REUTERS EVENTS™

A white paper in conjunction with

SIEMENS

The role of **artificial intelligence** in sustainable infrastructure

Managing grids and buildings for a climate-friendly future

Executive summary

The world is alive to the need for greater sustainability. Decarbonising energy systems and moving towards a circular economy are now at the top of corporate and government agendas. But having sustainability as a priority does not make it any easier to achieve. This is particularly the case in infrastructure, or the physical underpinnings of society. Buildings, power grids, transport systems and the like all represent massive investments that have been designed for longevity rather than low emissions.

Consequently, they cannot easily be replaced by more sustainable alternatives. Making today's infrastructure more sustainable could end up being a slow and costly process unless new tools and techniques can be applied to the task. One of the tools that shows significant promise is artificial intelligence or AI—the application of algorithmic processes such as machine learning to solve complex problems that could even be beyond the scope of human experts.

This paper, prepared in association with Siemens, Europe's largest industrial manufacturing company, looks at why AI could be particularly suited to solving some of the thorniest problems in infrastructure sustainability—and how it is already being used today.

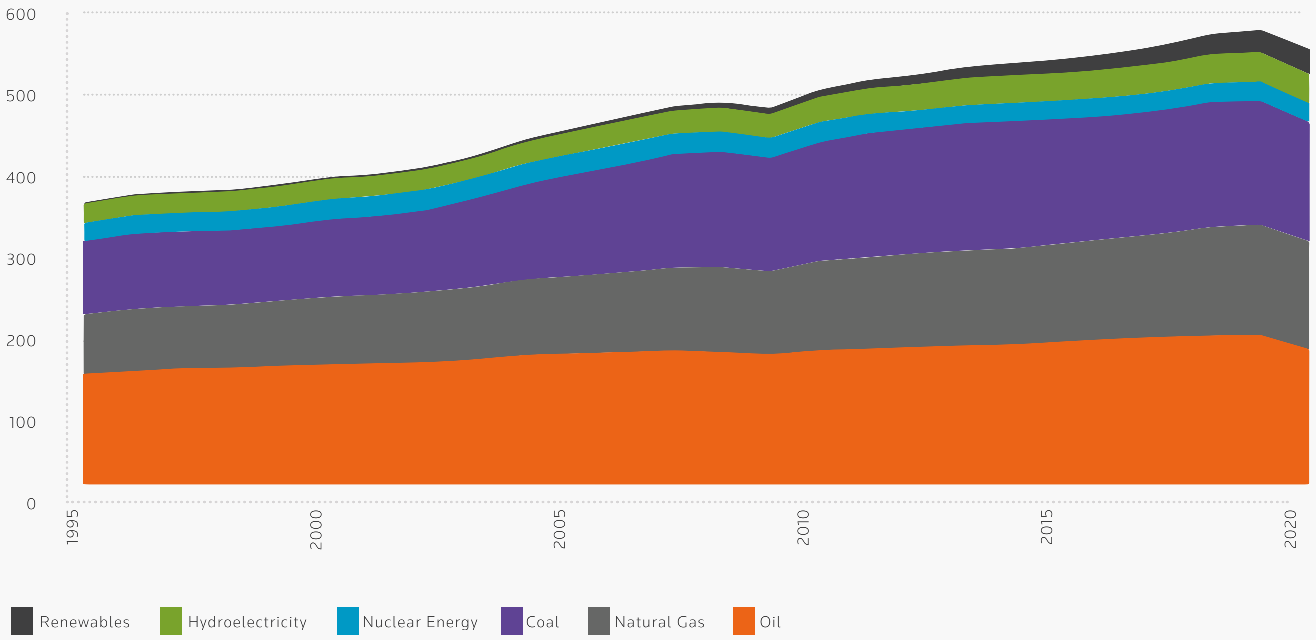
The scale of the sustainability problem

Modern society was born into a largely unchanging world in which natural resources were seemingly unlimited. In the last half century or so, however, it has become abundantly clear that humankind is extracting resources from the planet at a rate that is far higher than natural ecosystems can withstand, creating growing challenges for society, the economy and the environment.

These challenges are frequently interlinked and include issues such as biodiversity and habitat loss, air and plastic pollution, and climate change-induced extreme weather events and sea-level rises. Each one could have potentially cataclysmic impacts on society. Climate change alone, for example, could lead to 200 million refugees by 2050 if left unchecked, according to one projection by the United Nations.[i] However, in most cases the scale of the threat is matched by the scale of change needed to avoid disaster.

To avert the worst impacts of climate change, for example, fossil fuel consumption needs to be significantly reduced. Yet in 2020 fossil fuels accounted for more than 83 percent of all primary energy consumption in the world.

World consumption of primary energy up to 2020, in exajoules



Source: BP.[ii]

Sustainable infrastructure: a major challenge

This reduction also needs to happen relatively rapidly, by 2050 at the latest. This is well within the lifespan of many types of infrastructure being built today. Modern buildings, for example, typically last anywhere from 50 to 150 years.[iii] Primary grid infrastructure, like transformers or switchgears, meanwhile, can at least last 40 years and may take up to a decade to go from planning to construction, depending on permits and consenting timeframes.

This implies that infrastructure being designed and built today should in theory be ready for a zero-carbon world. Nothing could be further from the truth, however. As of 2020, for example, almost 200 gigawatts (GW) of new coal-fired generation assets were under construction and a further 298 GW were planned around the world.[iv]

Digital technology as a sustainability enabler

Since most of today's infrastructure was not specifically designed with low CO2 emissions in mind, it frequently performs poorly on sustainable measures. Buildings, for example, often require large amounts of fossil fuel for cooling or heating because they are designed like a greenhouse or poorly insulated. And traffic systems create carbon and other emissions because they do not allow for efficient routing of vehicles.

In most cases, replacing existing infrastructure with more sustainable designs is not an option. Infrastructure projects involve large capital expenditures for which private and public sector backers expect a meaningful return, which precludes early retirement. The decision to renovate or to rebuild needs to incorporate several aspects like the building substance or changes in building usage, e.g. the new working modes due to the Coronavirus pandemic, to achieve the most sustainable solution considering decommission, construction and life time. Few infrastructure projects today are designed with reduction, reuse or recycling in mind.

Because of this, improving the sustainability of infrastructure will almost certainly involve the use of tools and techniques that can allow existing structures to operate in more sustainable ways. Digital technology is seen as key enabler in this respect because it can be used to improve the monitoring and control of infrastructure, enhancing the efficiency and sustainability of operations. Furthermore, digital technology can be implemented in existing infrastructure much faster, compared to upgrading the infrastructure itself. E.g. Dynamic line rating may increase the capacity of transmissions lines during windy days and can be implemented without long lasting permits and consenting timeframes.

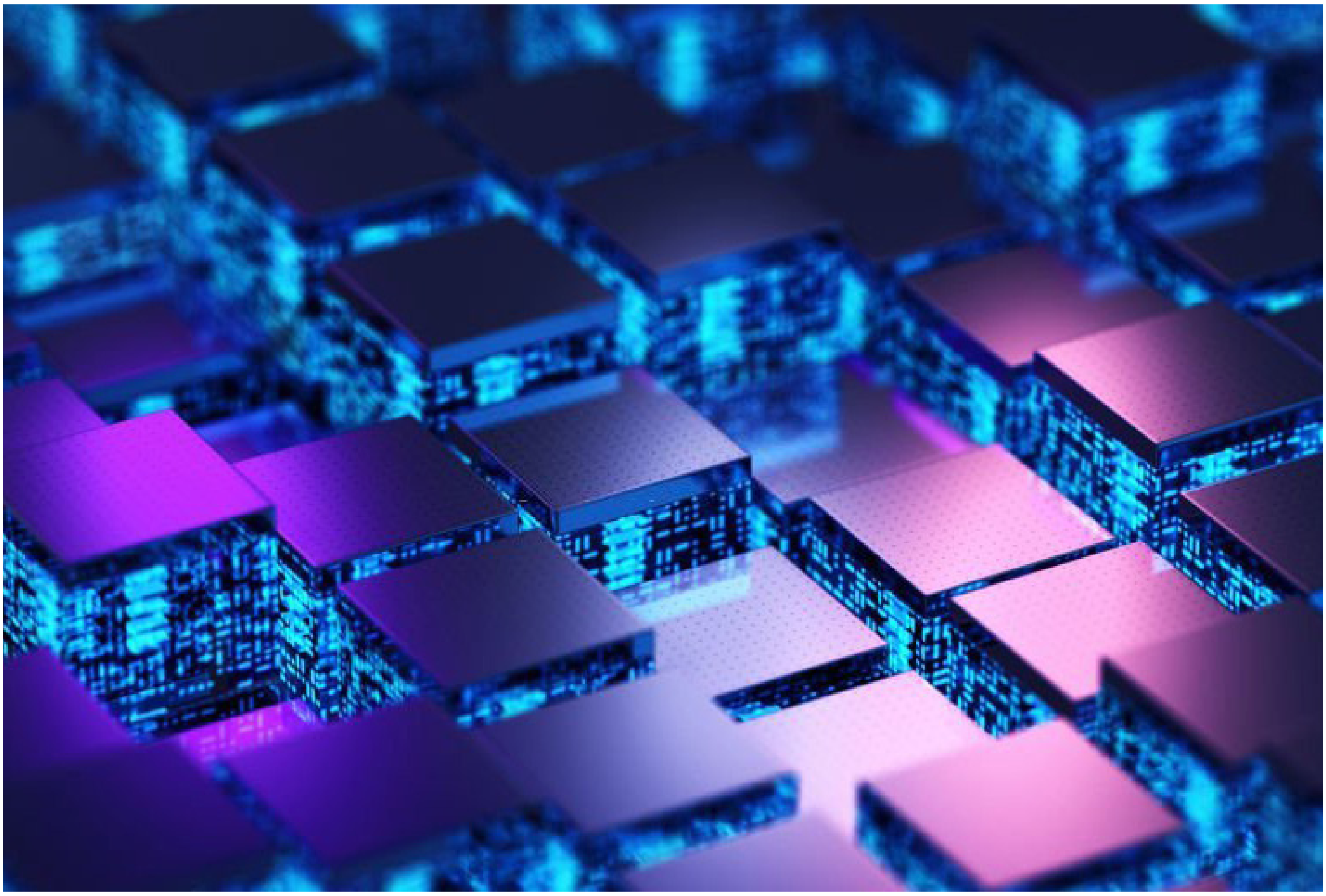
The role of AI

Typically, the digitalisation of infrastructure will involve the use of sensor networks and control systems to monitor the real-time status of an asset and improve its performance along more sustainable parameters. Even with relatively small digitalisation projects, however, the amount of data generated by an asset rapidly becomes hard for operational teams to manage and process efficiently.

On the flip side, physical and financial constraints may mean digitalisation programmes can only provide a partial picture of assets in real time, forcing asset managers to make decisions based on incomplete data. AI can help overcome both problems, processing large amounts of information in real time and applying heuristics to detect important signals and trends within incomplete data sets.

"You would need 100 data points to describe the system in the old style," says Thomas Kiessling, chief technology officer at Siemens Smart Infrastructure. "We might only have 15 data points out of the 100, but what AI can do is continuously search for patterns."

This capability can be used to detect emerging faults in grid infrastructure, for example, helping to avoid the need for remediation and upgrades.



Improving grid sustainability

A major focus for today's electricity grids is how to move from centralised fossil-fuel generation to decentralised renewable energy systems. This energy transition is key not just for the sustainability of electricity production but also for a host of other sectors. Allowing electric grids to power vehicles, for example, will improve the sustainability of transport.

And using electricity to produce low-carbon fuels such as green hydrogen, created from water using renewable energy, will enhance the sustainability of industrial processes. But switching to renewables is not a simple matter. The old, centralised grid structure, with fossil-fuel energy on tap, was easy to control. In the decentralised grid of the future, variable renewable energy supplies will have to be dispatched as efficiently as possible to keep the network steady.

At the same time, load centres—from major industrial hubs to household fridges and air conditioning units—will need to respond intelligently to changing levels of electricity supply. And a whole new class of electrical energy storage assets, such as electric vehicle batteries, will need to switch from consuming to delivering electricity as part of efforts to balance the grid.

Controlling such intricate, interconnected infrastructures on a second-by-second basis will be extremely hard using traditional systems. AI, on the other hand, could easily take care of tasks such as building-level energy optimisation.

Use case: high-impedance faults

While transitioning to low-carbon generation is a primary concern for the utility sector, it is not the only sustainability issue relating to electricity generation. Another less-publicised problem is the destruction of natural ecosystems by fires arising from high-impedance faults in electrical infrastructure. Detecting those faults "represents one of the biggest challenges in power distribution networks."[v]

High-impedance faults, where a power line meets a resistive object such as a tree branch, are a major fire risk but remain hard to detect because the current lost from the lines is so small that it is not apparent using traditional fault detection methods. AI systems, however, may be able to detect the faults by spotting patterns in distribution network power flows that are virtually impossible for humans to identify. Siemens is working on an AI-based high-impedance fault detector that could significantly reduce the incidence of faults, and with it the chances of forest fires that claim hundreds of lives a year while destroying natural habitats and worsening the effects of climate change.

Improving building sustainability

For most of modern history, buildings have been designed to be built and maintained as quickly and cheaply as possible. This means sustainable features such as insulation have remained a secondary consideration, resulting in buildings that are inherently wasteful. While this trend is changing with tighter regulations around building sustainability, for most buildings it is too late to alter the design. That does not mean the buildings cannot be made to operate more efficiently, however.

Around 75 percent of commercial buildings are not managed as efficiently as they could be, with lighting left on at weekends or levels of heating and cooling that are beyond the needs of the occupants. Simply using AI-based management systems to optimise energy use can save up to around 30 percent of the energy lost from these buildings, for example by updating based on real-time building automation configurations usage patterns.

AI can also help facilities managers to improve sustainability by crunching through large amounts of device and sensor data in search of significant trends. This can substantially remove the efforts involved in improving building sustainability, making it much easier to deploy and scale sustainable practices—an important point given that facilities management teams tend to be quite small.

Use case: making buildings smarter, faster

Improving building sustainability often involves equipping a space with sensors and controls to monitor and adjust features such as temperature and lighting. But lights and temperature controls do not act independently of each other: if lighting is switched off because employees are leaving their workplaces, for example, it is a fair bet that thermostats can be turned down as well.

Understanding how these devices interact with each other is a painstaking process. This means facilities teams can take months to create a model that will enable a sensor-equipped building to behave more sustainably. AI systems, however, can pick up on interrelationships within a matter of days, and can potentially do so using far fewer sensors than a human team would need.

This means building asset owners can make a much quicker return on sensor technology investments and even get away with lower capital expenditures for smart buildings in the first place. At the same time, facilities teams can deliver sustainability improvements more quickly and cost effectively, allowing more buildings to adopt sustainable practices in a shorter span of time.

With the vast bulk of buildings still lacking smart controls, this ability to improve sustainability in a shorter timespan and with fewer resources could be a major asset in helping to decarbonise existing building stock. In buildings, there is already an overriding argument to apply AI to its fullest extent. The environment "is perfect for learning networks," Kiessling says.

"I can constantly optimise the behaviour of a building with respect to its objective, which in most cases is keeping people comfortable and reducing operating costs."

The evolution of AI in infrastructure control

AI is a powerful tool, and it is getting continuously more powerful. In areas such as medicine, AI is outperforming human experts—and it is not always clear how the algorithms are doing it.[vi] For companies tasked with managing critical infrastructures such as electricity grids, handing the reins to a black box might be a challenging proposition, no matter how good the results are.

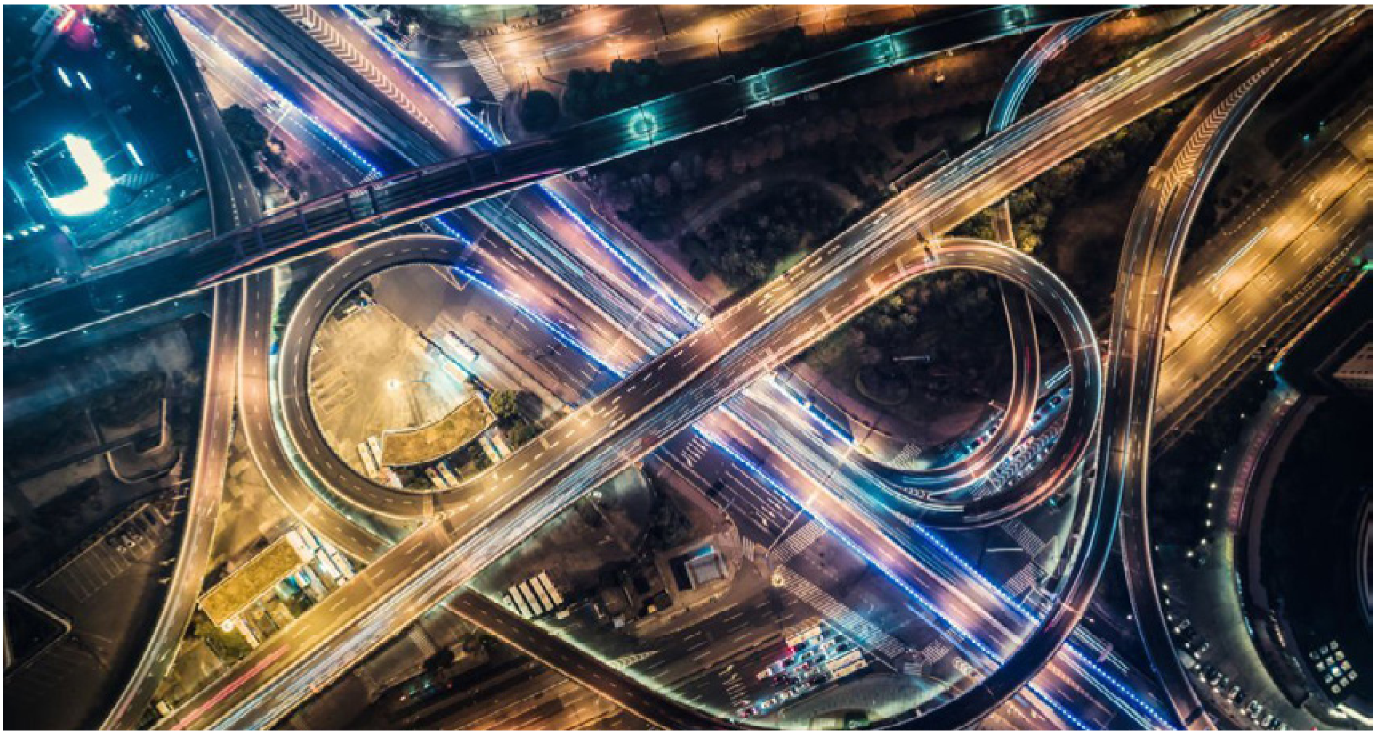
For this reason, early forays into the use of AI for infrastructure sustainability are likely to focus on supporting rather than replacing human decision making. At the same time, new forms of AI are being created that can report back on how they have achieved their results, aiming to improve confidence in and understanding of the algorithms' capabilities.

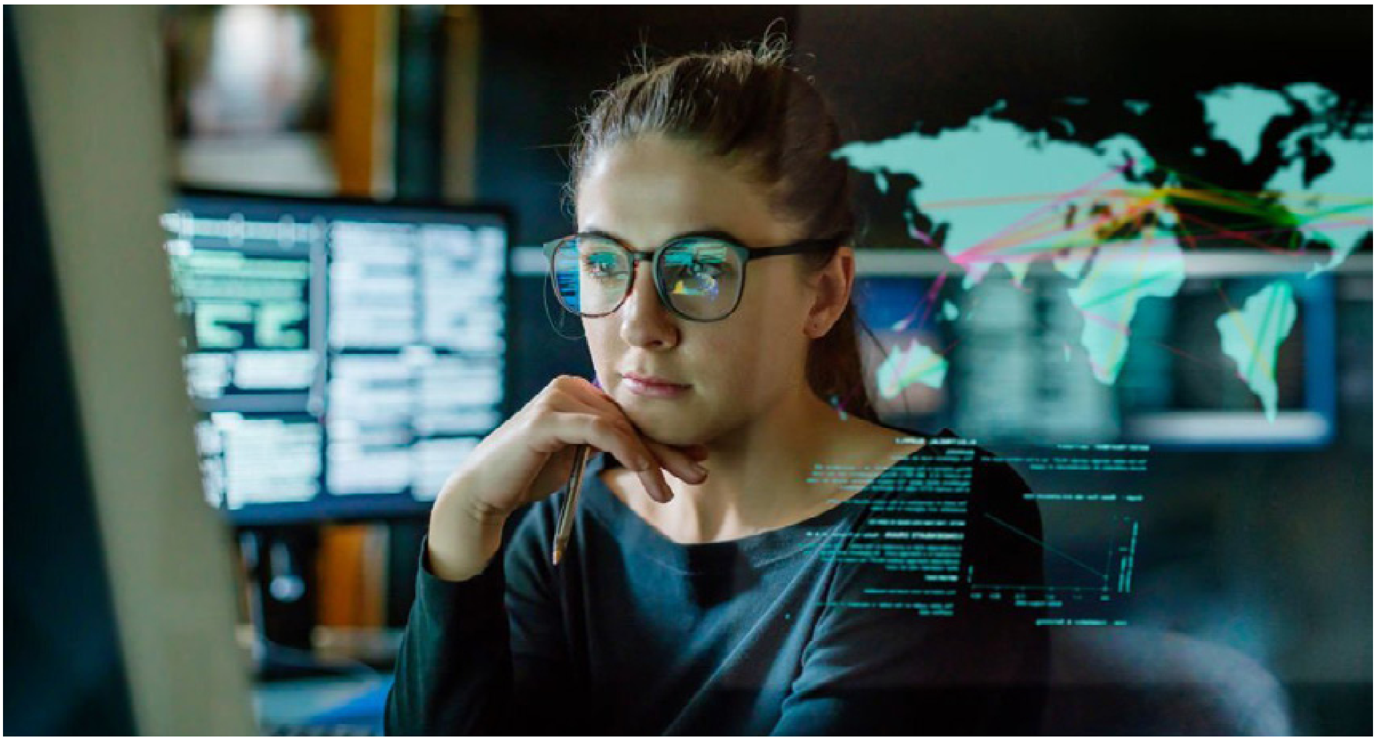
In time, it is possible to envisage different infrastructures becoming interconnected to a point that their complexity defies human-mediated monitoring and control.

"Distributed decision support and decision making is one of the key patterns in future energy networks. Local agents will take decisions then communicate the decisions to other local and upstream agents,"

says Kiessling. "A system like this will be more robust than today's central control systems."

Although AI for infrastructure operation might start with only providing support to humans, it should be designed for closed loop operation from the beginning. Typically, in buildings there is no staff available, which could apply AI recommendations in good time, and in grid control centers, operators don't have the time to take care on all operational improvement recommendations produced by AI.





Why AI is key to sustainability

"AI adoption is still in its infancy in infrastructure, with most projects still at proof-of-concept or pilot stage", says Scott Duncan, research engineer and branch chief for power generation systems at the Georgia Institute of Technology in the United States. However, the potential of the technology is immense because AI is good at handling complex data sets—and infrastructure projects tend to be one-of-a-kind initiatives with unique characteristics.

> "There is an opportunity for AI to learn things faster than we can, given all the variations," Duncan says. "The technologies are racing ahead."

In the short term, using AI to support human decision making will be an invaluable aid in improving the sustainability of infrastructure amid changing environmental conditions and the need to apply technologies and processes to decarbonisation. In fact, it is unclear whether the transition to a low-carbon, circular economy world can be achieved without AI in the timeframe required, particularly given a shortage of human expertise in complex fields such as operating grids and building controls.

"We could probably do it without AI, but I think it would require a lot of cost and a workforce that would be hard to spool up really quickly," says Duncan. "In the near future, I foresee the dynamics of the grid as being something that AI would be needed to help with. There's a lot of moving pieces that have to come together at once. I don't think we should do it without AI."

Outlook and conclusions

While AI research extends back to the 1950s, it is only in the last decade or so that the technology has come into its own, delivering credible results in a wide range of fields. Infrastructure management has largely sat on the margins of this trend, perhaps because many infrastructures have been viewed as relatively static following construction or commissioning. This view is changing with a growing need for sustainable operations.

Today's infrastructures increasingly need to adapt to changing environmental circumstances and be flexible enough to admit transitions related to energy flows, new materials and reuse and recycling. A stepwise approach to applying AI to the process of adaptation will allow operational teams to get the full advantages of the technology without undue risk. For mission-critical assets such as grids, "the humans need to stay in control," says Kiessling.

"There will always be concerns about handing over control to the machine. What we're doing is providing software that looks at the status of the system and comes back with suggestions how to improve metrics like stability, capacity, and quality, for example of the energy grid."

For complex operations, however, there will be a need for solutions working in closed loops – especially when there is not enough staff available to follow-up on recommendations produced by AI. And that is why humans need to entirely understand what AI is doing, it's a matter of trustworthy AI. It is of major importance that engineers have broad knowledge about AI and the connected systems. Otherwise, there will be a lack of trust and AI applications will not be fully utilized.

Whatever the level of integration, what is increasingly clear is that smarter infrastructure can have a significant impact on sustainability. That will make AI an intelligent choice for a growing number of infrastructure projects going forward.

References

[i] *David Wallace-Wells, The Uninhabitable Earth. London, Penguin Random House UK, 2019.*

[ii] *BP website, 2022: Primary energy. Available at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html.*

[iii] *The Constructor, 2022: What is the Life Span of a Building? Available at https://theconstructor.org/question/what-is-the-life-span-of-a-building/.*

[iv] *Simon Evans and Rosamund Pearce, Carbon Brief, March 26, 2020: Mapped: The world's coal power plants. Available at https://www.carbonbrief.org/mapped-worlds-coal-power-plants.*

[v] *Abdulaziz Aljohani and Ibrahim Habiballah, Energies 2020, 13, 6447: High-Impedance Fault Diagnosis: A Review.*

[vi] *Jason Deign, Cisco, June 9, 2020: Doctors win with a smart new addition to the team. Available at https://newsroom.cisco.com/c/r/newsroom/en/us/a/y2020/m06/doctors-win-with-a-smart-new-addition-to-the-team.html.*