrification initiative will have to balance tenants' expectations for comfortable, safe, and healthy environments with the building owners' need for continuous and cost-effective operations.

Electromobility and transport: EVs will dominate the roads

Offering the most cost-effective low-emissions technology in most vehicle segments, electric vehicles are set to take over our roads. According to the IEA's outlook, in the scenario of stated policies 25% of all new car sales will be electric by 2030, compared with 35% in the additional pledges scenario or 60% in the net zero emissions scenario.[7] And the large-scale roll-out of electric bus fleets is already happening. China is a trailblazer in this regard, notably in the megacity of Shenzhen with its fleet of over 16,000 electric buses. In the logistics sector, light commercial vehicles, like delivery vans, are following the same electrification trend.

The heavy freight segment could catch up, with widespread commercial adoption of electric heavy-duty vehicles forecast in the next two decades.

As a result, rapid emission reductions could manifest themselves, with emissions falling by one-quarter by 2030 in a net zero emissions scenario, due to electrification, efficiency improvements, and behavioral change.[8] Charging infrastructure is needed, including bidirectional charging at home and in enterprise assets, as well as megawatt charging points for long-haul transport.

Hard-to-electrify modes of transport

Other mobility sectors are more challenging to decarbonize. Aviation is a case in point, with battery-powered aviation still in its infancy. Synthetic drop-in e-fuels produced with renewable electricity could be a bridging technology.

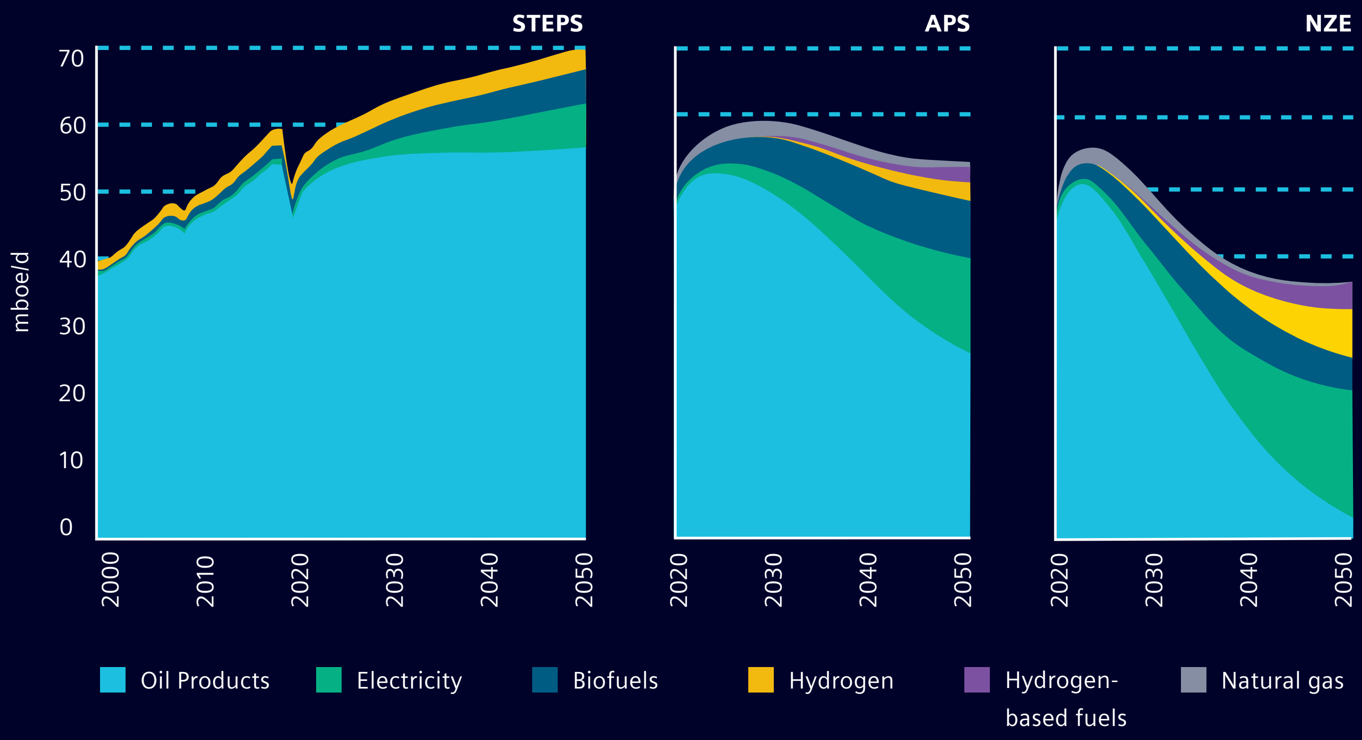
The decarbonization of maritime transport, i.e., shipping and harbor infrastructure, also presents a more complex picture with its multimodal ecosystem that includes power, mobility, heat, cooling, and vessels. Electrification with on-site and grid supply will deliver most of the solutions, backed up by green hydrogen or green methanol for container ships, ferries, trawlers, or naval vessels.

The success of decarbonization in the transport sector depends on how quickly oil can be replaced by battery-fueled alternatives; at present, fossil fuels still account for 90% of energy use in transport.

Considering that both passenger and freight activity are set to more than double by 2050[9] due to higher mobility demand in developing economies as living standards continue to rise, it is essential to embrace electrification and aim for a net zero emissions pathway. This outlook again underscores the need for more grid capacity and resilience.

Energy use in transport by scenario, 2000-2050

(in gigawatts)



Transport has long been the bedrock of oil demand, but its role weakens in the APS and NZE Scenario as electricity displaces very large volumes of oil

Note mboe/d = million barrels of oil equivalent per day

Electrification of industry and infrastructure: Almost the whole ticket

Complex assessments are needed for the decarbonization journey of industrial sites and infrastructures, such as manufacturing plants or chemical and process industry sites. They involve decarbonizing industrial processes and the materials used therein, the means of transport and whole supply chains, as well as all industrial buildings and infrastructures. In industry's transition to net zero, electrification again has a vital role to play.

The entire value chain must be electrified as much as possible. That includes switching all industrial and manufacturing processes from natural gas- and oil-based heating and cooling to electricity.

> "The next decade will also witness the maturity of the technologies that will bring about a full decarbonization of the industry sector."

For hard-to-abate industries with high heat intensity or other power-intensive plant processes, replacing coal with natural gas could be a first step to achieve emissions reductions, followed by a switch to biomethane, green hydrogen, and other biofuels for high-heat processes. These alternatives are, for the time being, still more costly than their fossil fuel counterparts.

An effective carbon tax will become the main lever for further abatement by always making low- or zero-carbon technologies the more economical option.

The demand for some carbon-guzzling materials such as steel and cement continues to increase, driven mainly by urbanization and industrialization trends in Africa, Southeast Asia, and India.[10] The use of lower-emissions materials, through improved energy mix in production or increased portion of recycled components, shall be explored.

Additionally, life extending measures must be pursued. Indeed, improved efficiency in the use of materials and greater reuse and recycling will offer a possibility to counterbalance the emissions' increase due to higher consumption of industrial materials.

Materials and energy efficiency, fuel switching to complement electrification efforts

Decarbonization of entire operations also means electrifying the industry's fleet, and this part will mostly use the blueprint set out in the electrification of the transport sector.

For the third part – buildings and infrastructure – the decarbonization effort in industry will follow the pathway set out by the building sector i.e., the implementation of energy efficiency measures thanks to building automation and digital twin solutions, the full electrification of buildings with electric HVAC solutions, and a switch to zero-carbon electricity.

Industrial sites tend to have more space than residential ones, and photovoltaics might typically cover about 20 to 30% of the load, unless there is a large-scale rollout of PV on a campus-style area. On-site PV generation combined with batteries will play a role, but will never cover 100% of the needed capacity, so grid back-up will remain indispensable.

In a net zero emissions scenario, stringent policies on materials efficiency, energy efficiency and fuel switching could see emissions in the industry sector reduced by nearly a quarter by 2030 compared to 2021 levels.[11]

The next decade will also witness the maturity of the technologies that will bring about a full decarbonization of the industry sector and make them ready for full-scale deployment from the 2030s onward.

In order to reach the 1.5-degree goal, the speed of emissions reductions in the industry and the transport sectors is scheduled to accelerate to 10% annually enabled mainly by electrification, and aided by low-emissions fuels and carbon capture, utilization, and storage (CCUS) technologies.[12]

"The entire value chain must be electrified as much as possible."

Can it cope? **Preparing the grid for the electrification push**

All three of the major sectors that need to be decarbonized – buildings, transport, and industry – will increase grid demand, since only a fraction of energy need can be covered through on-site generation. In addition, capacity is expanding due to a global increase of electricity demand driven by population growth and strong urbanization, especially in the BRIC states and other emerging countries. Today, the grid infrastructure is not set up to accommodate the surge in capacity, nor the dynamic nature of the interaction with renewable energy sources.

As a result, grid operators are facing a whole set of challenges including a steep rise in demand, fluctuating usage patterns, and the boom of renewables that will affect the grid on all levels. Especially lower-voltage networks – notoriously under equipped with sensors, actuators, or other intelligent grid assets – will have to deal with a highly volatile, decentralized generation structure and flexible usage patterns.

Smart grid solutions reduce CAPEX and accelerate grid transformation

Sizeable investments are earmarked to expand and modernize grid infrastructure. By 2050, grids will increase in length by about 90%. In the scenario of currently stated policies, the IEA anticipates annual investments of US$770 billion in infrastructure and storage in this period; in the additional pledges scenario, they are close to US$1 trillion per annum. Today, transmission bottlenecks are already creating inefficiencies and risks. Regulators from Germany to Vietnam have had to curtail the connection of new solar PV or wind projects to the grid, while in some countries, not all of the electricity generated could be transported to end users.[13]

Building new grid infrastructure is no simple task. It needs investments in substations, transformers, and countless cables and overhead lines, all of which require resources, space, political consensus – and time. It can take up to a year to build a substation and more than ten years to build a high-voltage line, depending on the jurisdiction and length of the line, with some of the longest lead times found in advanced economies. As we are running out of time and funds are finite, we need to harness the digital solutions that will let us redesign and strengthen the grid infrastructure faster and more cost-effectively.

How transmission system operators are affected

In the next two decades, as more and more fossil-fueled power plants shut down and distributed energy resources dominate in many countries, there will be no more rotating mass to stabilize the frequency of the grid. Power electronics will have to take on that role. Indeed, dynamic stability must be increasingly provided by power inverters that are fundamentally decentralized throughout the network. This is no easy task. We will have to redesign the whole grid to avoid short circuits, which in turn requires the industry to make a concerted effort to collaborate and adapt. e.g., by making generic inverter models and achieving standardization between various suppliers and operators in the market.

What it means for distribution system operators

Cross-industry collaboration is the order of the day. Transmission system operators (TSOs) must collaborate with distribution system operators (DSOs). Today, it is the TSOs' task to stabilize the grid. But in the absence of centralized power plants, DSOs must listen to grid stabilization signals and provide ancillary services (sector coupling) to TSOs so that the whole electrical grid system can function. Currently, the regulatory system is set up in such a way that these players (depending on country) are not always incentivized to cooperate.

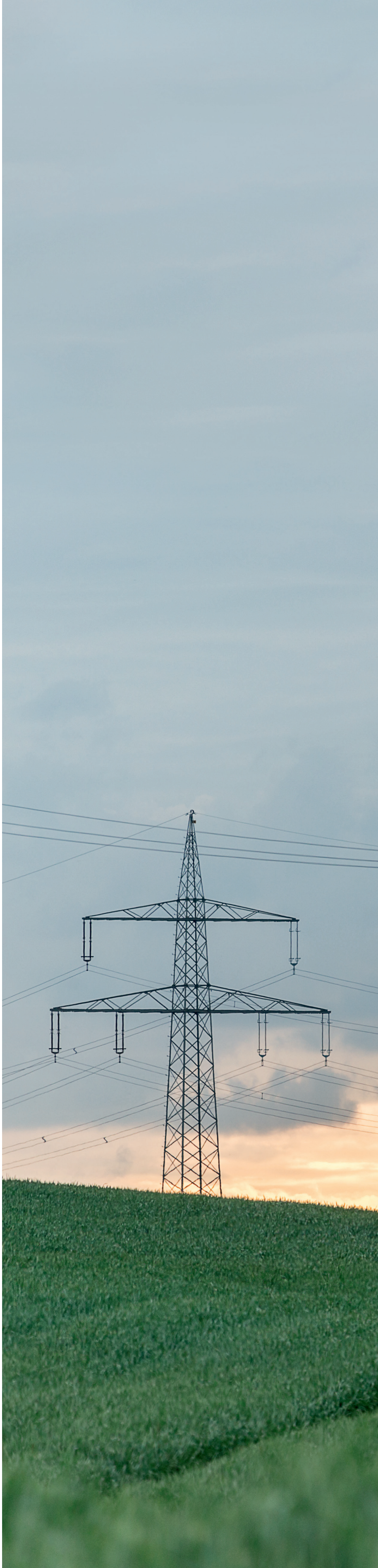
Such lack of collaboration leads to frequent redispatches – a throttling of generation capacity requested by a TSO or proactively planned by power plant operators to avoid grid bottlenecks – that have become necessary in regions with a high share of renewables. Redispatches are highly inefficient, counteract the decarbonization drive, make electricity more expensive for the end-consumer – and could be avoided with better coordination between TSOs and DSOs.

How it all plays out on the grid edge

The tripling of generation capacity will mostly take place on the grid edge. Today, for example, a DSO decides whether to accept connections of more high-power chargers, heat pumps (AC) or more solar capacity. However, there is currently no data available to determine whether this will lead to overvoltage events, voltage violations or power quality effects.

Once distribution grids are upgraded with the necessary sensors, neural networks can be used to extrapolate and triangulate the state of the low-voltage network and approximate the state of the network, helping to determine how much extra capacity can be added. The combination of Artificial Intelligence (AI) and decentralized automated decisions can be used to open the full reliable capacity of the existing network.

However, in many countries, the deployment of smart technology in the grid is incompatible with regulatory frameworks. As of today, it is often easier to get approval for a fixed asset – such as a substation upgrade with a return on investment that can be calculated for the next five years – and maybe risk overcapacity, than to begin developing a neural network. In the long run, digital solutions will help us save CAPEX. They are also our only tool to weather the perfect storm of challenges that is facing the grid infrastructure. Just as TSOs and DSOs have to rethink their traditional roles and join forces in a common bid to rebuild a better, more flexible, and resilient grid, regulators will need to adapt to a more entrepreneurial and flexible way of approving grid projects.



Conclusion: **The time for electrification is now**

By now, it should be clear to everyone that we simply cannot afford inaction. Already today, the climate crisis is making itself felt in devastating ways, and the Paris Agreement's 1.5-degree goal is slipping out of reach as economies continue to burn ever more fossil fuels. The breakdown of the climate will cause major disruptions to life and prosperity as we know it.

Most new climate policy initiatives are geared toward accelerating the speed of the energy transition, but they are not yet sufficient for achieving full decarbonization by 2050. Climate targets and ambitions have recently been raised by the European Green Deal and the Inflation Reduction Act in the US. They aim to boost clean energy technologies – while attracting even larger investment from the private sector,[14] since even the €1 trillion in mobilized funding pledged by the EU Commission over the next decade and the US$370 billion of the Inflation Reduction Act are not nearly enough to finance the rapid and all-encompassing transition that is needed.

In addition to the strong moral imperative to ensure that future generations can thrive in a livable environment, technologies that are good for the climate also make economic sense. In order to channel investments and technology development to the areas with the biggest decarbonization impact, we need a value tree analysis for the long-term development of energy systems. This will help regulators incentivize innovations that reduce CAPEX and improve OPEX.

There is no alternative to decarbonization, and electrification is critical for making it happen. The time to act is now. We must embrace the innovative products, systems, and solutions which form the basis for connectivity and digitalization and will ultimately propel us toward full decarbonization.

"The world is in a critical decade for delivering a more secure, sustainable and affordable energy system – the potential for faster progress is enormous if strong action is taken immediately."

References:

1. There is still a large gap between current ambitions and the 1.5 °C goal, according to the International Energy Agency's flagship report, the World Energy Outlook 2022. Under the stated policies scenario, the share of fossil fuels would still account for 60 percent or 32 gigatons of energy-related CO_2 emissions by 2050. The additional national pledges scenario – if implemented – would only lower these emissions to 12 gigatons by 2050. IEA (2022): Executive Summary, in: World Energy Outlook 2022. https://www.iea.org/reports/world-energy-outlook-2022/executive-summary.
2. WEO (2022), p. 44.
3. BloombergNEF's electric vehicle outlook 2023, https://about.bnef.com/electric-vehicle-outlook/
4. WEO (2022), p. 126.
5. Architecture2030, "Why the building sector?", https://architecture2030.org/why-the-building-sector.
6. IEA (2022), WEO 2022, p. 74.
7. IEA (2022), WEO 2022, p. 74.
8. IEA (2022), WEO 2022, p. 125.
9. IEA (2022), WEO 2022, p. 74.
10. IEA (2022), WEO 2022, p. 74.
11. IEA (2022), WEO 2022, p. 125.
12. IEA (2022), WEO 2022, p. 74.
13. IEA (2022), WEO 2022, p. 44.
14. WEO (2022), p. 41.

Sources:

- IEA (2022), World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report).
- https://www.statista.com/statistics/267233/renewable-energy-capacity-worldwide-by-country/))
- IRENA (2022), World Energy Transitions Outlook 2022, The International Renewable Energy Agency, Abu Dhabi.
- IRENA (2022), Renewable Energy Statistics 2022, The International Renewable Energy Agency, Abu Dhabi.
- Architecture 2030, Why the Built Environment? https://architecture2030.org/why-the-building-sector.
- Bloomberg (2023), BloombergNEF's electric vehicle outlook 2023, https://about.bnef.com/electric-vehicle-outlook/

Published by
Siemens Switzerland Ltd

Smart Infrastructure
Global Headquarters
Theilerstrasse 1a
6300 Zug
Switzerland
Tel +41 58 724 24 24

Status 09/2023