Digitalisation and Energy

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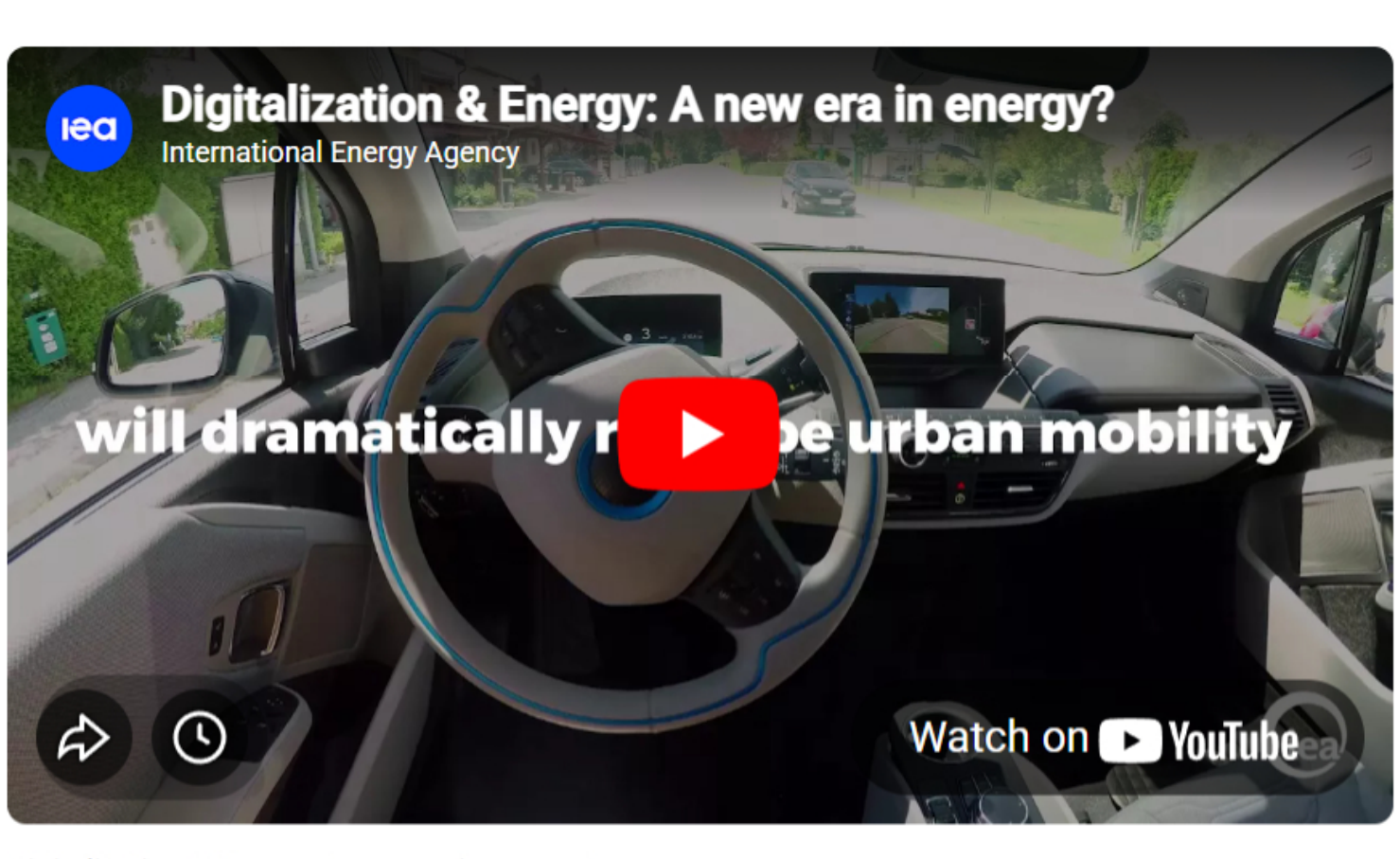
Digital technologies are everywhere, affecting the way we live, work, travel and play. Digitalisation is helping improve the safety, productivity, accessibility and sustainability of energy systems around the world. But it is also raising new security and privacy risks, while disrupting markets, businesses and workers.

Digitalisation & Energy is the International Energy Agency's first comprehensive effort to depict how digitalisation could transform the world's energy systems. The report examines the impact of digital technologies on energy demand sectors, looks at how energy suppliers can use digital tools to improve operations, and explores the transformational potential of digitalisation to help create a highly interconnected energy system.

This report seeks to provide greater clarity to decision makers in government and industry on what digitalisation means for energy, shining a light on its enormous potential and most pressing challenges. It also lays out no-regret recommendations to help steer the world towards a more secure, sustainable and smarter energy future.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Read more about automation, connectivity, electrification and sharing (ACES)

A new era in energy

Digitalisation: A new era in energy?

Over the coming decades, digital technologies are set to make energy systems around the world more connected, intelligent, efficient, reliable and sustainable. Stunning advances in data, analytics and connectivity are enabling a range of new digital applications such as smart appliances, shared mobility, and 3D printing. Digitalised energy systems in the future may be able to identify who needs energy and deliver it at the right time, in the right place and at the lowest cost. But getting everything right will not be easy.

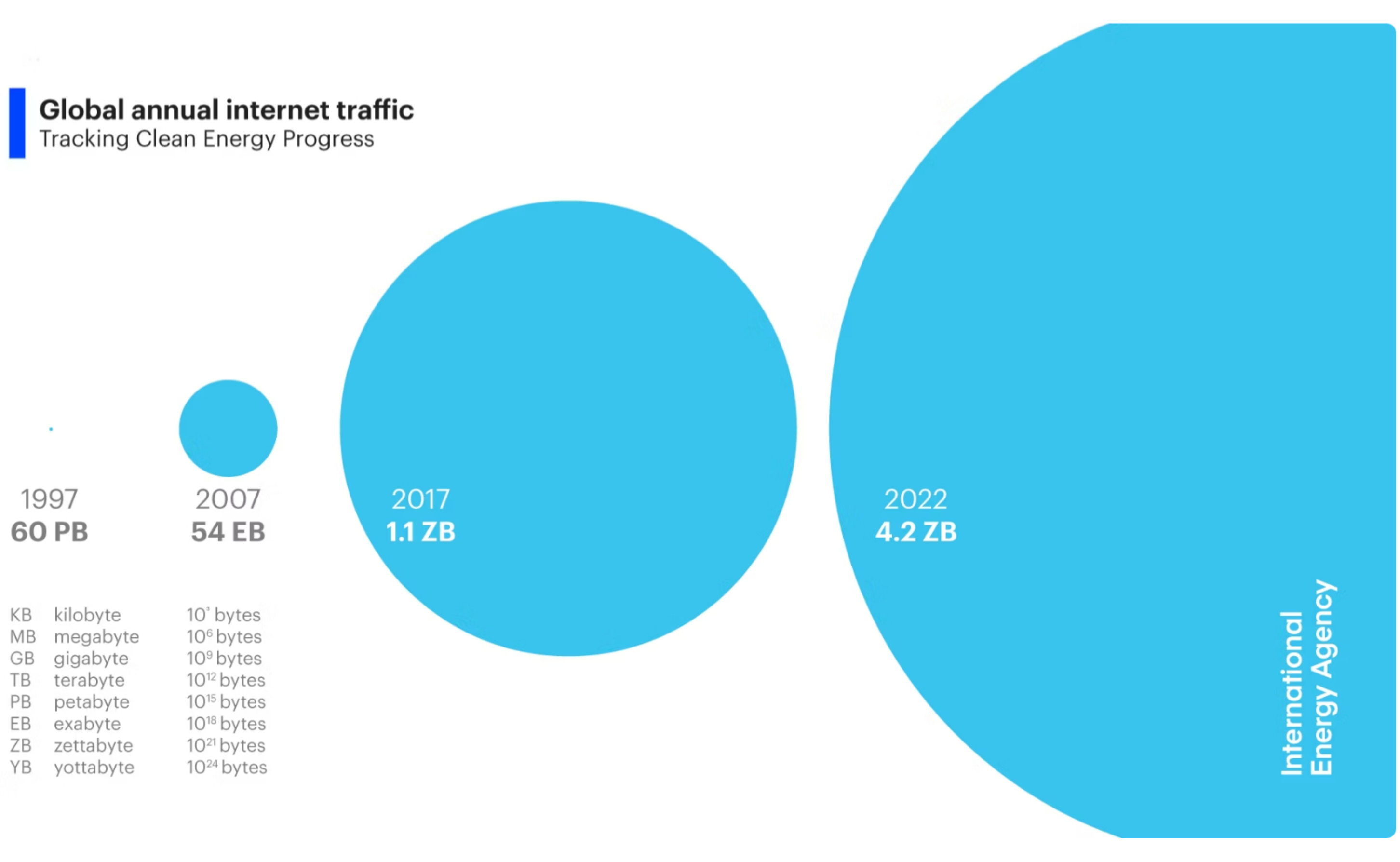
Digitalisation is already improving the safety, productivity, accessibility and sustainability of energy systems. But digitalisation is also raising new security and privacy risks. It is also changing markets, businesses and employment. New business models are emerging, while some century-old models may be on their way out.

Policy makers, business executives and other stakeholders increasingly face new and complex decisions, often with incomplete or imperfect information. Adding to this challenge is the extremely dynamic nature of energy systems, which are often built on large, long-lived physical infrastructure and assets.

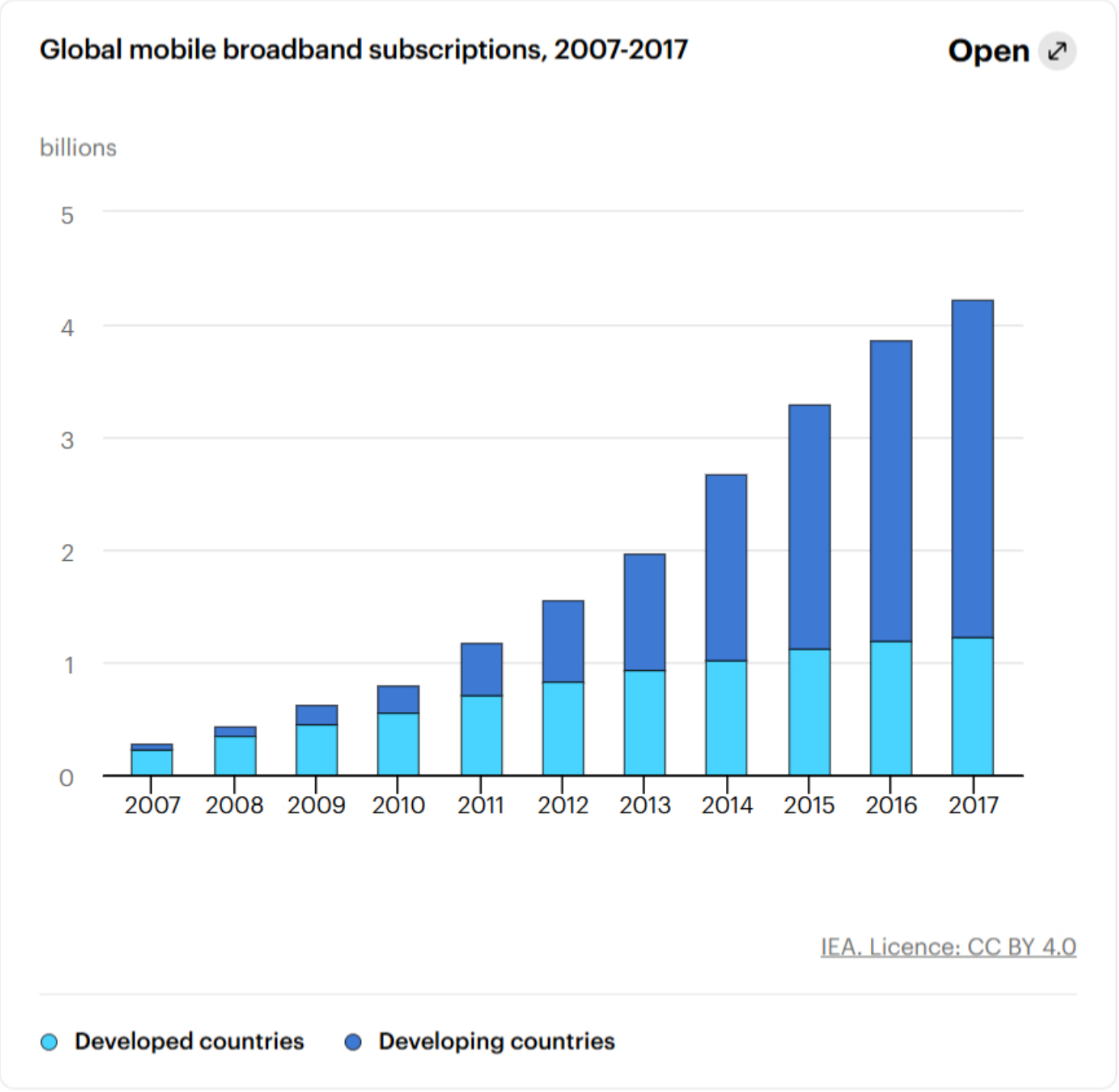
The ubiquity of data, connectivity and devices

Digitalisation trends are truly astounding. Data are growing at an exponential rate – internet traffic has tripled in only the past five years and around 90% of the data in the world today were created over the past two years.

This exponential growth has led to the use of increasingly large units of measurement. For example, global annual internet traffic surpassed the exabyte threshold in 2001 and is expected to pass the zettabyte threshold by 2017.


Global annual internet traffic
Tracking Clean Energy Progress

People and devices are also becoming connected in ever-increasing numbers. More than 3.5 billion people, or nearly half the global population, now use the internet – up from only 500 million in 2001. About 54% of households now have internet access at home. In the last five years, global mobile broadband subscriptions increased threefold and surpassed 4 billion active subscriptions in 2017. There are now more mobile phone subscriptions (7.7 billion) than people in the world.


Global mobile broadband subscriptions, 2007-2017

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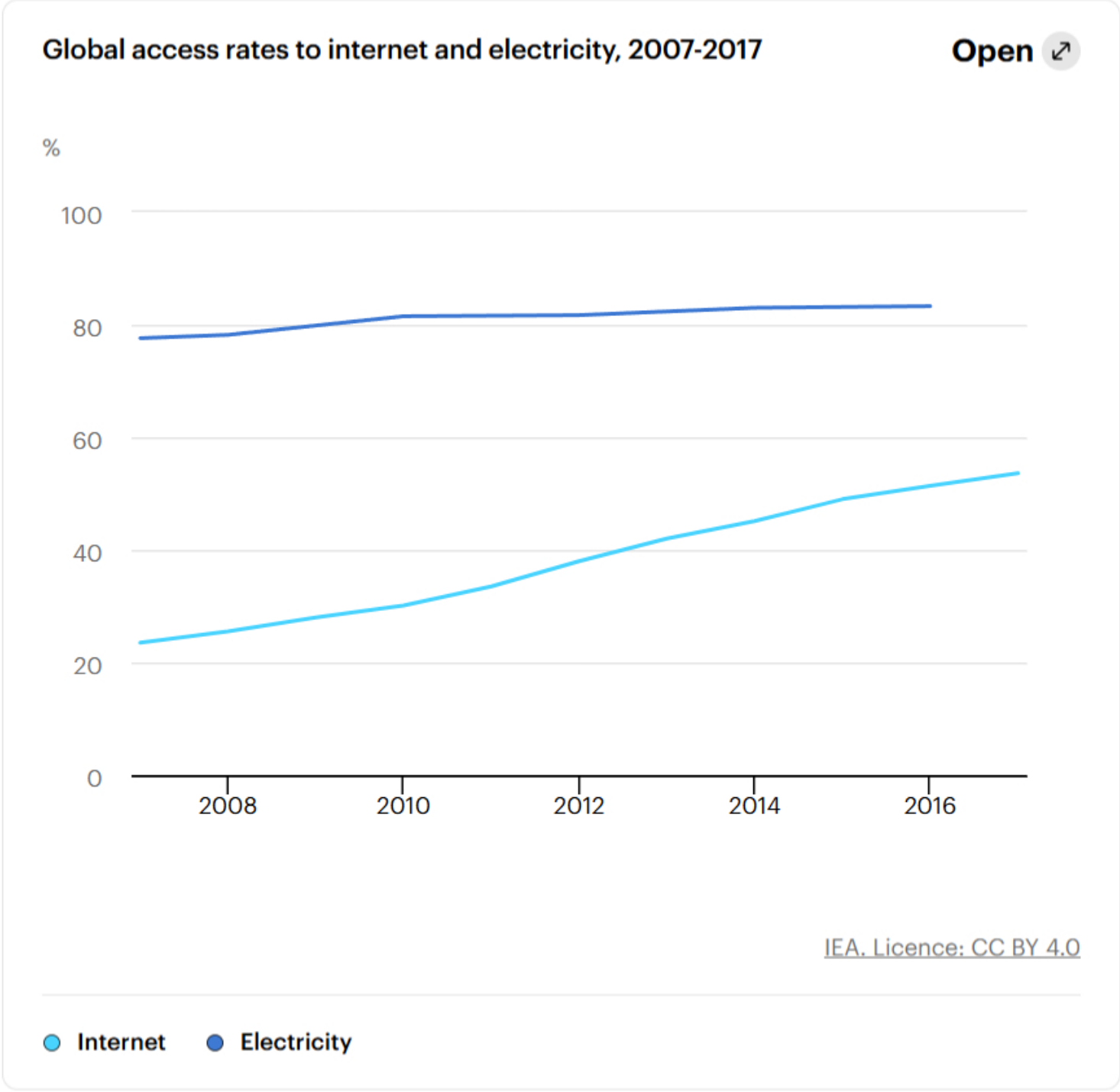
Global access rates to internet and electricity, 2007-2017

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Everyday objects such as watches, home appliances and cars are being connected to communications networks – the "Internet of Things" (IoT) – to provide a range of services and applications, such as personal healthcare, smart electricity grids, surveillance, home automation and intelligent transport. The number of connected IoT devices is forecast to grow from 8.4 billion in 2017 to over 20 billion by 2020.

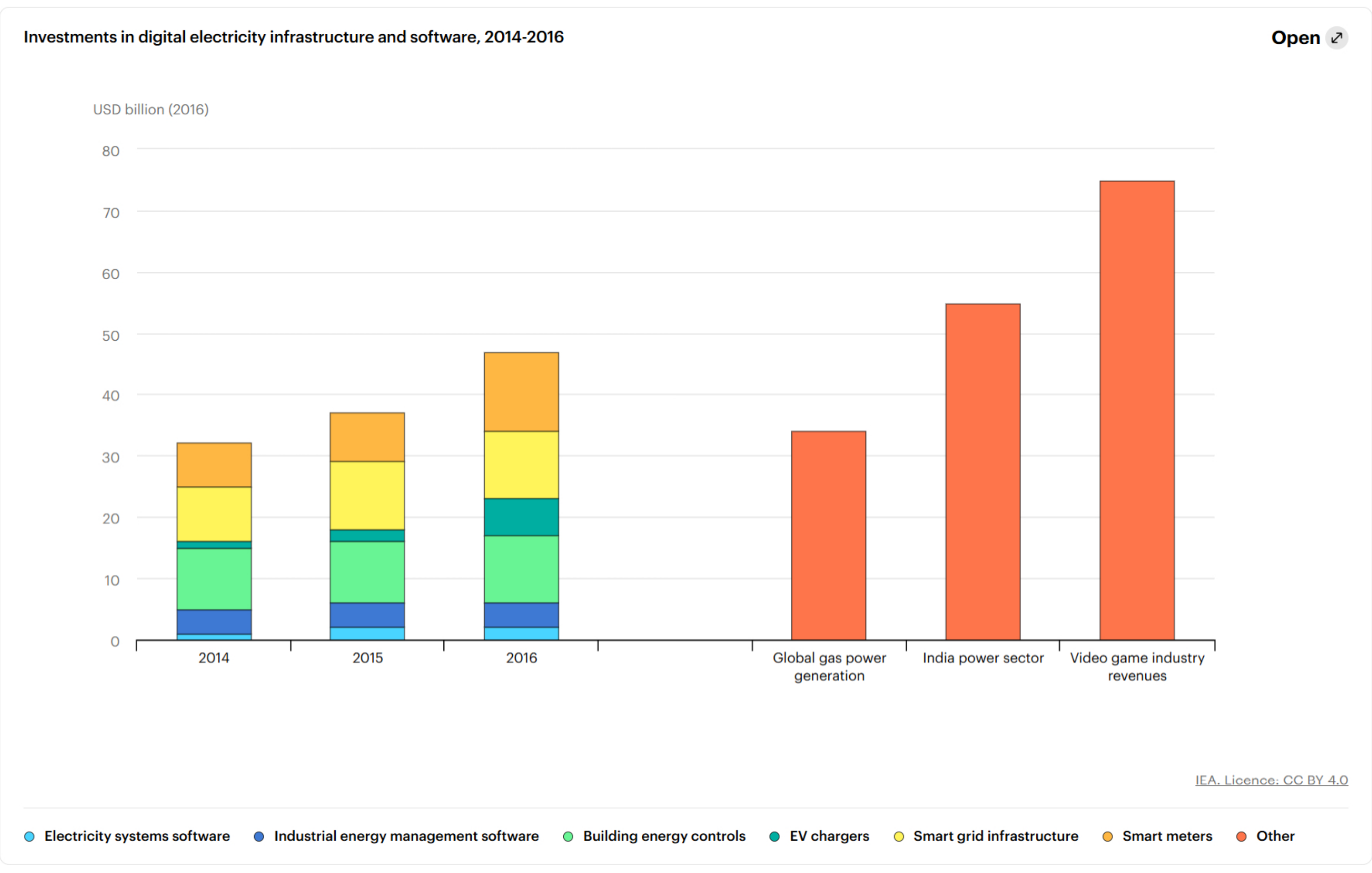
The impact of these tremendous digital advances and their rapid deployment across the energy landscape raise the fundamental question of whether we are on the cusp of a new digital era in energy. IEA analysis attempts to answer this fundamental question.

Digitalisation's impact on energy

The energy sector has been an early adopter of digital technologies. In the 1970s, power utilities were digital pioneers, using emerging technologies to facilitate grid management and operation. Oil and gas companies have long used digital technologies to improve decision making for exploration and production assets, including reservoirs and pipelines.

The industrial sector has used process controls and automation for decades, particularly in heavy industry, to maximise quality and yields while minimising energy use. Intelligent transport systems are using digital technologies in all modes of transport to improve safety, reliability and efficiency.

The pace of digitalisation in energy is increasing. Investment in digital technologies by energy companies has risen sharply over the last few years. For example, global investment in digital electricity infrastructure and software has grown by over 20% annually since 2014, reaching USD 47 billion in 2016. This digital investment in 2016 was almost 40% higher than investment in gas-fired power generation worldwide (USD 34 billion) and almost equal to total investment in India's electricity sector (USD 55 billion).


Investments in digital electricity infrastructure and software, 2014-2016

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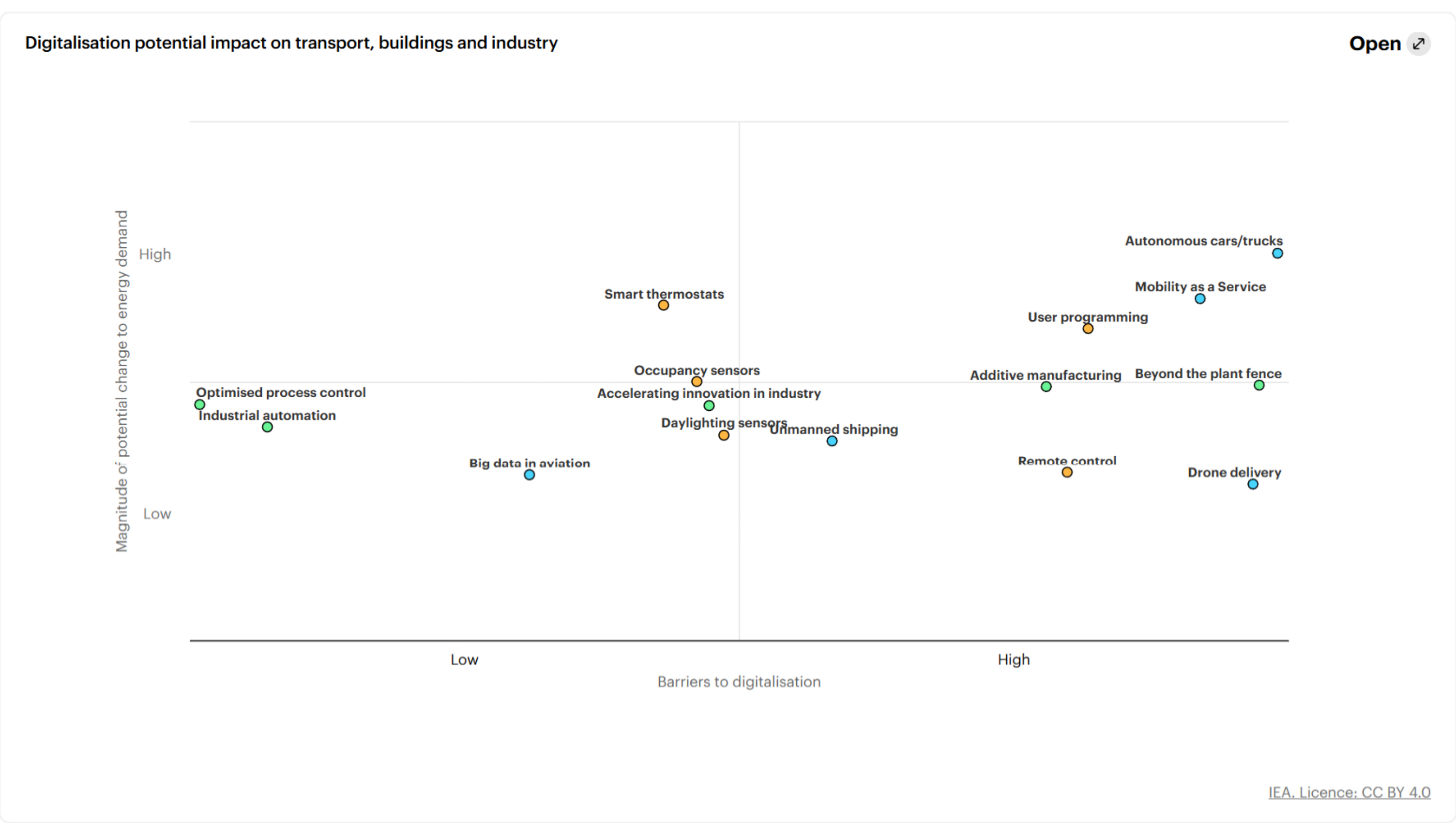
All energy demand sectors are feeling the effects

Digital technologies are already widely used in energy end-use sectors, with the widespread deployment of potentially transformative technologies on the horizon, such as autonomous cars, intelligent home systems and additive manufacturing (3D printing). While these technologies could reduce the energy intensity of providing goods and services, some could also induce rebound effects that increase overall energy use. The magnitude of potential impacts – and associated barriers – varies greatly depending on the particular application.

Digitalisation's potential impact on transport, buildings and industry


Digitalisation potential impact on transport, buildings and industry

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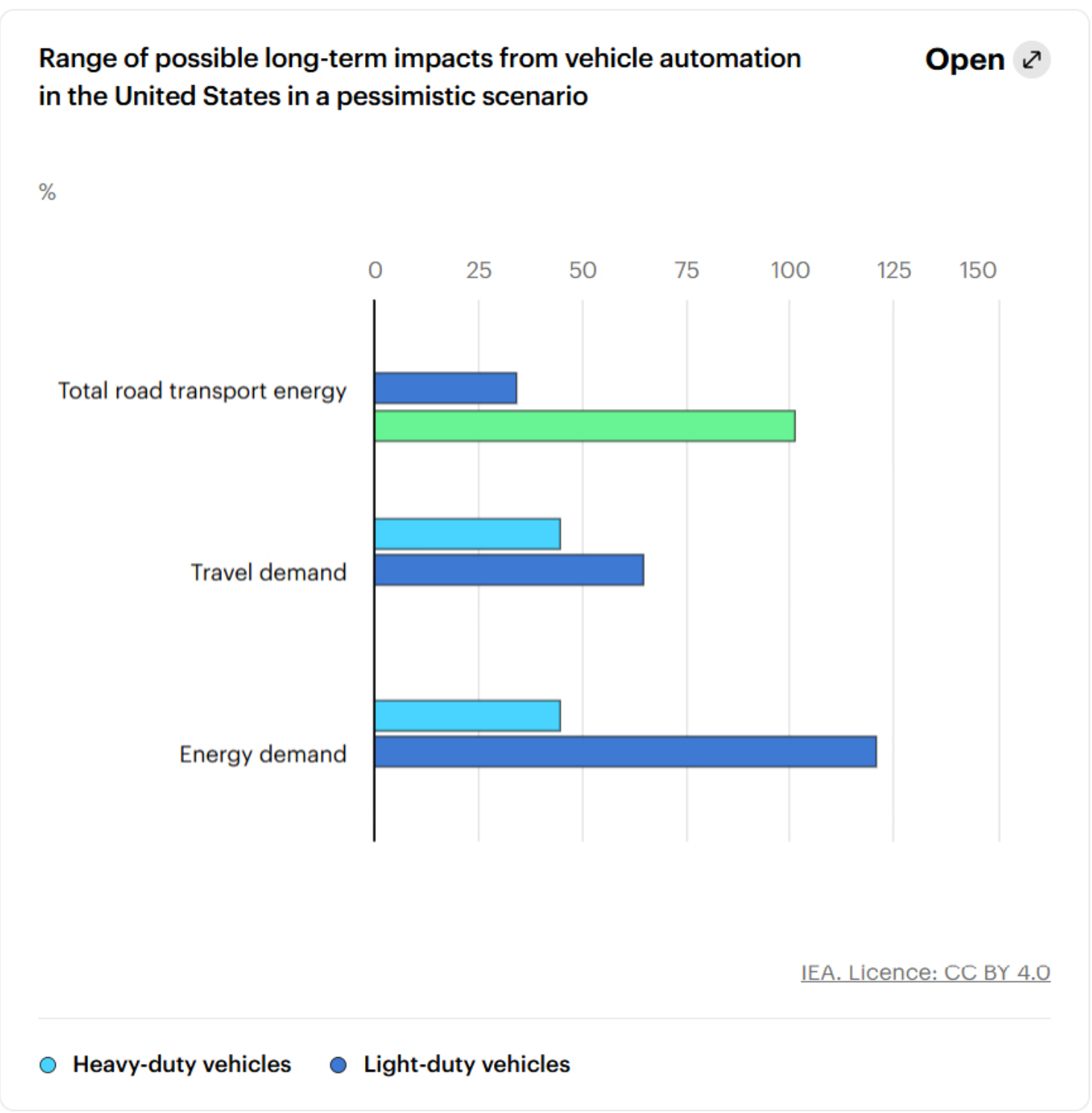
Transport

Transport currently accounts for 28% of global final energy demand and 23% of global CO2 emissions from fuel combustion. In the IEA Central Scenario, final energy consumption for transport grows by almost half to 165 exajoules in 2060, with most of the demand coming from road freight vehicles (36%) and passenger light-duty vehicles (28%).

Across all transport modes, digital technologies are helping to improve energy efficiency and reduce maintenance costs. In aviation, the latest commercial aircraft are equipped with thousands of sensors, generating almost a terabyte of data on an average flight. Big data analytics optimise route planning and can help pilots make in-flight decisions and reduce fuel use. Ships are also being equipped with more sensors, helping crew take actions to optimise routes, while advances in satellite communications are enabling greater connectivity.

The most revolutionary changes from digitalisation could come in road transport, where ubiquitous connectivity and automation technologies could fundamentally transform how people and goods are moved. The interactions among potential disruptions in road transport including the uptake of automated, connected, electric and shared (ACES) mobility will play a key role in shaping the future energy and emissions trajectory of the overall transport sector.

Automated driving technologies can improve safety and driving convenience through advanced sensing and automated decision-making capabilities that can assist or replace human control. The consequences of ACES mobility for energy and emissions are highly uncertain. They will depend on the combined effect of changes in consumer behaviour, policy intervention, technological progress and vehicle technology. Recent studies estimate a wide range of possible outcomes. For instance, over the long term, under a best-case scenario of improved efficiency through automation and ride-sharing, energy use could halve compared with current levels. Conversely, if efficiency improvements do not materialise and rebound effects from automation result in substantially more travel, energy use could more than double.


Range of possible long-term impacts from vehicle automation in the United States in a pessimistic scenario

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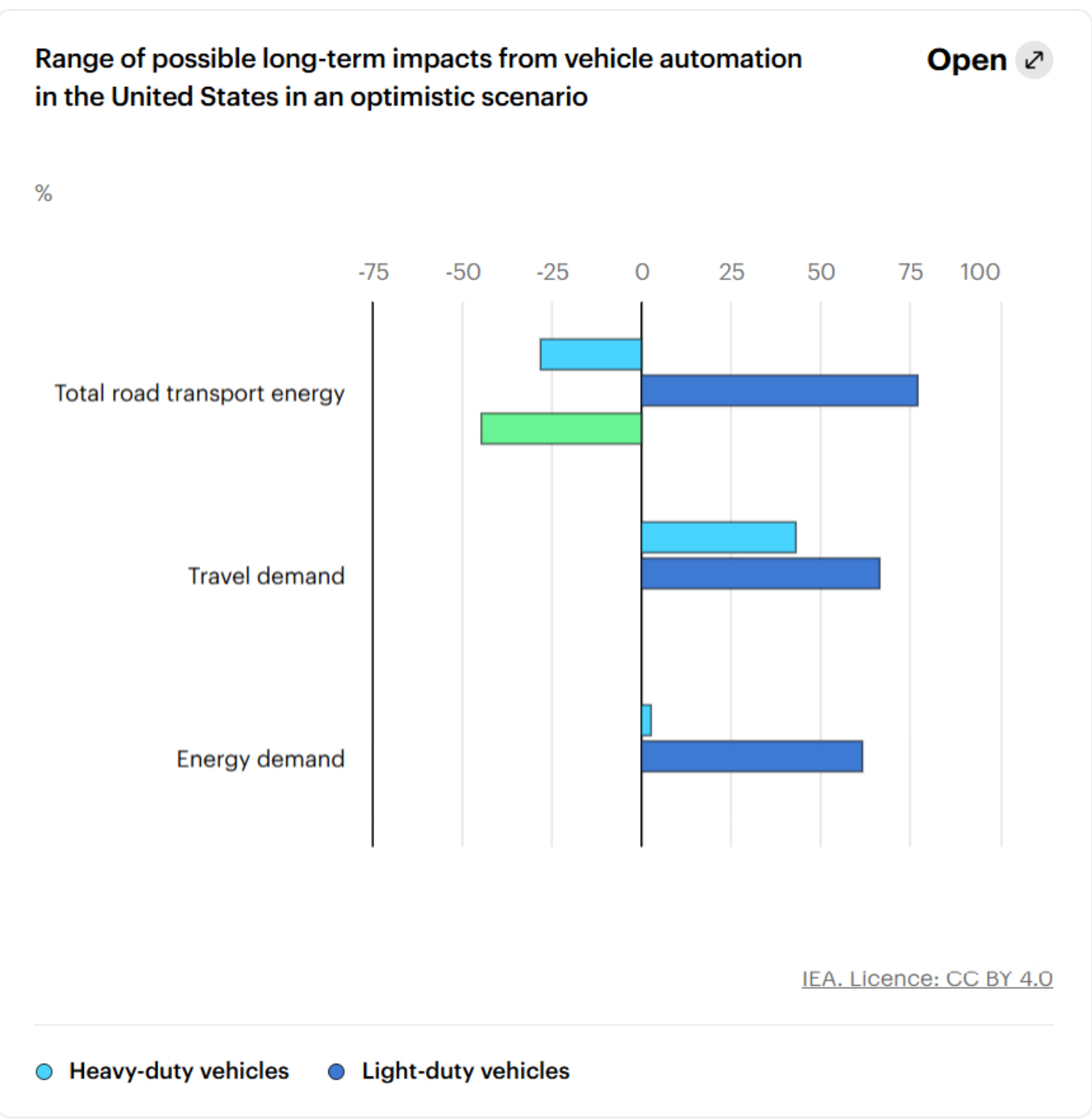
Range of possible long-term impacts from vehicle automation in the United States in an optimistic scenario

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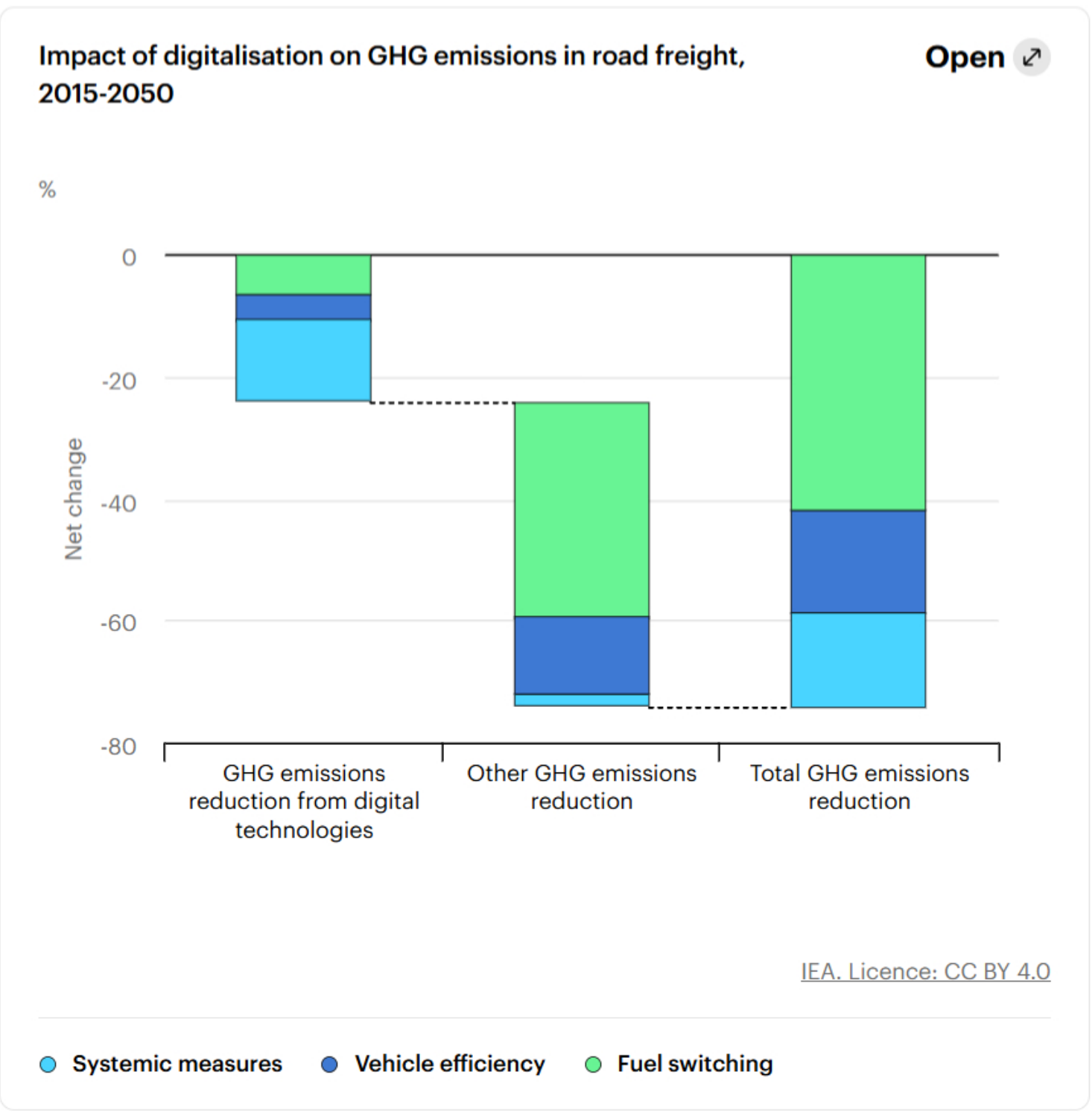
The recent IEA report, the Future of Trucks, found that applying digital solutions to truck operations and logistics could reduce road freight's energy use by 20-25%. Examples of such solutions include GPS coupled with real-time traffic information for route optimisation, on-board monitoring and feedback that enhances eco-driving performance, vehicle connectivity that can safely reduce gaps between platooning trucks to improve fuel efficiency, and data sharing between companies across the supply chain to ship more goods with fewer trips.


Impact of digitalisation on GHG emissions in road freight, 2015-2050

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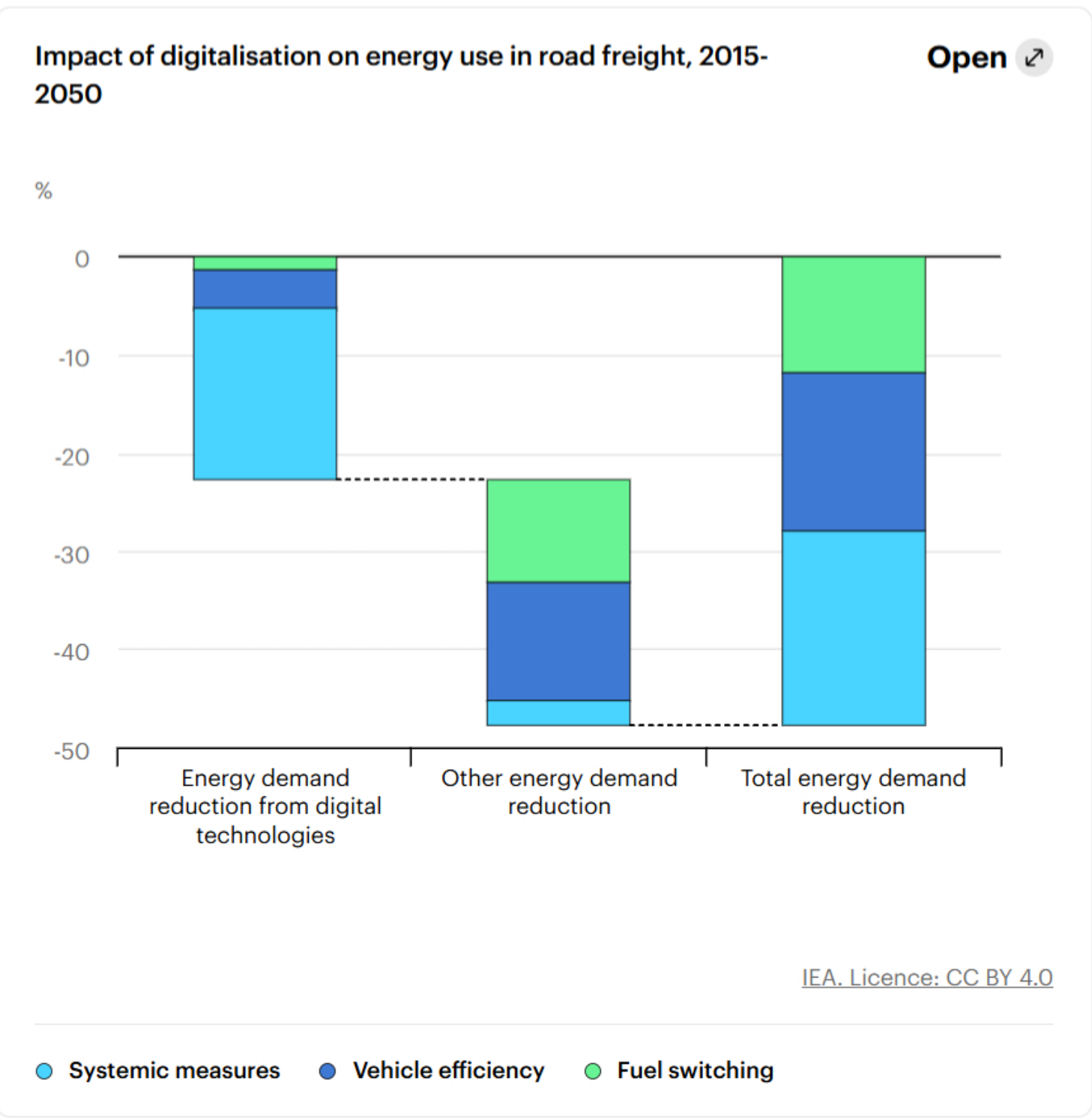
Impact of digitalisation on energy use in road freight, 2015-2050

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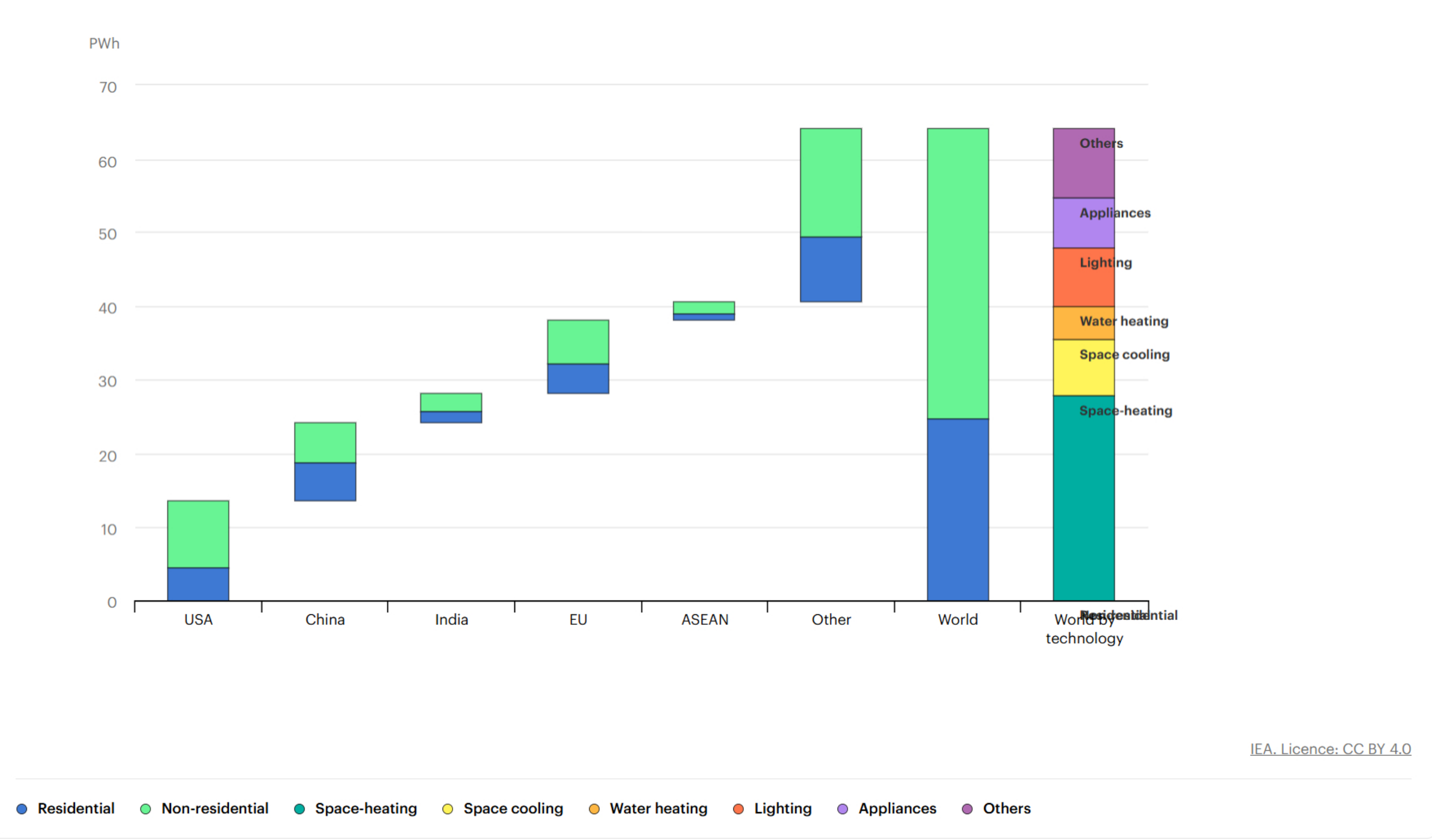
Buildings

Buildings account for nearly one-third of global final energy consumption and 55% of global electricity demand. Electricity demand growth in buildings has been particularly rapid over the last 25 years, accounting for nearly 60% of total growth in global electricity consumption. In some rapidly emerging economies, including China and India, electricity demand in buildings grew on average by more than 8% per year over the last decade.

In the IEA Central Scenario, electricity use in buildings is set to nearly double from 11 petawatt hours (PWh) in 2014 to around 20 PWh in 2040, requiring large increases in power-generation and network capacity.

Digitalisation, including smart thermostats and smart lighting, could cut total energy use in residential and commercial buildings between 2017 and 2040 by as much as 10% compared with the Central Scenario, assuming limited rebound effects in consumer energy demand. Cumulative energy savings over the period to 2040 would amount to 65 PWh – equal to the total final energy consumed in non-OECD countries in 2015.

Cumulative energy savings in buildings from widespread digitalisation in selected countries, 2017-2040 **Open**



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Help ensure that energy is consumed when and where it is needed, by improving the responsiveness of energy services (e.g. by using lighting sensors) and predictively with respect to user behaviour (e.g. through learning algorithms that auto-programme heating and cooling services).

Enable demand response to reduce peak loads (e.g. shifting the time of use of a washing machine), to shed loads (e.g. adjusting temperature settings to lower energy demand at a particular time) and to store energy (e.g. in thermal smart grids) in response to real-time energy prices or other conditions specified by the user.

Predict, measure and monitor in real time the energy performance of buildings, allowing consumers, building managers, network operators and other stakeholders to identify where and when maintenance is needed, when investments are not performing as expected or where energy savings can be achieved.

These benefits could be all be realised at a limited energy cost, as active controls are projected to consume only 275 TWh in 2040; far less than the 4 650 TWh they could potentially save that same year.

Industry

Industry is responsible for around 38% of global final energy consumption and 24% of total CO2 emissions. With the expected continuing expansion of industrial production over the coming decades, particularly in emerging economies, the value of digitalisation in improving the efficiency of energy and material use will only increase.

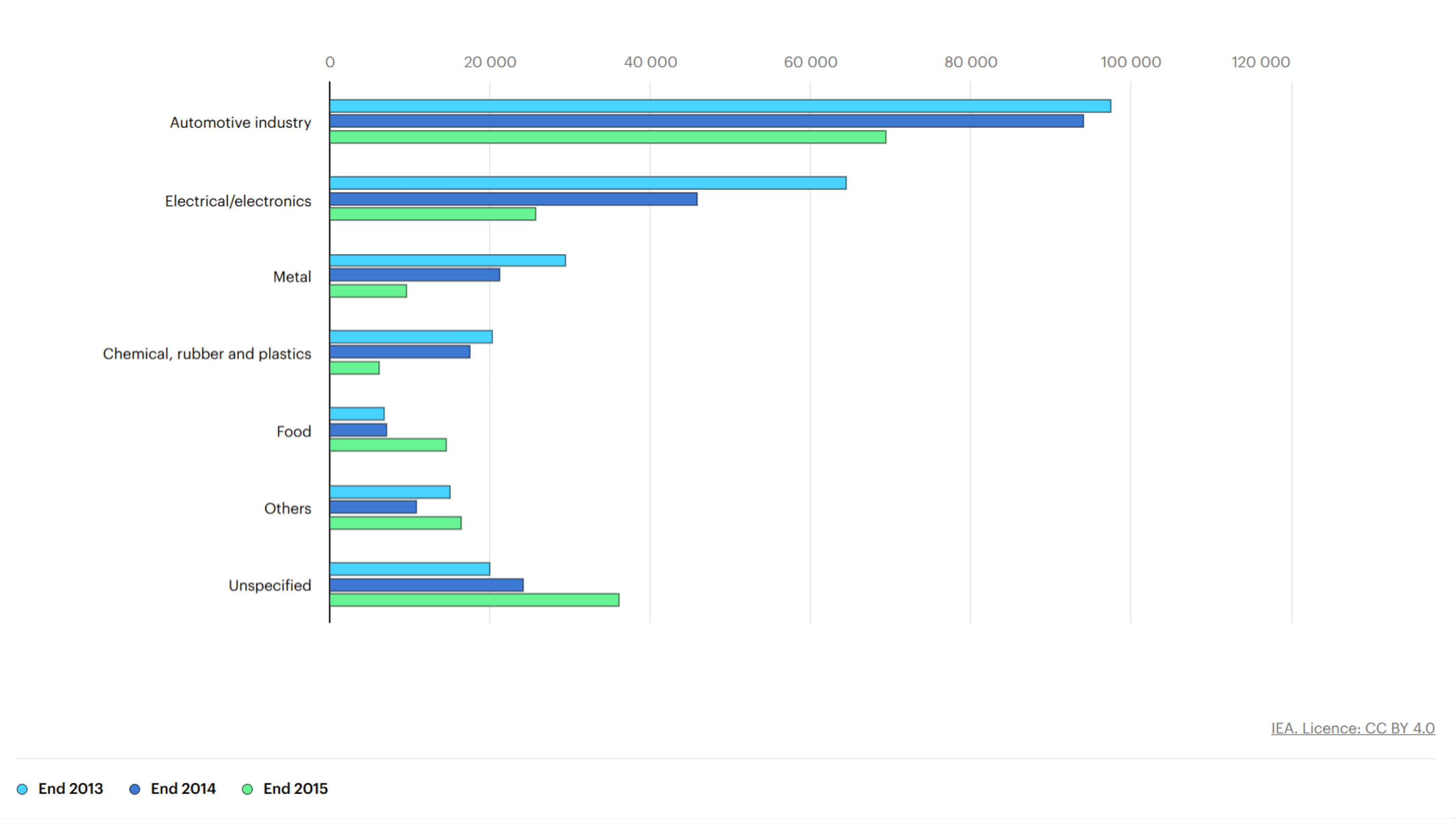
While it is expected that digitalisation in industry will continue in an incremental manner in the near term both inside individual plants as well as beyond the plant fence, some digital technologies may have far-reaching effects on energy use in certain areas, especially when they are applied in combination.

In industry, many companies have a long history of using digital technologies to improve safety and increase production. Further cost-effective energy savings can be achieved through advanced process controls, and by coupling smart sensors and data analytics to predict equipment failure.

Digital technologies have also had an impact on the way products are manufactured. Technologies such as industrial robots and 3D printing are becoming standard practice in certain industrial applications. These technologies can help increase accuracy and reduce industrial scrap.

Deployment of industrial robots is expected to continue to grow rapidly, with the total stock of robots rising from around 1.6 million units at the end of 2015 to just under 2.6 million at the end of 2019.

Number of industrial robots worldwide per sector, 2013-2015 **Open**



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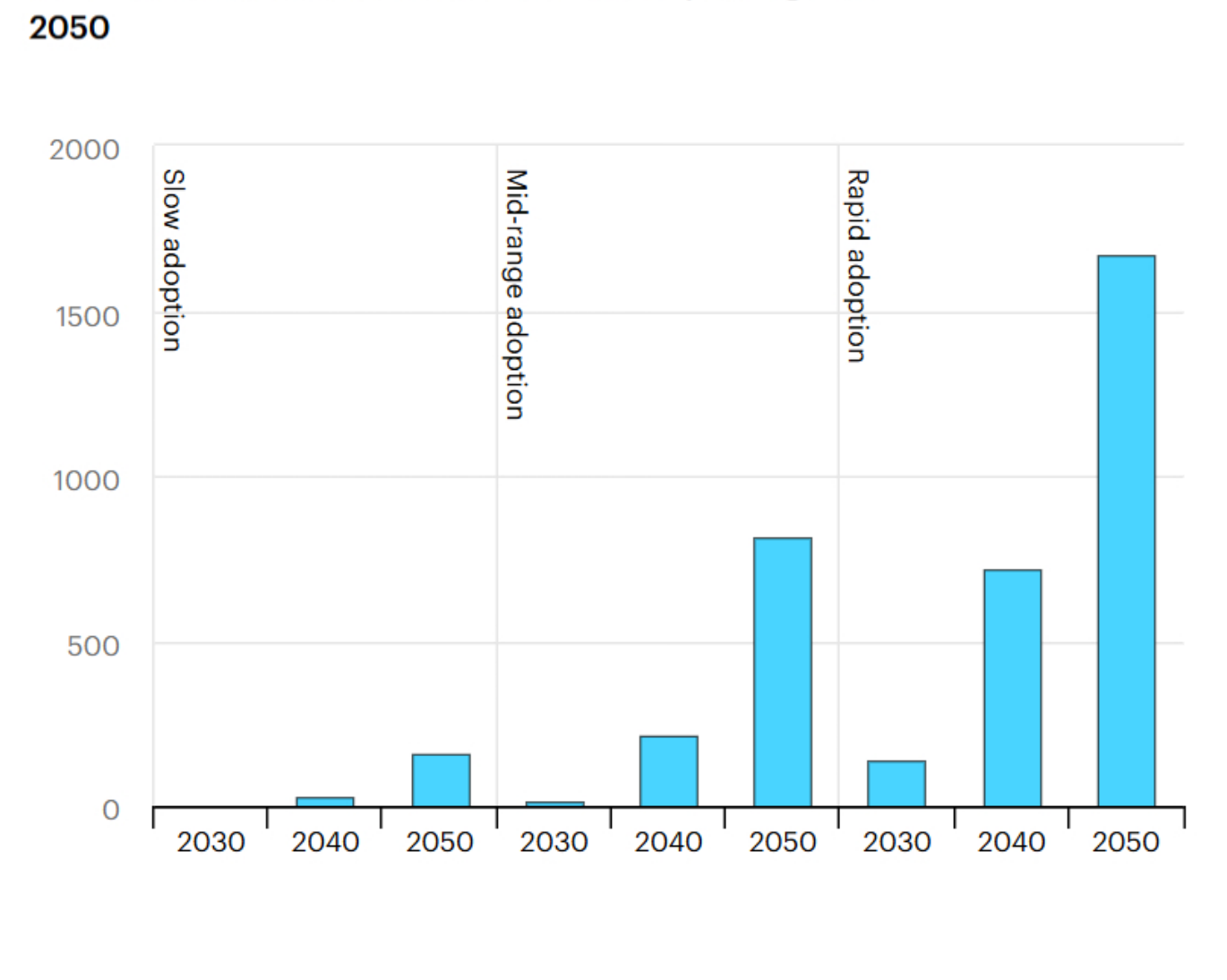
3D printing can produce products in layer by layer fashion, on demand and directly from digital 3D files. It has several advantages compared with conventional manufacturing, including reductions in lead time, reduction of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space and the ability to deliver manufactured pieces with complex shapes and geometries. It can yield significant energy and resource savings under the right conditions.

For example, one recent study quantified the energy and resource impacts of selected lightweight metallic additive manufacturing components in the US aircraft fleet, under different adoption scenarios to 2050. The assessment found that 9% to 17% of total typical aircraft mass could be replaced by lighter 3D printed components in the near term. If fully adopted, in 2050 this could avoid nearly 20 000 tonnes/year of metal demand and reduce the overall fuel use of the US aircraft fleet by up to 6.4%.

Potential reductions in fuel use in the United States commercial aircraft fleet from the use of 3D printing, 2030-2050 **Open**



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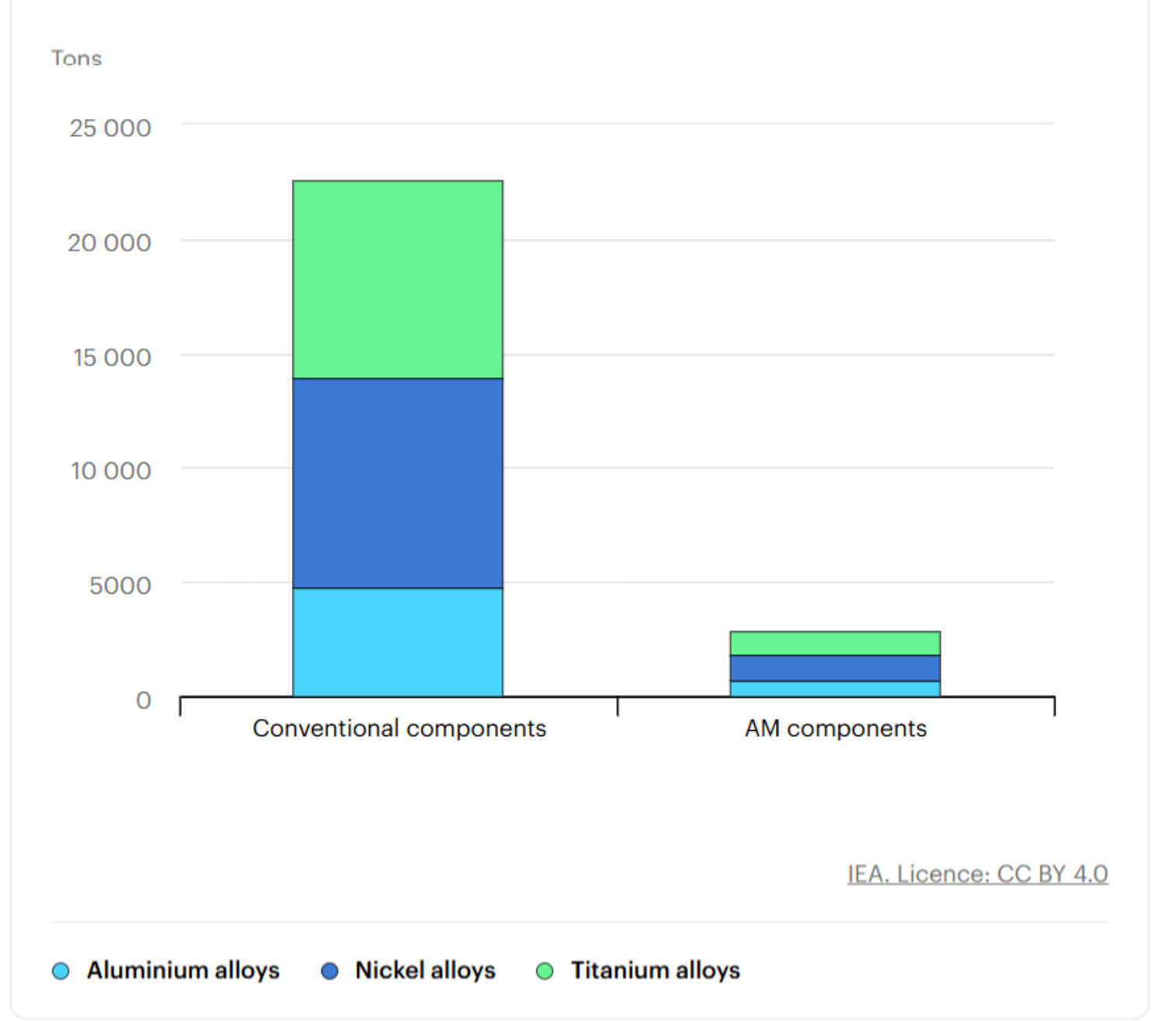
Potential reductions in metals demand in the United States commercial aircraft fleet from the use of 3D printing, 2050 **Open**



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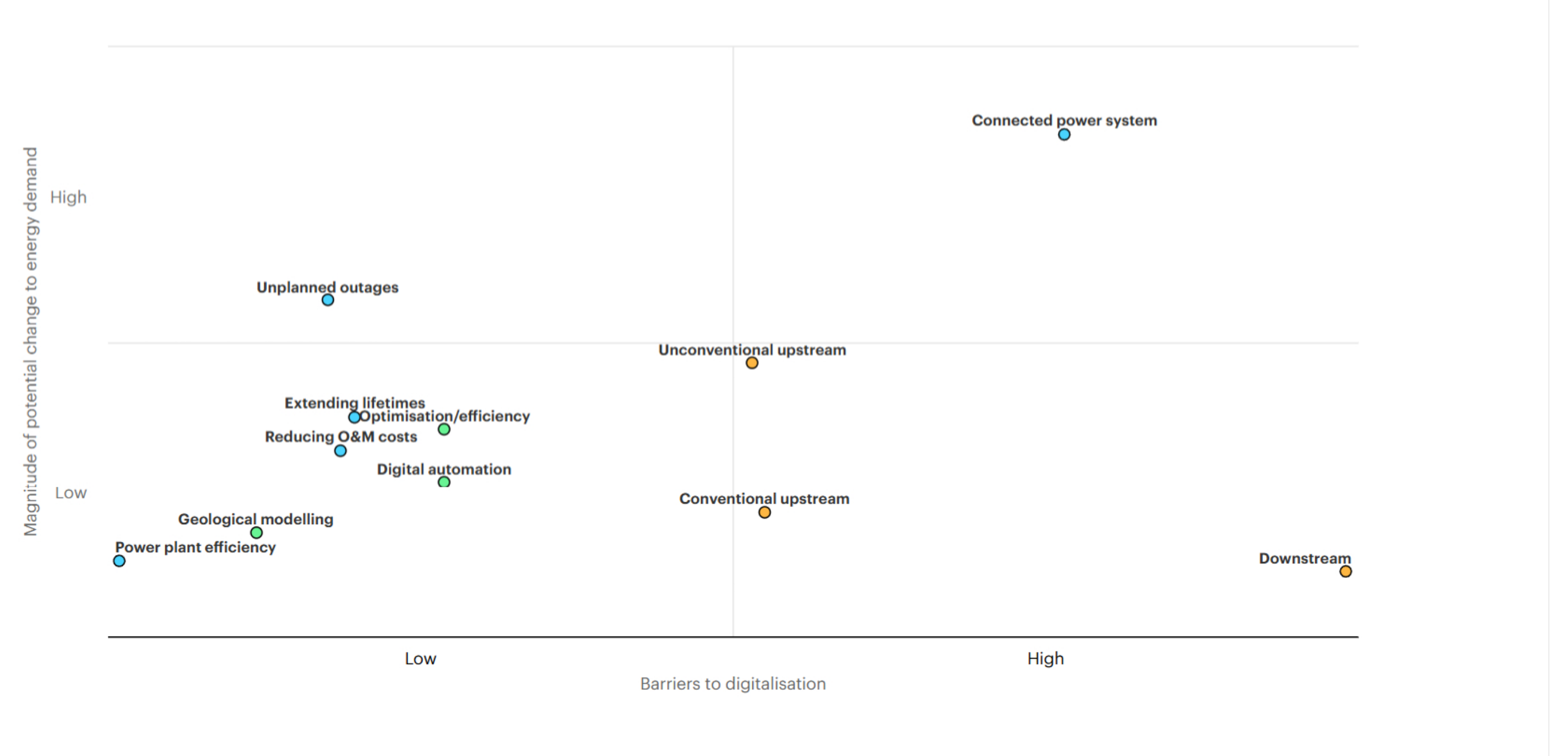
Energy suppliers will reap greater productivity and improve safety

Digitalisation can improve safety, increase productivity and reduce costs in oil and gas, coal and power. The magnitude of these potential impacts – and associated barriers – varies greatly depending on the particular application.

Digitalisation's potential impact on oil and gas, coal and power

Digitalisation potential impact on oil and gas, coal and power **Open**



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Oil and gas

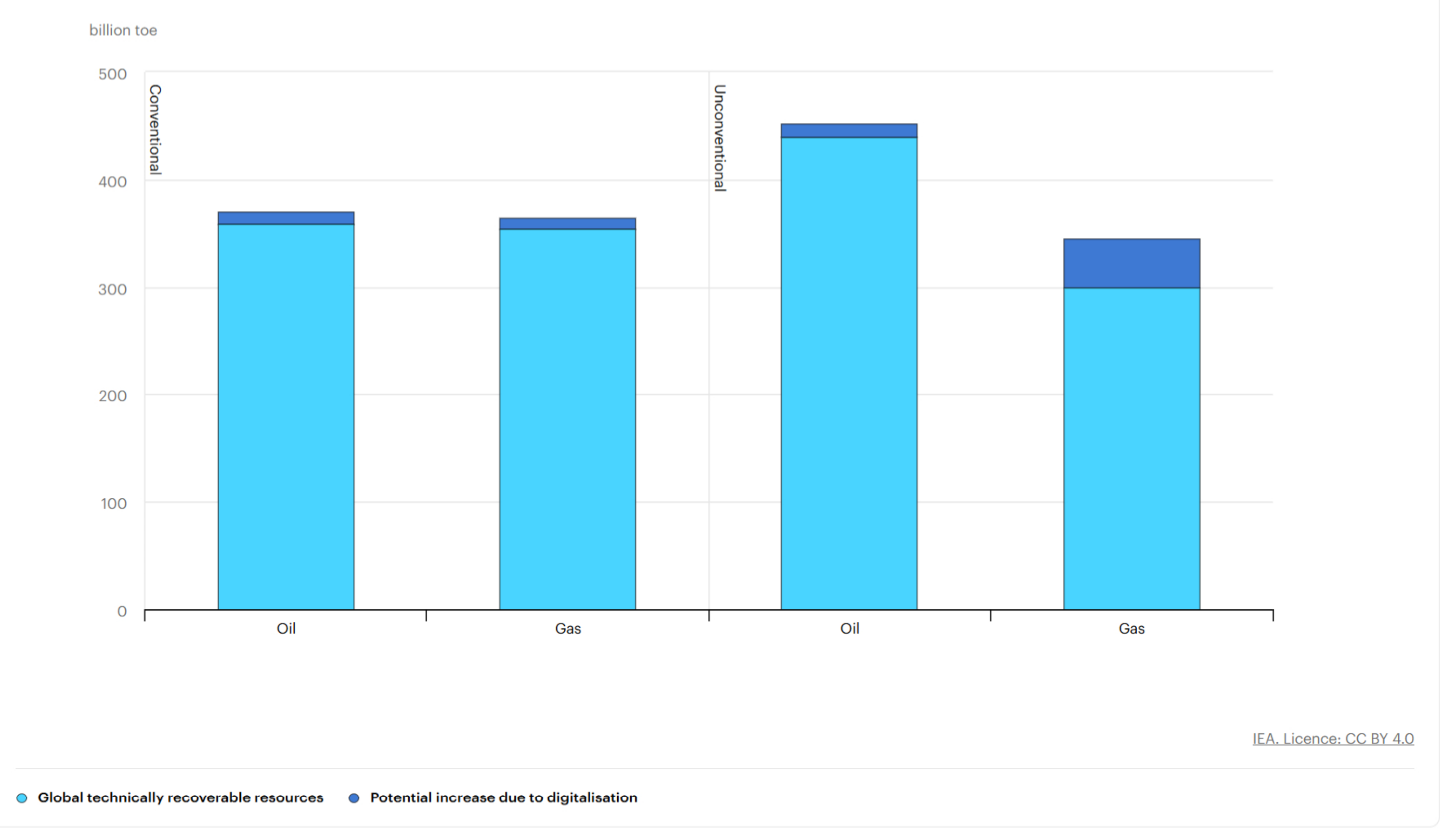
The oil and gas sector has a relatively long history with digital technologies, notably in upstream, and significant potential remains for digitalisation to enhance operations. Further digitalisation in the upstream oil and gas industry in the future is likely to initially focus on expanding and refining the range of existing digital applications already in use.

For example, miniaturised sensors and fibre optic sensors in the production system could be used to boost production or increase the overall recovery of oil and gas from a reservoir. Other examples are the use of automated drilling rigs and robots to inspect and repair subsea infrastructure and to monitor transmission pipelines and tanks. Drones could also be used to inspect pipelines (which are often spread over extended areas) and hard-to-reach equipment such as flare stacks and remote, unmanned offshore facilities.

In the longer term, the potential exists to improve the analysis and processing speed of data, such as the large, unstructured datasets generated by seismic studies. The oil and gas industry will furthermore see more wearables, robotics, and the application of artificial intelligence in their operations.

Widespread use of digital technologies could decrease production costs between 10% and 20%, including through advanced processing of seismic data, the use of sensors, and enhanced reservoir modelling. Technically recoverable oil and gas resources could be boosted by around 5% globally, with the greatest gains expected in shale gas.

Potential impact of digitalisation on global technically recoverable oil and gas resources **Open**



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Coal

Digital technologies are being used throughout the coal supply chain to reduce production and maintenance costs, and enhance workers' safety. Examples include semi- or fully-automated systems, robotic mining, remote mining, operation automations, mine modelling and simulations, and the use of global positioning system (GPS) and geographic information system (GIS) tools.

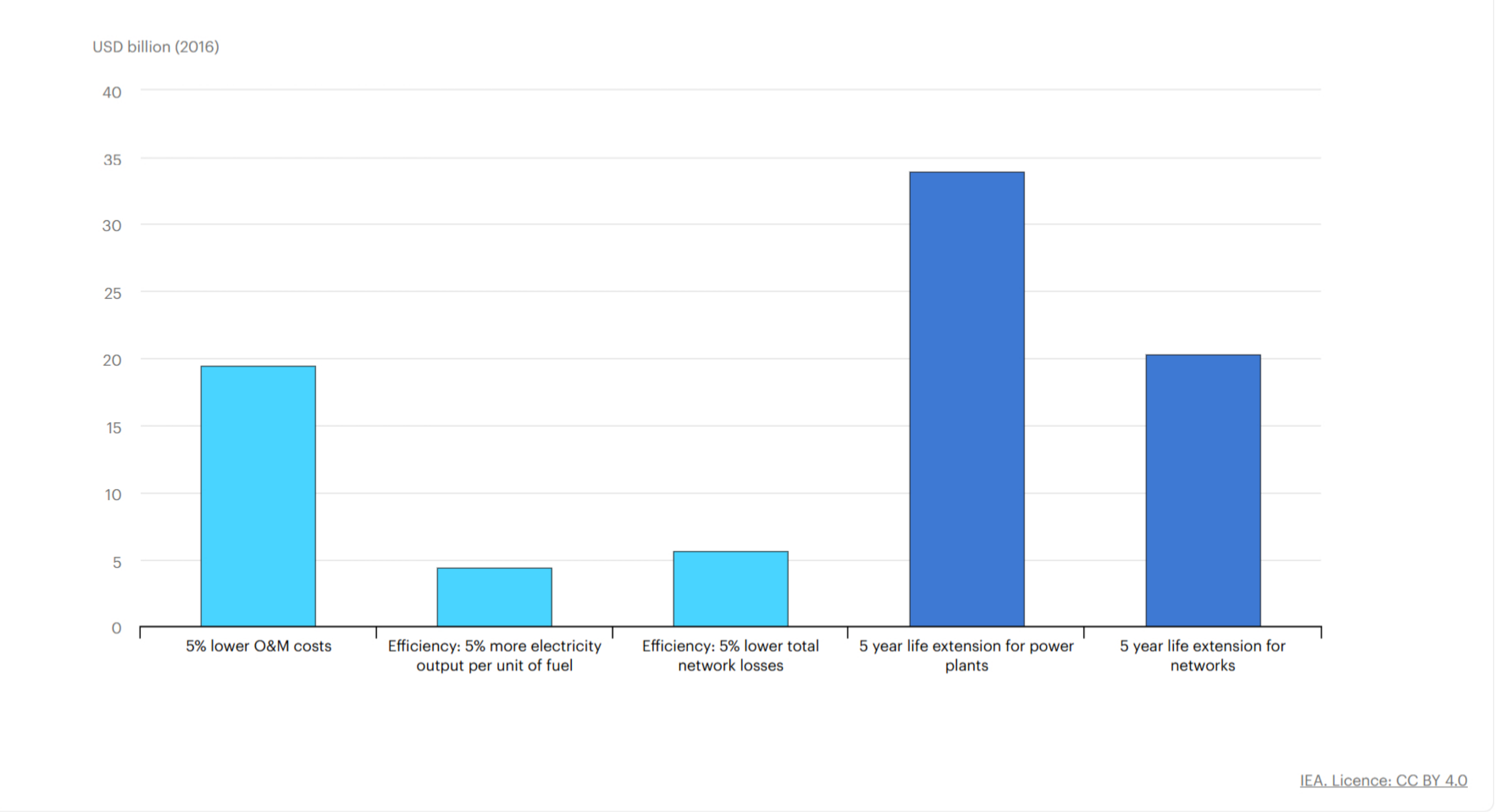
The increased availability of low-cost sensors and computer-aided simulations will bring new opportunities for coal operations. For example, sensors can provide the exact status of various components of the essential equipment in real time and analytics can compare the actual configuration with the "optimal" situation as designed so that the process can be optimised. Digital technologies, data analytics and automation will be increasingly adopted to improve productivity while enhancing safety and environmental performance through multiple applications.

Digitalisation's overall impact, however, may be more modest than in other sectors.

Power

Digital data and analytics can reduce power system costs in at least four ways: by reducing operations and maintenance costs; improving power plant and network efficiency; reducing unplanned outages and downtime; and extending the operational lifetime of assets. The overall savings from these digitally enabled measures could be in the order of USD 80 billion per year over 2016-40, or about 5% of total annual power generation costs based on the enhanced global deployment of available digital technologies to all power plants and network infrastructure.

Worldwide cost savings from enhanced digitalisation in power plants and electricity networks over 2016-2040 **Open**



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Digital data and analytics can reduce O&M costs, enabling predictive maintenance, which can lower costs for the owner of plants and networks and ultimately the price of electricity for end users. Over the period to 2040, a 5% reduction in O&M costs achieved through digitalisation could save companies, and ultimately consumers, an average of close to USD 20 billion per year.

Digital data and analytics can help achieve greater efficiencies through improved planning, improved efficiency of combustion in power plants and lower loss rates in networks, as well as better project design throughout the overall power system. In electricity networks, efficiency gains can be achieved by lowering the rate of losses in the delivery of power to consumers, for example through remote monitoring that allows equipment to be operated more efficiently and closer to its optimal conditions, and flows and bottlenecks to be better managed by grid operators.

Digital data and analytics can also reduce the frequency of unplanned outages through better monitoring and predictive maintenance, as well as limit the duration of downtime by rapidly identifying the point of failure. This reduces costs and increases the resilience and reliability of supply. Network failures are expensive, both for the utility and for the economy.

In the long term, one of the most important potential benefits of digitalisation in the power sector is likely to be the possibility of extending the operational lifetime of power plants and network components, through improved maintenance and reduced physical stresses on the equipment. For instance, if lifetime of all the power assets in the world to be extended by five years, the close to USD 1.3 trillion of cumulative investment could be deferred over 2016-40. On average, investment in power plants would be reduced by USD 34 billion per year and that in networks by USD 20 billion per year.

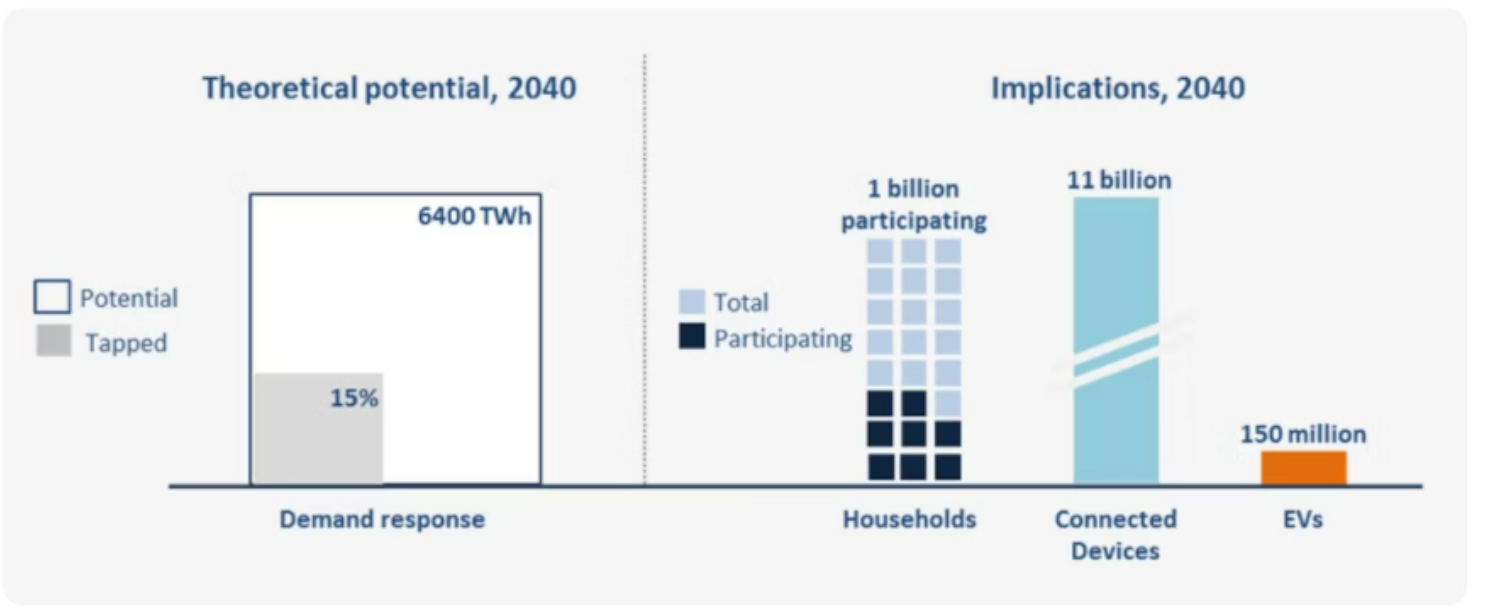
Fundamentally transforming electricity via digitally-interconnected systems

The greatest transformational potential for digitalisation is its ability to break down boundaries between energy sectors, increasing flexibility and enabling integration across entire systems.

The electricity sector is at the heart of this transformation, where digitalisation is blurring the distinction between generation and consumption, and enabling four inter-related opportunities: 1) smart demand response; 2) the integration of variable renewable energy sources; 3) the implementation of smart charging for EVs; and 4) the emergence of small-scale distributed electricity resources such as household solar PV. They are interlinked as, for example, demand response will be critical to providing the flexibility needed to integrate more generation from variable renewables.

Smart demand response

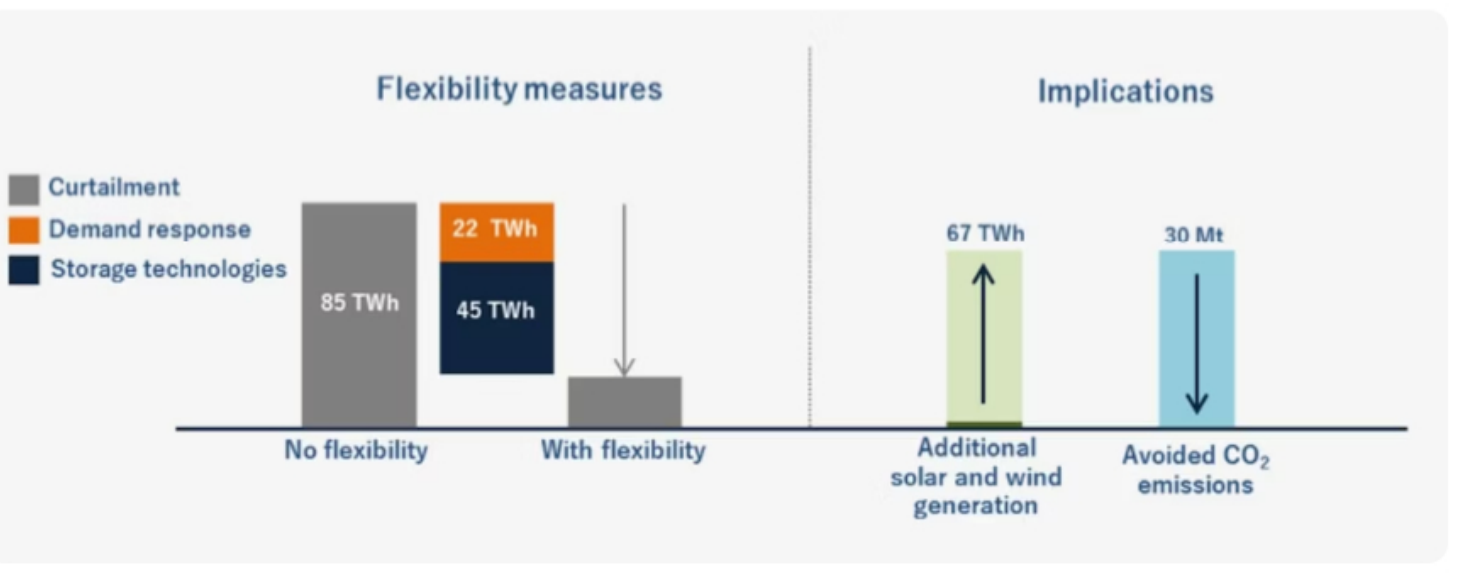
Smart demand response could provide 185 GW of system flexibility, roughly equivalent to the currently installed electricity supply capacity of Australia and Italy combined. This could save USD 270 billion of investment in new electricity infrastructure that would have otherwise been needed. In the residential sector alone, 1 billion households and 11 billion smart appliances could actively participate in interconnected electricity systems, allowing these households and devices to alter when they draw electricity from the grid.



Global potential of demand response and its implications

System integration of renewables

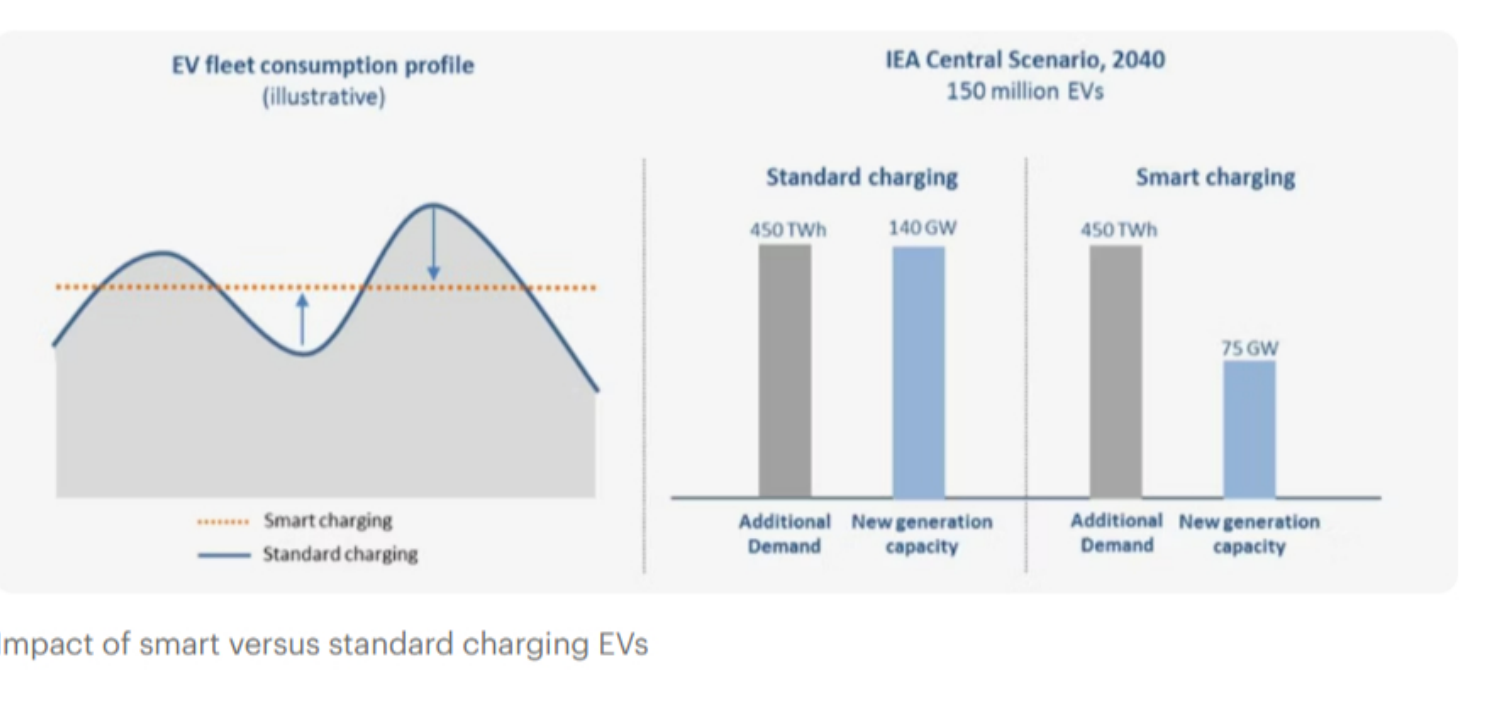
Digitalisation can help integrate variable renewables by enabling grids to better match energy demand to times when the sun is shining and the wind is blowing. In the European Union alone, increased storage and digitally-enabled demand response could reduce curtailment of solar photovoltaics (PV) and wind power from 7% to 1.6% in 2040, avoiding 30 million tonnes of carbon dioxide emissions in 2040.



Flexibility measures and their implications in the European Union in 2040

Charging technologies for electric vehicles

Rolling out smart charging technologies for electric vehicles could help shift charging to periods when electricity demand is low and supply is abundant. This would provide further flexibility to the grid while saving between USD 100 billion and USD 280 billion (depending on the number of EVs deployed) in avoided investment in new electricity infrastructure between 2016 and 2040.



Impact of smart versus standard charging EVs

Distributed energy resources

Digitalisation can facilitate the development of distributed energy resources, such as household solar PV panels and storage, by creating better incentives and making it easier for producers to store and sell surplus electricity to the grid. New tools such as blockchain could help to facilitate peer-to-peer electricity trade within local energy communities.

Energy use by information and communications technologies

Data centres

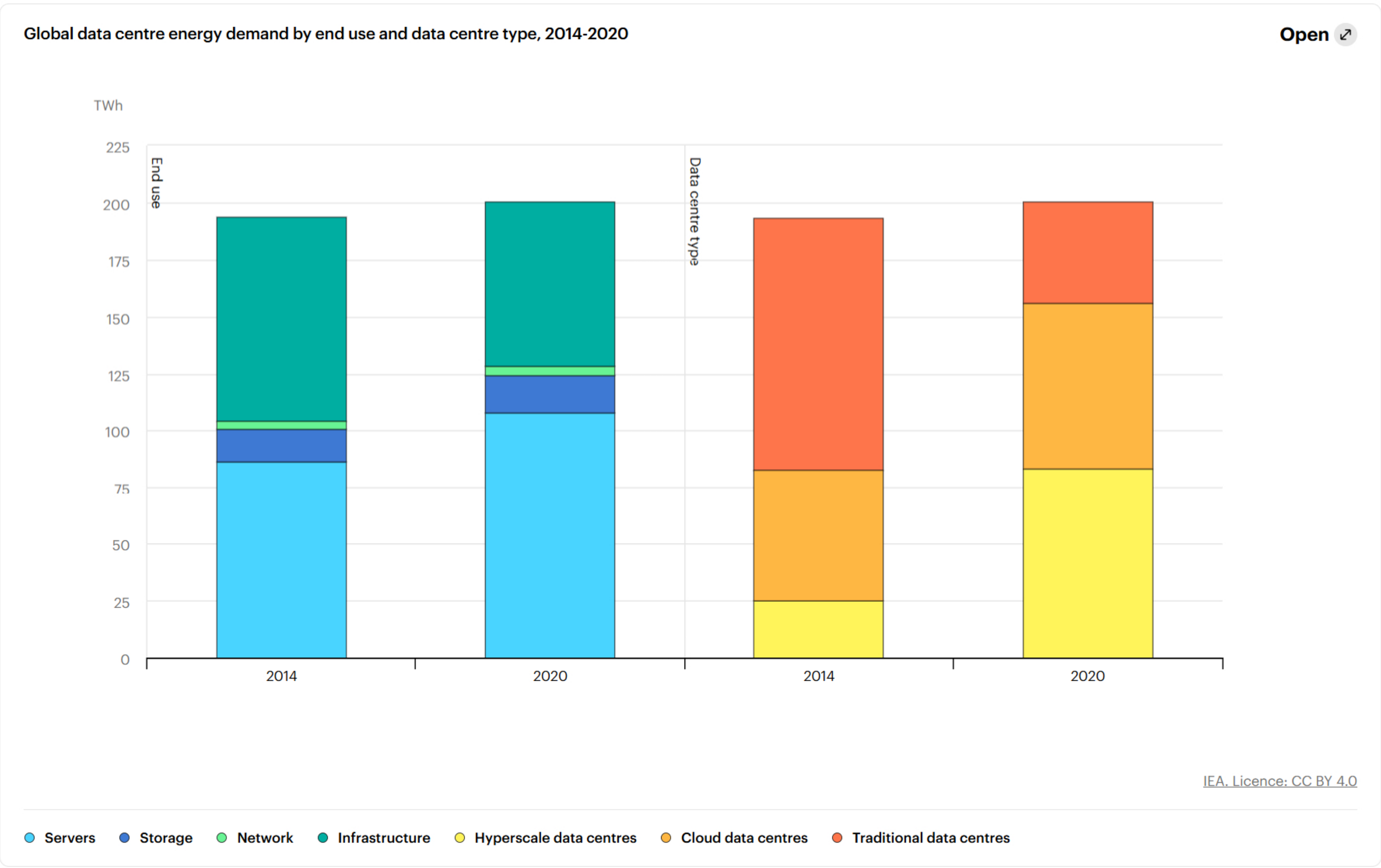
As the world becomes increasingly digitalised, information and communications technologies (ICT) are emerging as an important source of energy demand in their own right.

As billions of new devices become connected over the coming years, they will draw electricity at the plug while driving growth in demand for – and energy use by – data centres and network services. However, sustained gains in energy efficiency could keep overall energy demand growth largely in check for data centres and networks over the next five years.

Data centres worldwide consumed around 194 terawatt hours (TWh) of electricity in 2014, or about 1% of total demand. Although data centre workload is forecast to triple by 2020, related energy demand is expected to grow by only 3% thanks to continued efficiency gains.

The strong growth in demand for data centre services is offset by continued improvements in the efficiency of servers, storage devices, network switches and data centre infrastructure, as well as a shift to much greater shares of cloud and hyperscale data centres. Hyperscale data centres are very efficient, large scale public cloud data centres operated by companies such as Alibaba, Amazon, and Google.

Global data centre energy demand by end use and data centre type, 2014-2020



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Data transmission networks

Data networks, which form the backbone of the digital world, consumed around 185 TWh globally in 2015, or another 1% of total demand, with mobile networks accounting for around two-thirds of the total. Depending on future efficiency trends, by 2021 electricity consumption from data networks could increase by as much as 70% or fall by up to 15%. This large range highlights the potential role for policy to drive further efficiency gains.

Billions of new connected devices are expected to be connected over the next few years. The number of smartphones is expected to increase from 3.8 billion in 2016 to almost 6 billion by 2020, while the number of connected IoT devices is expected to triple from about 6 billion in 2016 to over 20 billion by 2020. Over the longer term, it is conceivable that most electrical devices – and even some consumer items such as clothing – could become connected IoT devices, using energy to collect, process, store, transmit and receive data.

Beyond the next five years, providing credible assessments of energy use by digital technologies is extremely difficult. Direct energy use over the long run will continue to be a battle between data demand growth versus the continuation of efficiency improvements.

Cross-cutting risks

Cyber security

While digitalisation can bring many positive benefits, it can also make energy systems more vulnerable to cyber-attacks. To date, the disruptions caused to energy systems by reported cyber-attacks have been relatively small. However, cyber-attacks are becoming easier and cheaper to organise, while digitalised equipment and the growth of the Internet of Things (IoT) are increasing the potential "cyber-attack surface" in energy systems.

Incident	Description (from open-source information)
Shamoon 1 and 2 (Saudi Arabia, 2012 and 2016)	"Shamoon 1" virus carried out cyber-sabotage and destroyed over 30 000 computers at Saudi Aramco.
Western Ukraine power grid (2015)	The first confirmed cyber-attack specifically against an electricity network.
The Mirai Botnet (2016)	"Mirai" malware exploited low security in connected smart devices, such as cameras, to use a botnet to deliver the largest DoS attack to date. This attack did not target or impact energy infrastructure, but illustrates the vulnerability of the Internet of Things (IoT).
Industroyer/Crash Override (Ukraine, December 2016 – reported May 2017)	A second brief but significant attack on the Ukrainian electricity system, thought to have been a test run for malware "Industroyer" (also known as "Crash Override"). This was an example of a cyber intrusion into the control systems of critical infrastructure.
Nuclear plant spear phishing attack (US, 2017)	This incident occurred in the United States. It used targeted email messages containing fake Microsoft Word résumés for engineering jobs, potentially exposing recipients' credentials for the control engineering network. The hackers also compromised legitimate external websites that they knew their victims frequented (known as a watering hole attack).
WannaCry (2017)	"WannaCry" ransomware hit hundreds of thousands of computers in thousands of organisations in some 150 countries. These attacks did not target energy infrastructure, but several energy companies reported problems. In China, over 20 000 China National Petroleum Corporation (CNPC) petrol stations went offline.

Full prevention of cyber-attacks is impossible, but their impact can be limited if countries and companies are well-prepared. Building system-wide resilience depends on all actors and stakeholders first being aware of the risks. Digital resilience also needs to be included in technology research and development efforts as well as built into policy and market frameworks.

Digital energy security should be built around three key concepts:

- **Resilience**, i.e. the ability of a nation, system or institution to adapt to changing contexts, to withstand shocks, and to quickly recover or adapt to a desired level of stability, while preserving the continuity of critical infrastructure.
- **Cyber hygiene**, i.e. the basic set of precautions and monitoring that all ICT users should undertake. This includes awareness, secure configuration of equipment and networks, keeping software up to date, avoiding giving staff and users unnecessary system privileges or data access rights, and training.
- **Security by design**, i.e. the incorporation of security objectives and standards as a core part of the technology research and design process.

International efforts can also help governments, companies and others to build up digital resilience capabilities. A variety of organisations are involved, each contributing its comparative strengths, including to share best practices and policies as well as to help mainstream digital resilience in energy policy making.

Privacy

Privacy and data ownership are also major concerns for consumers, especially as more detailed data are collected from a growing number of connected devices and appliances. For instance, data on energy use in households collected by smart meters can be used to tell when someone is home, using the shower, or making tea.

At the same time, aggregated and anonymised individual energy use data can improve understanding of energy systems, such as load profiles, and help lower costs for individual consumers. Policy makers will need to balance privacy concerns with these other objectives, including promoting innovation and the operational needs of utilities.

Economic disruption

A review of key energy sectors demonstrates the many – and varied – ways in which digital technologies can affect jobs and skills in the energy sector. Overall, digitalisation is likely to lead to further efficiencies along the supply chain, but is less likely to replace still-sizeable labour needs for major engineering and construction activity related to physical infrastructure. Jobs composed of a high share of automatable tasks – such as those involving predictable, routine and repetitive physical activities, and the collection and processing of data – may be at higher risk of automation than those with less routine activities.

Workers supporting digital infrastructure will need specialised ICT skills, such as coding and cybersecurity, while across the energy sector, all workers will need generic ICT skills to operate digital technologies. Complementary "soft" skills such as leadership, communication and teamwork skills will become increasingly important for the growing number of opportunities for ICT-enabled collaborative work.

The pace and extent of digitalisation and its impacts on jobs in the energy system remain highly uncertain, and will depend on a number of factors that will vary across regional and sectoral contexts. Policy makers in the energy field should participate in broader government-wide deliberations about these effects and how to respond to them.

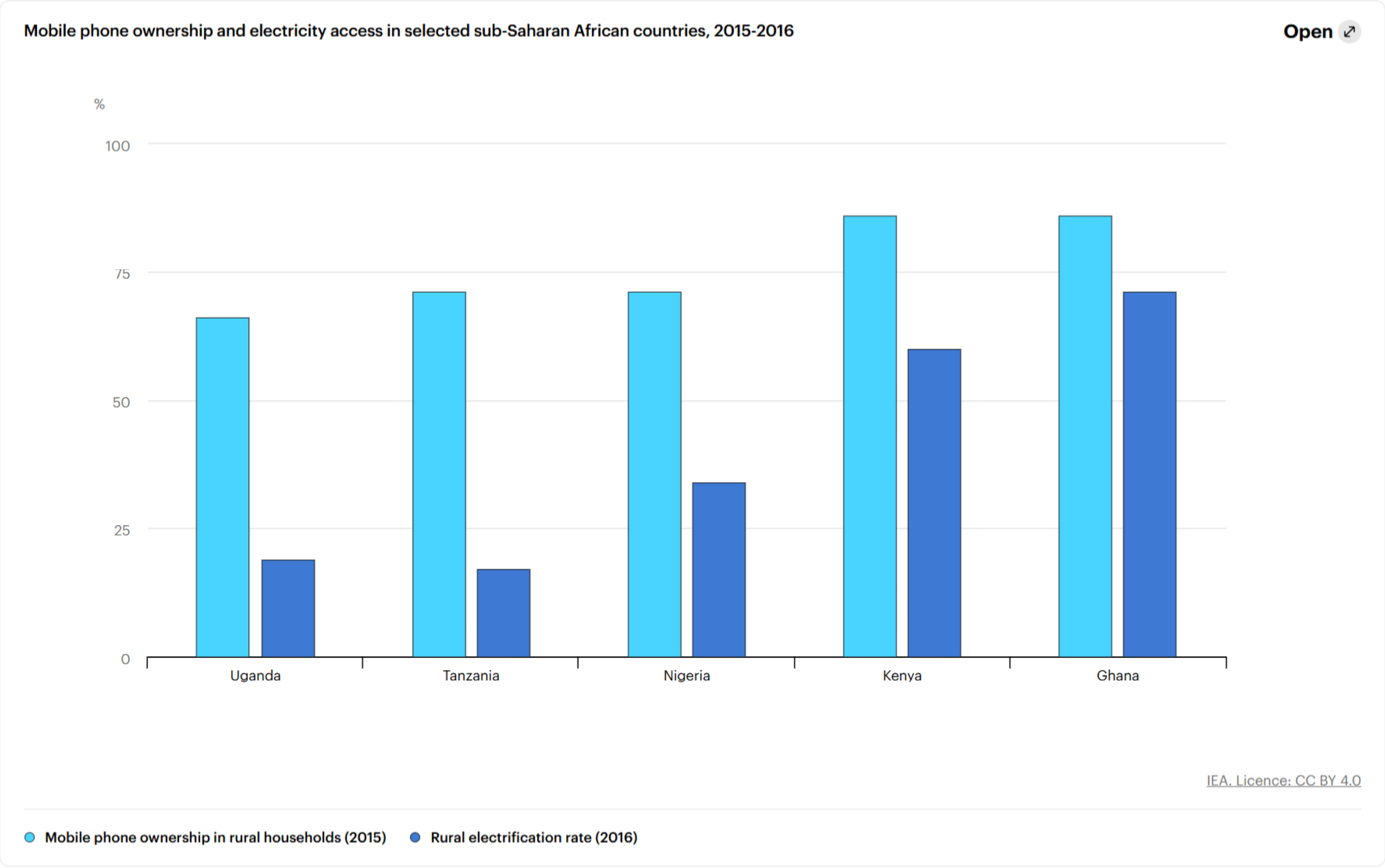
Policy

Promoting energy access, sustainability and security

Policy and market design are vital to steering digitally enhanced energy systems onto an efficient, secure, accessible and sustainable path.

For example, digitalisation can assist in providing electricity to the 1.1 billion people who still lack access to it. In certain countries in sub-Saharan Africa, mobile phones are more prevalent in homes than electricity, and mobile phones and the associated infrastructure, such as cell towers, may be able to help facilitate access to a large array of energy services.

Mobile phone ownership and electricity access in selected sub-Saharan African countries, 2015-2016



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New digital tools can also promote sustainability, including satellites to verify greenhouse gas emissions and technologies to track air pollution at the neighbourhood level. More precise accounting is critical for verification schemes and towards ensuring integrity in carbon certification schemes such as carbon markets. The technology is complex and satellite launches are expensive and difficult to schedule, but by 2030 several satellites are expected to be operational, forming a co ordinated fleet of monitoring stations shared by several space agencies.

Digitalisation could also benefit specific clean energy technologies like carbon capture and storage (CCS). Digital technology applications for CO2 capture are similar in nature and benefit to digitalisation in industry and power generation. Specifically, optimisation of control processes through automation and enhanced data collection and analytics are likely to reduce overall costs. Much of the digital transformation and innovation from the oil and gas industry appears to be transferable to CO2 storage assessment and development as well.

Policy-making processes can also benefit from more timely and sophisticated collection and publication of energy data that greater access to digital data could facilitate. For example, digital data can revolutionise an evolving process known as "data fusion", in which datasets are created which are far more powerful than a simple sum of their parts. One example is work in the United Kingdom to combine data for local areas about annual consumption of electricity and/or gas with information on building stocks (type of buildings, floor area, age of buildings), energy audits, and socio-economic indicators.

No-regrets policy recommendations

Digitalisation can facilitate positive change, but only if policy makers undertake efforts to understand, channel and harness digitalisation's impacts and to minimise its risks. While there is no simple roadmap to show how an increasingly digitalised energy world will look in the future, the IEA recommends ten no-regrets policy actions that governments can take to prepare. This list is not intended to be exhaustive or definitive, and recognises that national circumstances and contexts vary between countries. It is hoped it will foster further discussion among governments, companies and other stakeholders.

- **Build digital expertise within their staff:**

Energy policy makers need to make sure they are well informed about the latest developments in the digital world, its nomenclature, trends, and ability to impact a variety of energy systems (both in the near and longer term). A major part of this endeavour consists of ensuring that energy policy makers have access to staff with digital expertise. Education policies and technical training to ensure an adequate pool of relevant expertise for both the private and public sectors will also be critical. Conferences, workshops and exercises can also help.

- **Ensure appropriate access to timely, robust, and verifiable data:**

Opportunities provided by digitalisation to improve energy statistics can only be realised with access to data. For example, these could include:

electricity consumption data at a high level of detail in both space and time; information on installed distributed energy resources; and data about energy infrastructure. Ensuring timely and robust, verifiable and secure access to the necessary data, from business and across government, while protecting privacy, is critical. Policy makers should consider how guidelines and mechanisms can enable sharing of data.

- **Build flexibility into policies to accommodate new technologies and developments:**

While energy infrastructure can be expected to last 50 years or more in many instances, software, applications, and even ICT hardware turns over quickly. As policy makers design a range of energy policies, they should ensure appropriate flexibility to deal with new developments in digital and communication technologies, while these continue to rapidly evolve, often in hard-to-predict ways.

- **Experiment, including through "learning by doing" pilot projects:**

As explored throughout this report, there is no way to predict with certainty how particular digital technologies will interact with specific energy system applications, especially in complex real-world situations that involve multiple policy objectives and uncertain (and sometimes unintended) feedbacks. Accordingly, governments should consider setting up and exploring a wide variety of real-world experiments that can yield "learning by doing". California's programme of pilot projects in electricity demand response and smart grids is a good example. Governments may also consider setting up equivalent digital "sandboxes" along the lines of fintech test zones developed in Australia, Indonesia and Singapore. Such sandboxes, for example, could be set up to enable testing of peer-to-peer transactive energy markets or autonomous vehicle experimental zones.

- **Participate in broader inter-agency discussions on digitalisation:**

Many jurisdictions around the world are developing digital strategies for their whole economies. For example, since May 2015, the European Commission has delivered 35 legislative proposals and policy initiatives in its Digital Single Market strategy. Energy policy makers should be active in these inter-agency discussions to ensure energy sector perspectives and equities are taken into account.

- **Focus on the broader, overall system benefits:**

In line with broader IEA recommendations, the costs and benefits of digitalisation in energy should be considered not only per component or per individual consumer, but also in terms of overall net benefits to the security, sustainability and affordability of the system as a whole. This approach is particularly important in electricity where the transition to smart energy systems may require significant changes in market design.

- **Monitor the energy impacts of digitalisation on overall energy demand:**

Policy makers should be aware of the possibility that new digital devices and services have the potential to increase energy consumption, for example, as a result of growing quantities of smart household and consumer electronics. Understanding consumer behaviour and being always up-to-date in monitoring the energy efficiency of new energy-using devices will be increasingly important.

- **Incorporate digital resilience by design into research, development and product manufacturing:**

As an efficient way to reduce overall digital security risks, policy makers should include security considerations in all publicly supported technology research and design programmes, and in product manufacturing through standard-setting.

- **Provide a level playing field to allow a variety of companies to compete and serve consumers better:**

Governments should strive to provide technology-neutral and delivery-route-neutral policies and platforms for digital energy (for example in relation to the role of smart meters or other energy management systems), to allow a variety of companies to compete to find new business models and to serve consumers better. Considerations of security, privacy, economic disruption and other concerns will also need to be taken into account.

- **Learn from others, including both positive case studies as well as more cautionary tales:**

It is acknowledged that each country is different in many ways that are relevant to digitalisation's increasing impact on energy systems; nonetheless, there are lessons to be learned from the experiences of other governments and jurisdictions. These lessons can include both positive case studies as well as more cautionary tales. Useful collaborations and best policy sharing can take place in a variety of fora, including the Connected Devices Alliance and a wide range of IEA Technology Collaboration Programmes.

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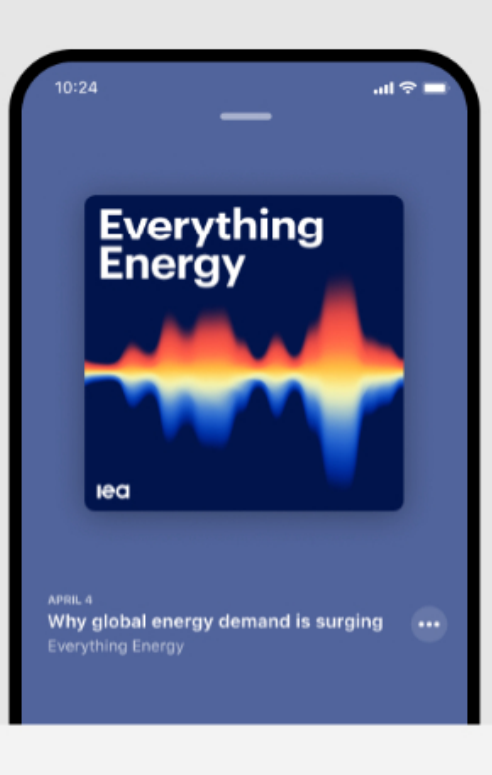

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