MIT Technology Review Insights

Produced in partnership with ERICSSON

How connectivity and 5G can enable transformational reductions in carbon emissions for industry

Decarbonizing industries with connectivity & 5G

Preface

"Decarbonizing industries with connectivity and 5G" is an MIT Technology Review Insights report sponsored by Ericsson. The report was produced through interviews with senior technology, business, and renewable energy executives worldwide conducted in July and August 2021, to evaluate how the use of 5G and other digital cellular technologies can enable the decarbonization of three sectors: energy, manufacturing, and transportation. Ross O'Brien was the writer, Francesca Fanshawe was the editor, and Nicola Crepaldi was the publisher. The research is editorially independent, and the views expressed are those of MIT Technology Review Insights.

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Foreword

Welcome to this MIT Technology Review Insights report.

This report, sponsored by Ericsson, comes when we have the first installment of the IPCC's Sixth Assessment Report, which makes clear that "unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5 °C or even 2 °C will be beyond reach.[1]"

From our involvement in the Exponential Roadmap, we know that limiting global warming to 1.5 °C is associated with halving overall global emissions by 2030.[2] Meeting reductions of this magnitude requires ready-to-go, exponential solutions. Many such solutions are digital in nature, and feature in the Exponential Roadmap.

The Roadmap, a product of research institutes, technology innovators such as Ericsson, and climate action organizations, is consistent with the Paris Agreement and features 36 scalable solutions to halve global greenhouse gas emissions by 2030. This timely Insights report focuses on the decarbonization opportunities in three sectors: energy and electrification, manufacturing, and transportation. We hope it will increase your appetite to explore how 5G may be used to help businesses to achieve their sustainability targets.

In its conclusion, the report notes that mobile infrastructure is a unique and fundamental enabler of decarbonization. Connectivity, particularly 5G, with its ultra-low latency and high speed, enables digitalization to scale and surge.

5G acts as a platform upon which exponential digital technologies, such as artificial intelligence, extended reality, and the internet of things (IoT) can flourish. With 5G, for example, we forecast the number of IoT connections to grow exponentially from 12.4 billion in 2020 to 26.4 billion in 2026.

Through connected technologies, the private and public sectors can harness all manner of uses and solutions to combat carbonization and climate change. Efficient logistics and manufacturing, renewable energy systems, and low-carbon transportation are just some of the known uses. It is fair to anticipate many unforeseen uses and benefits in the years ahead.

As the IPCC notes, however, time is against us. Yet, in 2020-21 and the pandemic era, we have seen that practices and emission levels can change rapidly. Building on these insights, we can use digitalization, underpinned by mobile network services and cloud technologies, to accelerate the decarbonization of enterprises by years.

We need to act now and continue spurring that digitalization, starting with increasing access to the innovation platform 5G, allowing scalable technologies, digital practices, and lower carbon generating solutions to flourish.

We sincerely thank all those who contributed their insights to the report and hope that you enjoy reading this introduction to 5G.

Erik Ekudden
Senior Vice President and CTO, Ericsson

CONTENTS

01 Executive summary

The UN Intergovernmental Panel on Climate Change's (IPCC) sixth climate change report, released in August 2021, declared that humans are "unequivocally" to blame for the precarious and worsening state of global warming, and that rapid action to cut greenhouse gas (GHG) emissions must be taken to limit its impact.[3] This comes five years after countries around the world committed to the 2015 Paris Agreement, agreeing to limit global warming to well below 2 °C, and ideally to 1.5 °C compared to pre-industrial levels.[4] According to the IPCC, this translates to the halving of global emissions by 2030.[5]

Enterprises and industries must therefore redouble their GHG reduction and removal efforts with speed and precision, but to do this, they must also commit to deep operational and organizational transformation. Of the many digital technology tools and technology-enabled processes organizations have at their disposal to accelerate their decarbonization efforts, cellular infrastructure, and particularly 5G, is a uniquely broad and powerful enabler to lessen carbon footprints.

The advantages of 5G network capabilities that include ultra-low latency, real-time and predictive analytics, and a step-change in transmission speeds offer businesses new opportunities to advance digital transformation efforts and improve efficiencies. Automated systems, mobile applications, and managed networks of digital devices and IoT will all be provisioned faster, at greater scale, and with more flexibility through 5G. By enabling increasingly interconnected supply chains and networks, improving data sharing, optimizing systems, and increasing operational efficiency, the capabilities enabled by 5G and other cellular technology could soon contribute to an exponential acceleration of global efforts to reduce carbon emissions.

Sectors like energy, manufacturing, and transport could have the biggest impact on decarbonization efforts through the use of 5G, as they are some of the biggest GHG-emitting industries and all rely on connectivity to link to one another through communications network infrastructure. Organizations in these sectors extract value from digital cellular networking technology because their operational models and business ecosystems are also based on interdependent networks (for example, extended supply chains) and use connectivity to increase operational efficiencies. In so doing, they create virtuous cycles of shared data and insights that are optimizing systems for lower resource usage and carbon emissions.

The speed and efficacy with which decarbonization solutions are deployed are critical factors in their overall impact, and will lay the foundations for their accelerated and ongoing efforts to reduce carbon emissions.

The key findings of this report are:

Cellular digital transformation increases efficiency–and sustainability. By allowing a data-driven operation of core business processes, cellular connectivity enables organizations in the energy, manufacturing, and transportation sectors to use energy and materials more efficiently, advance circular economy ambitions, and enhance the remote traceability and optimization of their products and services. 5G and other digital cellular technologies are a key part these strategies: their speed of deployment, lower latency, and their ability to help organizations connect and manage disparate and remote assets are particularly useful capabilities for solving challenges common to all, including reducing costs, improving outputs, and lowering carbon emissions.

Data-based decarbonization. Digital channels are essential to business operations today, and while efficiency gains (and the cost savings that accompany them) are usually the most important motivation for their adoption, the increased data and insights that they deliver also make businesses more environmentally and operationally sustainable. Carbon neutrality pledges and environmental, social, and governance (ESG) reporting make it essential that businesses prove their bona fides with analytics that verify their low-carbon operations–perhaps even resulting in formal "no carbon" certification of their products and services. Increasingly, these capabilities are delivered over cellular networks.

Systems empowering systems for radically lowered emissions. Cellular-based technology allows firms to achieve considerable sustainability gains by increasing energy efficiency through better monitoring, or reducing waste and material costs through optimized management practices. But the real step-change in reducing emissions globally will come when 5G infrastructure facilitates interconnected systems to allow vast amounts of data sharing across supply chains, logistics networks, and energy grids. While existing communications networks allow this to some extent already, the increased speed and reliability of 5G will enable networks and organizations to take their value chains to the next level.

Definitions

In this report, the terms "wireless," "cellular," and "5G" are all used at times to describe forms of connectivity. While similar, there are differences between how the terms are used. For the purposes of this report, the definitions are as follows:

- **"Wireless"** refers to data communication network infrastructure that transmits information using radio technology. While the term usually includes cellular networks, in this report it refers to WiFi, radio-frequency identification (RFID), or other transmission modes where radio-based devices communicate to and from a single wireless router.

- **"Cellular"** is used in this report to mean radio-based communications networks where fixed base stations communicate with each other to "hand over" signals from a wireless device, which allows them to maintain connectivity as it moves over a large distance.

- **"5G"** is used to describe cellular networks using a "fifth generation" of technology that is recognized to have higher-speed connections through wider channels, lower latency, and higher bandwidth capabilities than previous generations.

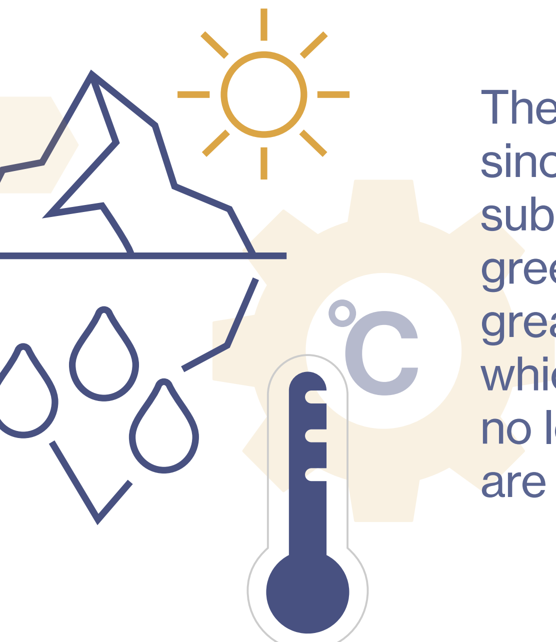
02 The environmental sustainability challenge

Doing the math

Unprecedented numbers of people, governments, and corporations have been mobilizing resources and action to reduce carbon emissions. Nearly a third of Fortune 500 companies have committed to achieving a major climate change goal by 2030, most through achieving “carbon neutrality” or “net-zero emissions.”[6,7] Commitment to reduce carbon-intensive activity and promote carbon-negative activity is seen as table stakes in international efforts to meet Paris accord commitments aimed at keeping global warming under 2 °C, and ideally no more than 1.5 °C.

The ongoing, and seemingly endless, climate disasters put the necessity to decarbonize in sharp relief. In 2021, these included a blistering “heat dome” of nearly 50 °C in the normally temperate Pacific Northwest of the US and Canada, deadly and destructive flooding in China and across Europe, and wildfires globally from Turkey to California, the latter of which had damaged close to a million acres by September 2021.[8]

The IPCC’s sixth climate change report—an aggregated assessment of scientific research prepared by some 300 scientists across 66 countries—has served as the loudest and clearest wake-up call to date on the global warming crisis.[9] Determining that the earth’s temperature has risen by 1.1 °C since the Industrial Revolution, the authors unequivocally attribute the increase to human activity. Without substantial and immediate reductions in carbon dioxide (CO2) and other greenhouse gas emissions, they write, temperatures will rise between 1.5 °C and 2 °C before the end of the century. At that point, the authors conclude, it is likely that the rate of weather and



The earth’s temperature has risen by 1.1°C since the Industrial Revolution. Without substantial and immediate reductions in greenhouse gas emissions, the earth is at greater risk of passing “tipping points” beyond which global environmental disasters can no longer be avoided even if temperatures are reduced later on.

environmental disasters will lead to “greater risk of passing through ‘tipping points,’ thresholds beyond which certain impacts can no longer be avoided even if temperatures are brought back down later on.”[10]

Governments and companies are thus under intense pressure to transform the way energy and materials are generated and consumed to quickly reduce emissions. Decarbonization efforts must be targeted, swift, and ongoing. Solutions must be deployed now.

In search of exponential results

The Exponential Roadmap is a report released in 2020 by a partnership of research institutes, technology innovators, and climate action organizations, which analyzed the global carbon impact of several industrial and economic sectors, and identified 36 technologies and practices that could contribute to halving global emissions by 2030.[12]

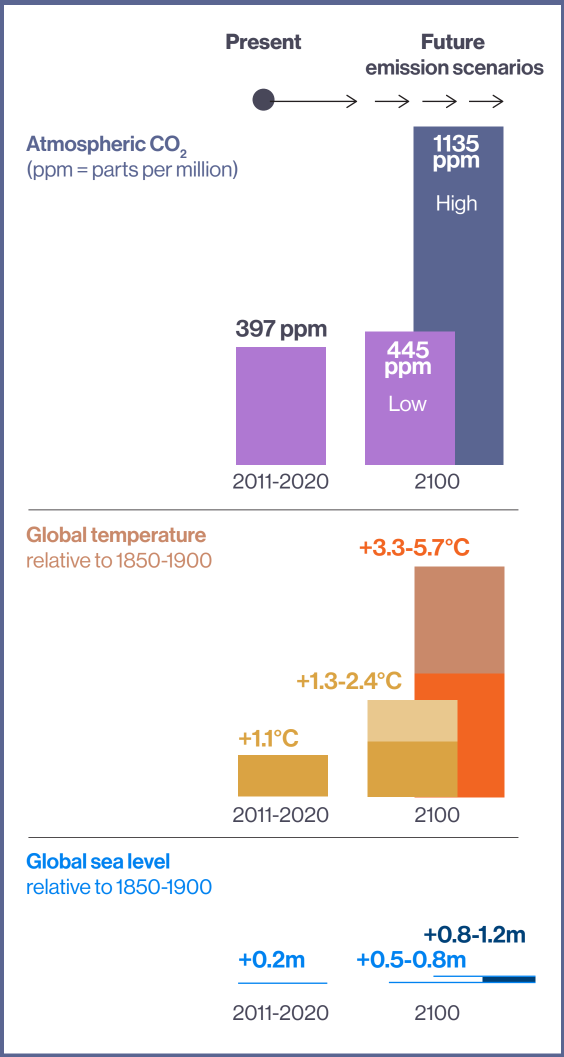
This report, “Decarbonizing industries with connectivity and 5G,” draws upon the findings of the Exponential Roadmap and focuses on the decarbonization impact of digital solutions on organizations in three sectors: energy, manufacturing, and transportation. It specifically looks at how the use of 5G and other digital cellular technologies can enable those efforts.

The higher performance and improved efficiency of 5G—which delivers higher multi-gigabit peak data speeds, ultra-low latency, increased reliability, and increased network capacity—has the potential to help businesses and public infrastructure providers to enhance numerous applications and use cases that require effective digital management and monitoring of distributed operations with resilience and analytic insight. In so doing, 5G will help factories, logistics networks, power companies, and others to operate more efficiently, more consciously, and more purposely in line with their explicit sustainability objectives through better insight and more powerful network configurations.

Energy, manufacturing, and transportation were selected as areas of focus in this report for three reasons. Firstly, these sectors are among the biggest carbon emitters globally. Overall, energy use is responsible for about two-thirds of GHG emissions, according to the Exponential Roadmap. This is made up of 32 gigatonnes (Gt) of annual CO2 emissions (32 billion metric tonnes, or about 35.27 billion US tons), plus 3.3 Gt of CO2 equivalent

Figure 1: The potential consequences of rising greenhouse gases in the atmosphere

Atmospheric carbon dioxide concentrations, global temperature, and global sea level in the present day compared to future climate change low-emissions scenarios (SSP 1 – 2.6) and very high emissions scenarios (SSP 5 – 8.5).



Source: Intergovernmental Panel on Climate Change, 2021[11]

Statistical note: Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global challenges developed by the IPCC and used to help produce the IPCC Sixth Assessment Report on climate change, published on 9 August 2021. They are used to derive greenhouse gas emissions scenarios with different climate policies. The scenarios range from SSP1: Sustainability to SSP5: Fossil-fueled development.

Broadband cellular connectivity is a uniquely powerful enabler for decarbonization transformation levers, including efficiency and optimization, analytics and insight, and new pathways and disruptions.

emissions (CO2e) from other greenhouse gases.[13] The manufacturing sector is responsible for 17 Gt CO2e annually, which represents 32% of the global total,[14] and transport-related emissions total 8.6 Gt CO2e per year, which represents 16% of the global total.[15] Decarbonization in these sectors would have a substantial impact on meeting the goals of the Paris Agreement.

Secondly, all three sectors rely on connectivity: firms in manufacturing, energy, and transportation extract value from cellular networking technology because their operational models and business ecosystems are also based on interdependent networks. A factory is comprised of assembly lines fed by complex supply chains, while electricity distribution grids and public transportation services are themselves networks. Companies use connectivity to accelerate their digital transformation efforts, increase operational efficiencies, and create virtuous cycles of shared data and insights that could drastically decrease carbon emissions.

Thirdly, digital cellular connectivity is particularly important to the digital transformation efforts of firms in these three sectors. 5G and other cellular technology capabilities offer performance benefits for all industries, but the speed of deployment, the lower latency, high bandwidth, and the ability to connect and manage disparate and remote assets are particularly useful to solve challenges common to manufacturers, electricity grid developers, and transportation and mobility companies, as this report will explore.

This report will show that the impact of cellular connectivity on emissions reduction begins with its ability to increase enterprise efficiency and optimization. Tools and practices that create operational performance improvements can, in turn, reduce energy consumption, help manage inventory, or increase recycling efforts.

Cellular networks also augment a firm's analytics capability. IoT devices, autonomous vehicles, or simply smartphone-wielding workers all feed data into digital platforms that give decision-makers greater visibility into their operations, and the insight they need to optimize them. The same analytic tools provide a broader view of activities that create greenhouse gas emissions, such as applications that measure the carbon footprints or ESG implications of business activities. Having an understanding about the corresponding carbon emissions of operational activities can help decision-makers to decarbonize exponentially.

Finally, cellular-based capabilities enable new disruptive business pathways that create lower-carbon outcomes. New on-demand mobility models or autonomous vehicles are redesigning transportation and, in so doing, creating opportunities for firms and individuals to deliver people and goods with much lower carbon footprints. Similarly, when manufacturers use wireless-connected augmented reality devices to build products, or firms monitor and manage their energy consumption levels over 5G networks, they not only optimize their business operations, they can have transformative impact on their carbon emissions.

This report, "Decarbonizing industries with connectivity and 5G," argues that the capabilities enabled by broadband cellular connectivity primarily, though not exclusively, through 5G network infrastructure are a unique, powerful, and immediate enabler of carbon reduction efforts. They have the potential to create a transformational acceleration of decarbonization efforts, as increasingly interconnected supply chains, transportation, and energy networks share data to increase efficiency and productivity, hence optimizing systems for lower carbon emissions.

03 Electricity and energy supply

Boosting efficiencies

Under all the likely scenarios the IPCC analyzed in its most recent report, the world will reach the 1.5 °C temperature increase benchmark (compared to pre-industrial levels) within the next decade. But all is not lost. Under scenarios where emissions levels are radically reduced, the earth's temperature could fall back down below the 1.5 °C limit in the years following. Yet, to achieve this, the world must undergo substantial economic, societal, and industrial changes, including a tremendous transformation in energy production. In an earlier report, the IPCC estimated that by 2050, between 70% and 85% of all electricity generated must come from renewable sources to avoid the worst impacts of climate change.[16]

The world still has some ways to go to reach those levels. In a 2019 report, the Renewable Energy Policy Network estimated that little more than a quarter of global electricity comes from renewables[17]. But momentum is clearly building: the International Renewable Energy Agency (IRENA) reported that 260 gigawatts of renewable energy capacity was added to the world's power grids in 2020, accounting for over 80% of all new electricity globally, exceeding the expansion of renewable energy capacity in 2019 by 50%.[18] The vast majority (91%) of new renewable capacity has come from either wind or solar sources, which represents significant progress in the industry's efforts to transition away from fossil fuels. The Exponential Roadmap[19] estimates that adopting solar and wind energy could contribute nearly half of emissions reductions required by 2030.[20]

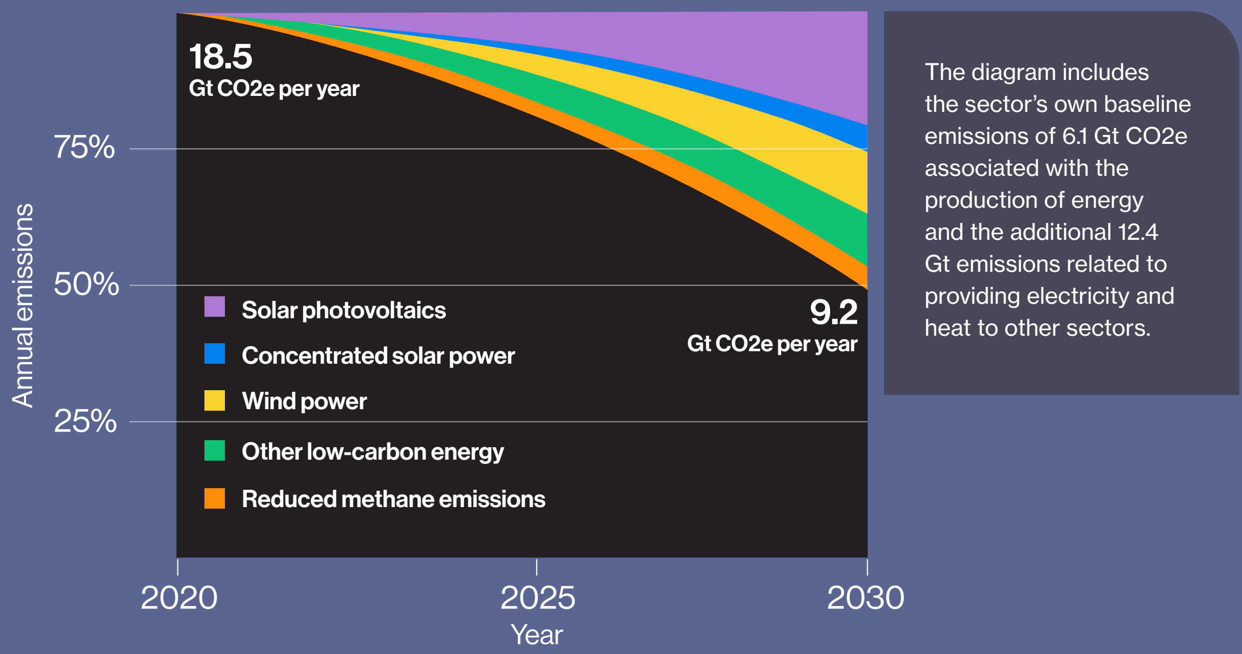
However, increased dependence on solar and wind sources also creates management and operational challenges for electricity producers. One is the growing risk of network disturbances, as renewable power generation is variable and uncertain. Electricity is also difficult to store, meaning power companies must carefully balance generation and consumption, a process that unpredictable renewables further complicates. A third challenge is that renewable energy generation sources are often small and widely dispersed, which puts pressure

> "5G-enabled cellular networks are a clear enabler for each of the so-called 'four Ds' of renewable energy: decentralization, decarbonization, digitalization, and–increasingly important for this fast-changing and entrepreneurial space–democratization."

Antonello Monti, Professor, RWTH Aachen University

Figure 2: Potential reduction of total emissions in the energy sector by 2030

As the cost of solar and wind electricity falls, and storage follows a similar trajectory, it is possible to halve global emissions at low or no cost in the energy sector by 2030



Source: The Exponential Roadmap report, 2020.[22]

on load balancing and energy planning efforts—increasingly so as growing numbers of homeowners install solar panels and look to sell their excess generation back to the grid.

Per Rosenqvist, managing director of Norway's Statkraft Financial Energy, Europe's largest generator of renewable energy, says these trends have engaged his company "in a complex energy transition project," both for Statkraft and its clients, which are primarily energy-intensive industrial firms in Nordic countries. Europe's clean power generation market, once based on reliable and stable hydro and nuclear production, "is now changing as we move to more intermittent, and more volatile, power generation supplied from wind and solar sources," says Rosenqvist.

As the world's electricity businesses increasingly rely on smaller, more dispersed, and less consistent generation facilities, it is hard for them to efficiently connect clean electricity supply to their main grids. Better data management, enhancements to energy storage, and distribution management systems help address these issues. Digital transformation efforts, enabled by cellular connectivity, allow power companies to manage their energy transitions more effectively through more dynamic load management, and low-latency networks help synchronize[21] smaller and more dispersed renewable production facilities with traditional grids.

Professor Antonello Monti, who specializes in energy grid automation at Germany's RWTH Aachen University, believes Europe's strong regulatory push toward renewables "creates a need for intelligent connectivity at the grid's edge. By 2030, the EU needs to achieve a 55% carbon footprint reduction, and fast edge connectivity will enable Europe's electricity companies to contribute to this goal," he says. Monti believes 5G technologies in particular will, in turn, be a critical tool in enhancing edge connectivity, as they provide higher levels of reconfigurability for power grids, allowing local networks to also work separately from the main network, and help renewable energy installations operate more dynamically and efficiently. "5G networks enable the incorporation of the millions of devices that are defining the networks of the future," Monti observes. He adds that cloud-based edge networks facilitated by 5G "allow enterprises to have their intelligence available close to where the devices are, minimizing run trip times," referring to the amount of time critical data needs to pass from devices to processing capabilities, and then back to the devices with revised instructions.

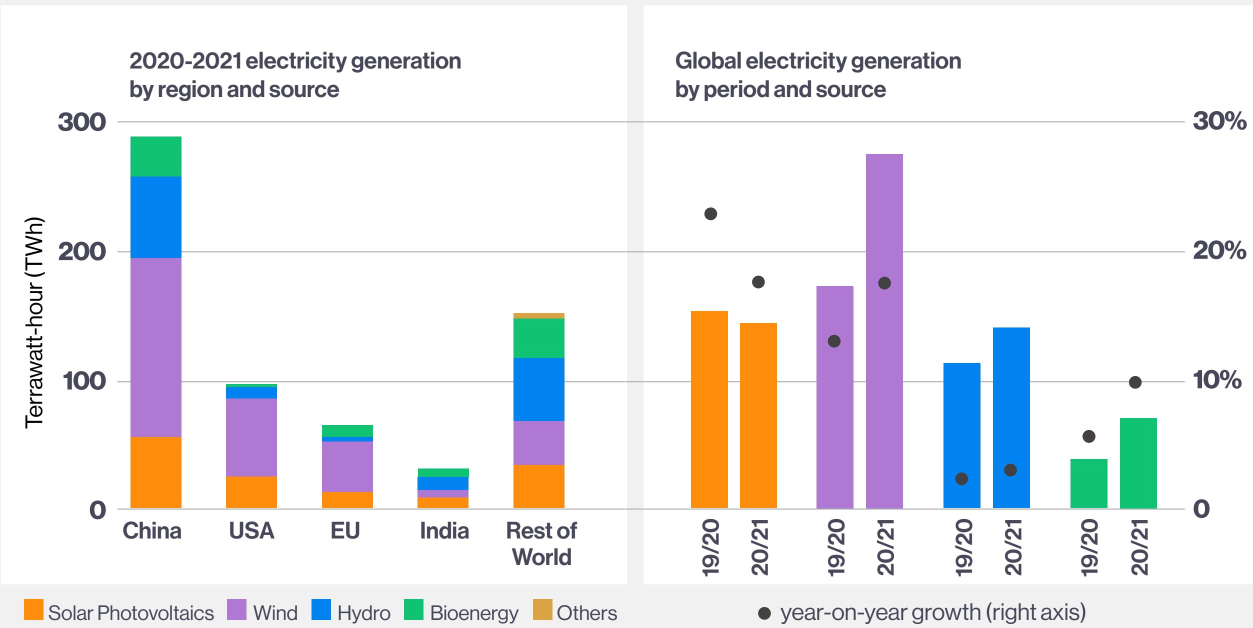
As Statkraft's Rosenqvist explains, these capabilities allow energy firms to "measure a more complete production line" —that is, to more effectively measure the sequence of production operations. According to Rosenqvist, cellular technology makes the information to do so "extremely cheap and accessible."

"This is, in my view, the big revolution," says Rosenqvist. "With 5G networks, we can very quickly and efficiently connect routers to all of our sensors and machines, and build a system not only for our own company or only for our customers on the power consumption side, but for the complete value chain." This, he observes, provides information in real time that makes it possible to increase energy efficiency.

Across the EU, there are several ongoing trials to achieve these efficiency goals using cloud-based data-driven monitoring and control systems. They are being conducted by an EU-wide consortium of technology firms, research institutes, and power companies known as the Service Oriented Grid for the Network of the Future (SOGNO). Professor Monti at RWTH Aachen, who works on SOGNO initiatives, points to a particularly promising trial involving the development of a decentralized, self-healing grid management system for two wind farms in Kerry and Waterford, in Ireland, that aims to reduce the duration of customer outages.[23] Many of these trials are based, in part, on broadband cellular platforms. As Monti explains, "5G-enabled cellular networks are a clear enabler for each of the so-called 'four Ds' of renewable energy: decentralization, decarbonization, digitalization, and democratization." It is this last "D" Monti believes is the most important for the energy industry's sustainable future, as a growing percentage of the world's new

Figure 3: Renewable electricity generation increase by technology, country, and region

Renewable electricity generation is set to expand by more than 8% in 2021, the fastest year-on-year growth since the 1970s.



Source: IEA Global Energy Review 2021.[24]

> "Travel-related emissions are decreased and technician efficiency increases when we remotely pinpoint a problem on the system and empower community members to repair it."
>
> Nick Warren, Executive Director, the WindAid Institute

production of renewable energy will come from either small entrepreneurial startups, or from consumers with solar-powered homes themselves. By democratizing renewable energy, it becomes increasingly accessible to individuals and smaller organizations.

Easily deployable wireless network infrastructure also helps power generation companies to create energy management platforms, which Statkraft and others are beginning to use to help their clients reduce their overall emissions. As Rosenqvist explains, "it's not enough for us to sell clean power; any energy company can put up solar cells and start doing this. We need to get closer to our customers, as they are asking us to be responsible for their overall power management portfolios." This has a secondary benefit of providing Statkraft's customers with better visibility of their costs, which Rosenqvist says they have very little of today.

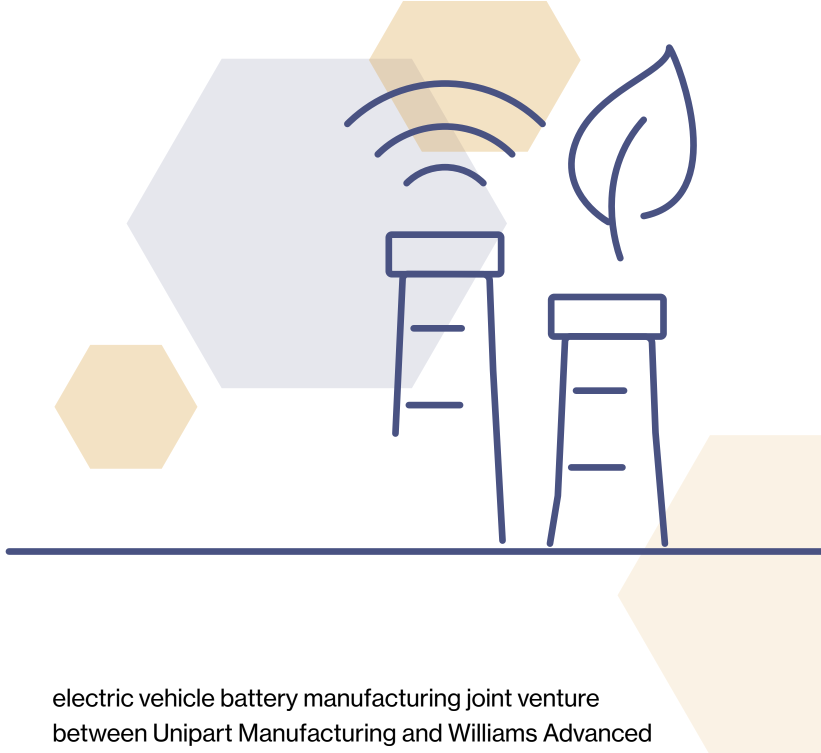
5G for remote monitoring

WindAid Institute is a nongovernmental organization that has built a system of 60 wind turbines—some as small as 500 watts—for remote communities in northern Peru. The electricity is used to charge smartphones, computers, headlamps, and water pumps. Executive Director Nick Warren says it is difficult to implement remote monitoring of its installations with the spotty 2G wireless coverage currently available in the areas where they work. But even with basic data, limited applications, and a relatively high electricity load, WindAid has found that remote monitoring systems help improve upkeep and increase oversight. "More visibility into turbine operating conditions diminishes our travel dramatically; it often takes several hours for a technician to reach a site, so travel-related emissions decline and technician efficiency increases when we remotely pinpoint a problem on the system and empower community members to repair it."

Cellular communication is a key enabler for new power grid architectures and operational models. WindAid's celllular-based management systems track basic operational data, including wind speed, turbine output and usage, and battery levels. Aggregating this data reduces turbine repair time and increases system-wide knowledge and insight. "When we monitor commonalities, we can help community members to pinpoint common trouble-shooting issues—electronics, battery maintenance, switching out blades," all of which increase turbines' overall time in operation.

The management system also allows WindAid to analyze environmental conditions such as seasonal wind strength, which helps them to improve the design of turbines and power generation systems. As a result, Warren observes, "our new default systems are being built as hybrid wind and solar systems." In the long term, with more precise data from better and more powerful mobile broadband connectivity, Warren believes WindAid can connect remote turbines into more efficient and sustainable micro-grids, and eventually generate granular power generation data to potentially create carbon credits.

04 Manufacturing



Better visibility

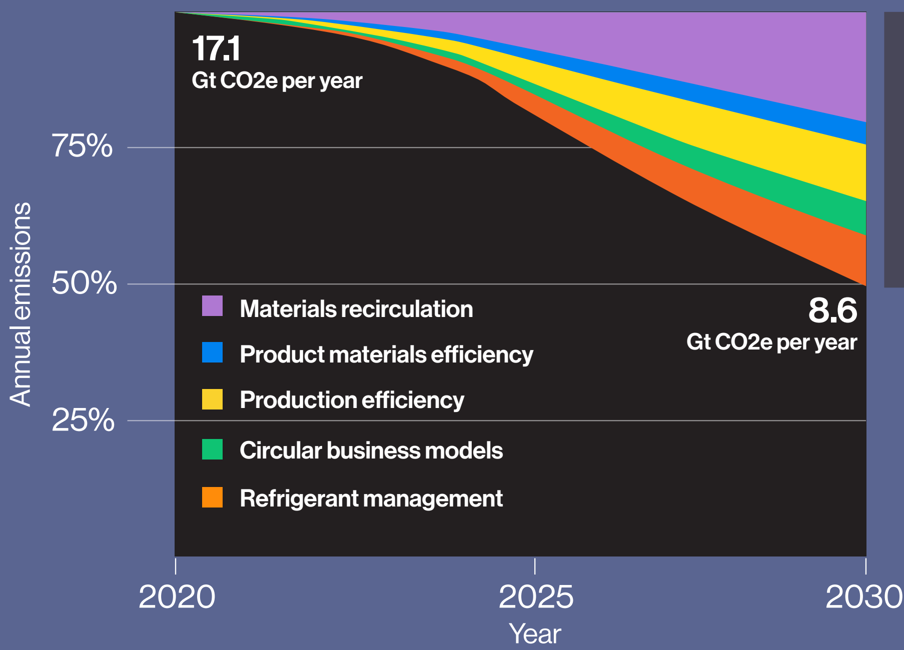
The Exponential Roadmap estimates that material reuse and recycling could make the single biggest impact on reducing carbon emissions in the manufacturing sector, potentially accounting for nearly half of emissions reductions by 2030. Cellular-connected production management systems and IoT tracking could also play a significant role. Manufacturers and producers are already leveraging these systems: more efficient temperature and humidity control in factories and warehouses can reduce electricity consumption, lessen inventory wastage, and extend the shelf life of sensitive materials such as prepared food, vaccines, or microprocessors. The Exponential Roadmap estimates that such measures could contribute 20% of the carbon emissions the sector could remove from its operations by 2030.

Production efficiency could contribute another 25% of potential carbon reductions. For Hyperbat, a UK-based electric vehicle battery manufacturing joint venture between Unipart Manufacturing and Williams Advanced Engineering, production efficiency is achieved in line with greater flexibility. “Our manufacturing sustainability initiative is driven by the need to be flexible,” says Hosein Torabmostaedi, Hyperbat and Unipart Manufacturing’s digital and innovation manager. “We want to get to a point where we can put a manufacturing line directly into a container and ship it to anywhere in the world, and make our batteries at the customers’ point of use, thus reducing the emissions generated in the shipping, distribution, and warehousing processes,” he says. These efforts to drive manufacturing closer to Hyberbat’s end users complements an information and process management initiative that “puts systems at the backbone of the business to digitally manage interaction with the suppliers and customers, from deployment and planning of our operations to executing our operations on the shop floor. This is an enormous amount of data and Hyperbat believes it is best managed using 5G’s increased speed and bandwidth,” says Torabmostaedi. The resulting

> “There is an expense to installing a cellular system initially, but in so doing we avoided another $60,000 worth of cable installations. As a result fewer contractors drove to our site, less cable was manufactured and shipped to the factory. Additionally, once a cellular network is up and running with sufficient bandwidth, each new connection that you create is virtually free.”
>
> David Hart, Industry 4.0 Transformation Leader, Ericsson

Figure 4: Potential reduction of total emissions in the industrial sector by 2030

The industrial sector was responsible for 32% of the global total carbon dioxide emissions in 2018. If large industrial companies make significant changes, industry-related emissions could be cut by 50% by 2030.



Refrigerant management here refers to the effective phasing out of environment-damaging refrigerants, including chlorofluorocarbon and hydrofluorocarbon refrigerants.

Source: The Exponential Roadmap report, 2020.[25]

flexibility "impacts not only our costs and performance, but also our carbon-reduction efforts," he adds.

One of the technology levers Hyberbat is exploring to boost efficiency are systems that use virtual reality (VR) and augmented reality (AR) to allow on-site teams to conduct design reviews and oversee manufacturing processes using 5G-enabled AR glasses. Thanks to private wireless cellular networks, the factory floor is becoming a much more agile environment. 5G connectivity combined with the latest technology can produce significant efficiency gains on the manufacturing floor as well as collaboration across different industries. To use this VR system, says Torabmostaedi, Hyberbat's production teams "require an enormous amount of data including work order instructions and high-quality production data," which are currently best managed using 5G infrastructure.

While accurately measuring and managing legacy operational activities addresses a large part of the challenge, a complementary option is integrating sustainability into the design and operation of building facilities from the ground up. In 2018, telecommunications company Ericsson built a smart manufacturing facility for 5G radios and other network elements in Lewisville, Texas.

Digital transformation underpinned that effort: an industrial IoT platform connects the entire mixed-use warehouse, office, and production facility, gathering and analyzing data, and communicating actionable issues through a mobile alerting system "which lets production crews know when materials are running out or whether machine downtime is exceeding their threshold, so they can take proactive views on the data," says David Hart, the industry 4.0 transformation leader at Ericsson's 5G smart factory. This, in turn, increases productivity and reduces energy use by over 15%, Hart estimates.

The reliability of cellular, as opposed to wired or WiFi, communications infrastructure helps increase operational resilience. "We are running automated guided vehicles over 5G connections and thanks to fewer communication

> "Manufacturers will learn more about their true operating parameters in the next 10 years than they have in the last 50, by analyzing real world live data mapped to each individual product–that's how Industry 4.0 and the connectivity of 5G and LTE (long-term evolution) will change the way manufacturing runs."
>
> David Hart, Industry 4.0 Transformation Leader, Ericsson

drops, they are about 15% more efficient than those connected to WiFi access points," says Hart.

Sensors and analytics platforms measure environmental conditions, such as temperature, humidity, and water levels, both inside the facility and in the surrounding grounds. Hart observes that close environmental monitoring can avoid wasting humidity-sensitive components, such as chipsets and motherboards, and in the longer term, provide a more precise and holistic analysis of production conditions, serving as a sustainability catalyst through predictive manufacturing. "What we glean from these connected networks of manufacturing equipment and the environmental situations is real-world data, not lab data, are going to provide huge benefits to manufacturing in terms of both productivity and sustainability, and in understanding what our true manufacturing parameters are."

Over the next 10 years, Hart says manufacturers "will learn more about their true operating parameters than they have in the last 50 years, by analyzing real-world live data mapped to each individual product. That's how Industry 4.0 and the connectivity of 5G and LTE (long-term evolution) will change the way manufacturing runs."

Ultimately, Hart says, the precision with which production data is captured and analyzed could possibly create the ability to put a "zero-carbon" stamp on products made in such facilities, "not dissimilar to all the non-GMO and 'wholegrain' stamps that have come along over the course of time in the food industry. There's a group of people who will buy zero-carbon products, and that group is going to grow," Hart adds.

A little energy management goes a long way

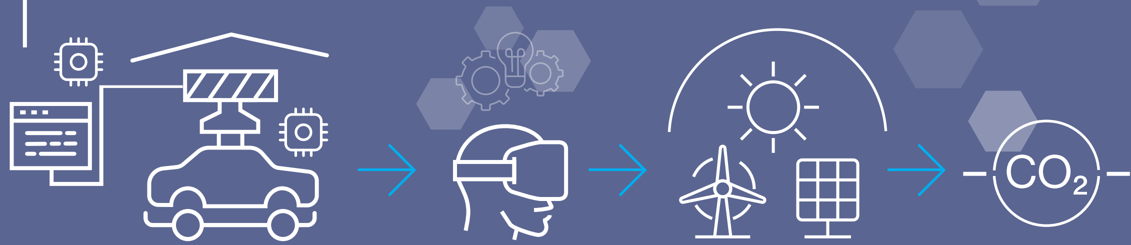
Temperature control, as a component of energy management systems, is a very simple and effective measure for companies. "Simple benchmarking data allows you to understand how much energy one facility is using compared to all your other facilities," explains Alan Seigrist, chief financial officer and head of strategy for Energybox, a provider of IoT-based power and environment management systems that oversees an estimated 50,000 facilities for enterprises across the US and Europe. Even simple data, when regularly gathered—Energybox sensors record energy use samples every two to five seconds—can produce impactful results. Seigrist notes that this kind of monitoring can help to quickly identify and analyze the root cause of spikes in power consumption, whether they are faulty light sensors or springtime pollen clogging up air conditioning units. Moreover, says Seigrist, "in the last 12 months, there's been a noticeable increase in customers who are coming to us because we can help them automate significant parts of their environmental, social, and governance (ESG) reporting."

To do this efficiently, Seigrist explains, "we prefer wireless applications because the configuration is much easier, and more reliable than Ethernet connections. With 4G or 5G connections, our hubs start to communicate as soon as they are turned on." Mobile connectivity also plays an important role as energy management systems become more reliant on a growing and distributed constellation of assets and resources: "the hardest nut to crack is communication, from the hubs to cloud resources to sensors," says Seigrist. "There are multiple points along the way, and that network has to be robust."

5G-enabled decarbonization in the lifecycle of an electric car

The decarbonization effects of 5G have the potential to be pervasive, with transformative benefits throughout the value chains of many industries and across the lifecycle of many products. Take, for example, the ways cellular connectivity can lessen the carbon footprint of an electric car, from its production to its use out on the road.

1 Produced in a smart factory



By autonomous and automatic robots connected via multi-access edge computing (MEC) to production systems.

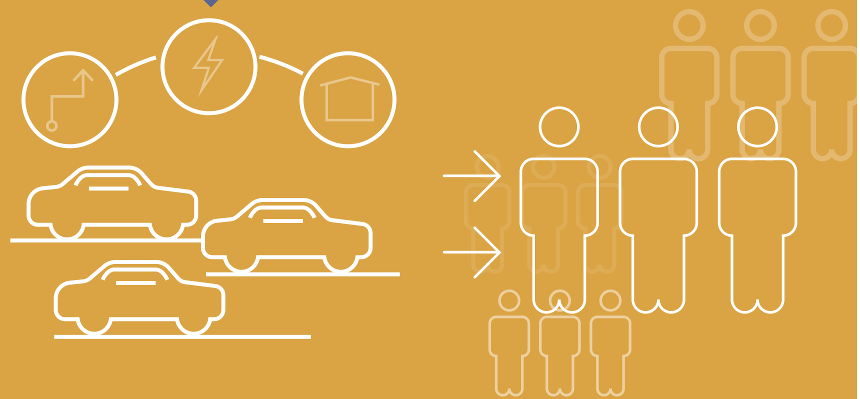
With on-site production teams augmented by VR and AR.

Using materials that have been maintained in optimal conditions through environment management systems.

With components that have a traceable environmental footprint.

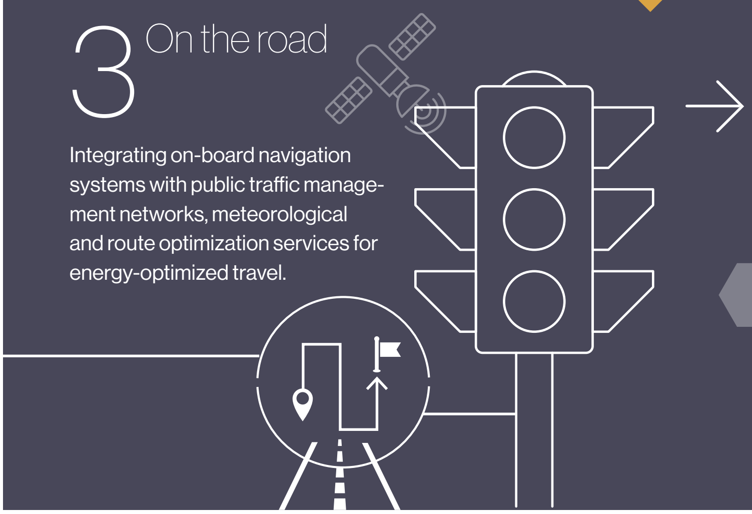
2 Delivered to a consumer

Via carbon-optimized logistics services like electric conveyance, warehousing, and storage facilities that are managed by energy management systems. All logistics partners are ESG compliant.



3 On the road

Integrating on-board navigation systems with public traffic management networks, meteorological and route optimization services for energy-optimized travel.



Keeping track of charging station data to determine availability, proximity, and payment methods.

Sharing trip progress and status data with traffic management services to contribute to better system efficiency for fleet vehicles.

05 Transportation

Making better connections

Much like the energy sector, the operational structure of the transportation industry closely emulates that of a communication network. The economic success of both sectors depends on the efficient conveyance of units of value (of vehicles, people, and goods in the case of transportation, or of data in the communications sector) across shared infrastructure resources (be it road, rail, or cellular networks). The synergies that result from collectively and systematically integrating transportation and communication networks—such as telematics, smart city analytics, and traffic management solutions—can quickly lead to efficiencies that reduce emissions.

A key challenge to accelerating decarbonization through connectivity, however, is that currently, most transportation "systems" are still largely siloed. Fleets of trucks operated by logistics firms, public subway operators, or individual drivers of electric vehicles largely exist in separate parallel data universes. Fortunately, transportation industry players, particularly new mobility firms, are acutely aware of the need to integrate cross-system operational intelligence in order to achieve transformative carbon benefits.

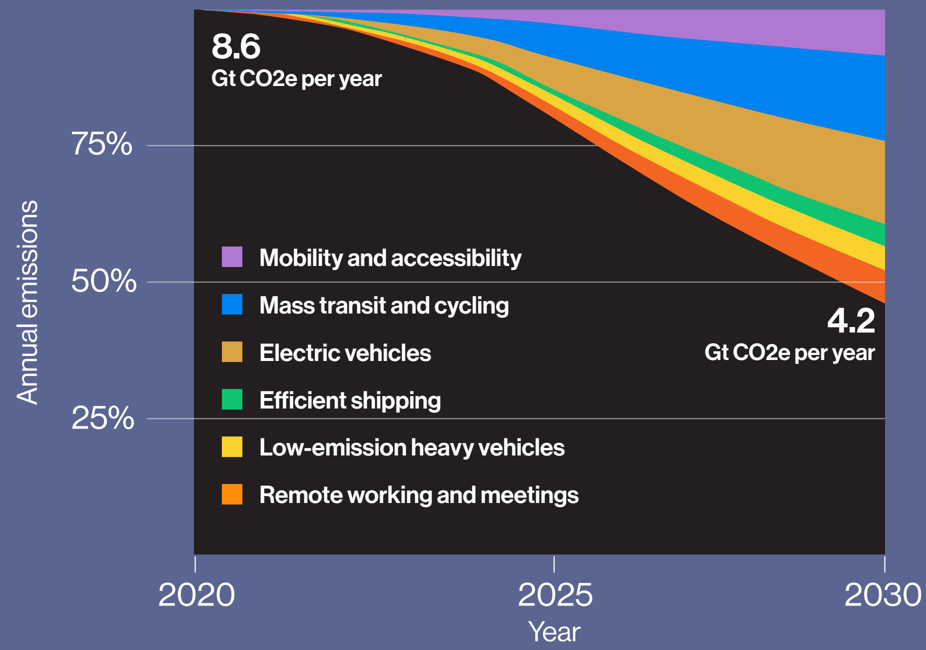
"The transportation world will soon be ubiquitously connected, electrified, and autonomous," says Tony Sandberg, director of e-mobility for the Swedish commercial vehicle manufacturer Scania Group. These trends, in turn, will cause an entire ecosystem of connectivity to grow around transportation industry participants, says Sandberg, "so we recognize that we cannot only be a producer of vehicles, we need to provide transport solutions. This means integrating services, products, and charging solutions into a complete offer. We need to move up the ladder into a system perspective." Sandberg estimates that Scania has 600,000 trucks worldwide, which are connected to a fleet management system measuring operational metrics such as vehicle speed, payload, fuel consumption, and the number of stops per route.

Sandberg acknowledges that while Scania does not currently use these metrics to measure their vehicles' emissions, he believes it will soon be possible to integrate individual operational indicators that can eventually be developed into a holistic view of every vehicle's carbon impact. But this, in turn, will require a cross-sectoral digital integration. "To utilize the potential of all the collected data within each individual transport management system and to connect each one to every other, data must be shared between public and private transportation network platforms and new mobility private firms," says Sandberg.

The real-time data provided by such cross-system integration could eventually lead to a digital ecosystem where supply chain participants share information on the carbon impact of their goods and services. "The value chain of sustainability data will be very long, and very wide," adds Sandberg.

Figure 5: Potential reduction of total emissions in the transport sector by 2030

Transport currently accounts for around 16% of the total global CO2 emissions. If cleaner transit technologies are more widely implemented, emissions in the sector could be reduced by more than 50% by 2030.



Source: The Exponential Roadmap, 2020.[26]

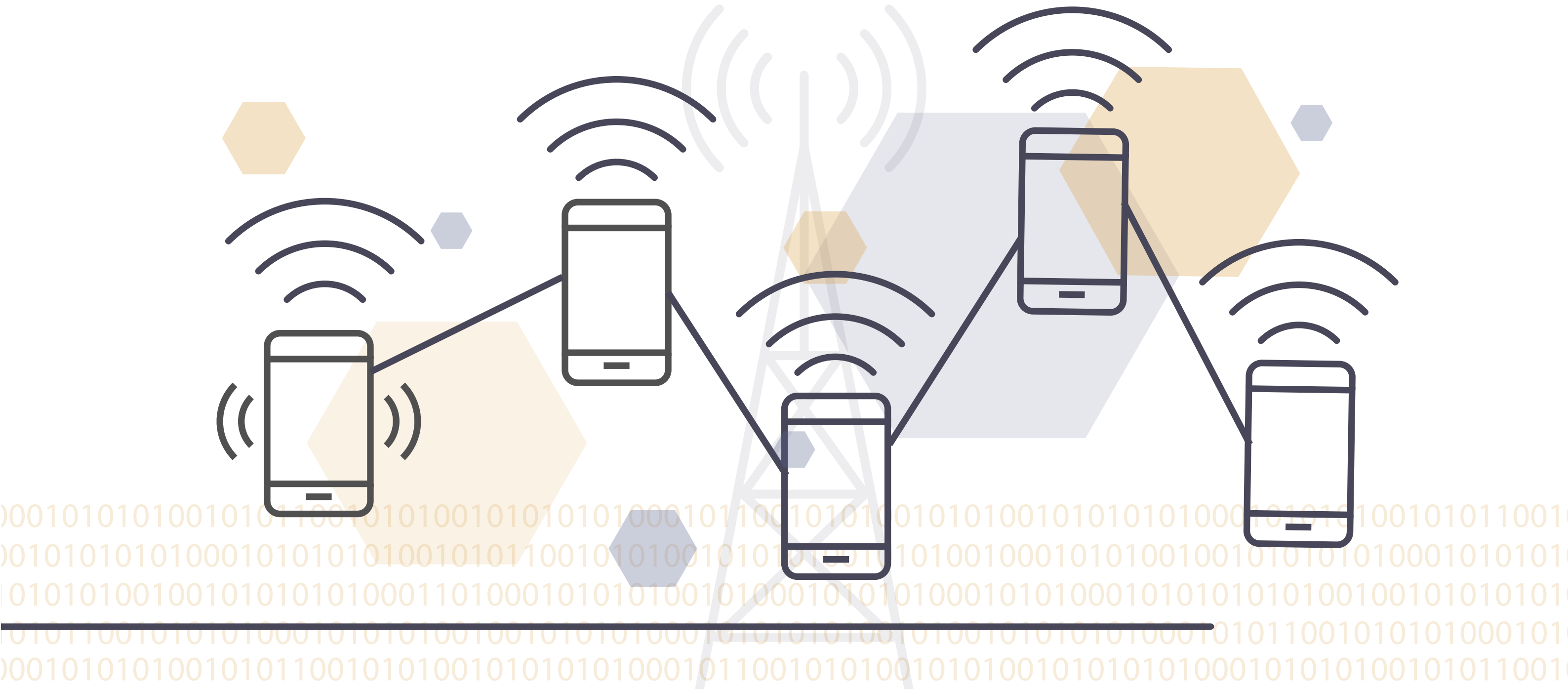
This increased visibility will make sustainable transformation pervasive, impacting entire manufacturing and sourcing processes. Hyberbat's Torabmostaedi points to a growing number of technology firms looking at enabling this, such as blockchain company Circularise, which works with auto manufacturers such as Porsche to use blockchain technology to allow purchasers to identify the source and carbon impact of components and materials.

Accruing carbon benefits

Mehdi Akbarian, vice president of product for Swedish autonomous electric truck company Einride's freight mobility platform division, is working to reduce the carbon emissions of the company's fleet—one of the largest logistics fleet of its kind in Europe. Akbarian estimates that currently each of Einride's trucks releases around seven tons of CO2 emissions each year over the course of its operational "life." This is a substantial reduction in comparison to the 95 to 107 tons of CO2 a traditional diesel-powered truck emits per year. Einride aims to "get this down to two tons of CO2 per year," Akbarian says.

But he notes that new transportation technologies and modes of mobility need to be developed in order to maximize the utilization of the embodied carbon emissions from upstream activities over the life cycle of a vehicle. "In order to take the CO2 savings from 30% or 40% to 90%, we really need to ensure that the asset utilization goes up," and that requires more than just automation. "Autonomy without electrification just doesn't lead to sustainability," Akbarian says. Retrofitting vehicles with autonomous systems increases operational efficiency and reduces costs, "which means transport companies can send goods long distance with trucks because they cost half as much as they used to – actually making the carbon impact much worse."

That's where electrification of vehicles comes in, and specifically, connectivity with the goal of sustainability, allowing transportation and mobility firms and individual vehicle operators to leverage data to plan efficient trips. "Topography is really important for energy consumption and for regeneration of energy. Traffic information is also really relevant. That's a bit higher



> "Much of the infrastructure we need to promote sustainable transportation is already installed: the largest network of mobile sensors today is actually everyone's mobile phones."
>
> Andrew Pickford, Associate Partner, Ernst & Young Transactions

resolution than just kind of the static location and geography of the roads. Then there is charging infrastructure and the energy construction, which is not necessarily the road itself. Then there are conversations about traffic lights, and importantly around public charging infrastructure—the locations of charging stations, the frequency of availability, and the invoice management system. There's a lot of information that needs to get transferred. Electric vehicles can't be operated effectively without all this data."

Mapping more efficiently

Another area where cellular connectivity could enable real-time data visibility and help reduce carbon emissions is in the mapping of public transportation networks and traffic flow, including the integration of digital/smart outdoor signage. Adam Bell is the CEO of Nearfield Management, a technology development startup that builds wireless smart management systems that gather operations and traffic data and use a neural network-based platform to analyze and make real-time optimization decisions. Nearfield deploys cellular-connected digital signage managed by a "quantum-inspired" neural network technology that "plug[s] into the local ecosystem to collect and analyze road traffic and other data," allowing transportation departments to optimize traffic flow, by enabling both centrally-controlled management and by transmitting traffic instructions to digital signs, including route detours.

Nearfield is currently deploying such digital signage via 5G networks in a smart city pilot project with the government of Thailand. "5G is an important digital transformation enabler, one more step on the ladder of where cellular communications is going: more energy-efficient, more data-efficient communications than telco lines or WiFi," Bell observes. Nearfield deploys "call zones"—small signs on roadsides, in coffee shops or hotels—connected by a central quantum neural network, which improve traffic flows through way-finding messages or alerts based on traffic, weather, and lighting conditions. Not only does the system reduce emissions by making traffic flow more efficiently but, Bell notes, the very low-wattage signs themselves are "sustainable from the start."

As the need for energy-efficiency management services from producers and other enterprises grows, Bell believes that mobile operators may begin to offer their transport enterprise clients managed services using analytics to monitor and reduce energy and resource consumption—call it "sustainability-as-a-service"—as a way to further monetize their investments in 5G networks and licenses. "Most mobile operator corporations are looking at sustainability strategically in the long run, but for now, their 5G investments mean they need to develop networks of partners who are going to roll out things that drive their revenues up, new applications with IoT."

Ubiquitous mobile sensors

Andrew Pickford, an associate partner at Ernst & Young Transactions based in Hong Kong, who advises governments on digital transformation and sustainable transportation, believes that the use of mobile networks and devices in and of themselves contributes to sustainable transportation efforts, due to their low cost, speed of deployment, and ubiquity. "Mobile sensors are a fraction of the cost of fixed sensors, but much of the infrastructure we need to promote sustainable transportation is already installed: the largest network of mobile sensors today is actually everyone's mobile phones," says Pickford. This makes it faster and cheaper to deploy powerful digital solutions that improve traffic conditions and public transportation usage.

As a result of this vast network of mobile sensors already in existence, cellular network operators "are sitting on copious management data," says Pickford. "We need to start thinking about how these data and dynamic information-capturing capabilities could be reused" to improve the efficiency of human and vehicle mobility, which would contribute to sustainability efforts, Pickford adds. "[While] many of the data points generated by mobile phones are not necessary for mission control— getting the vehicle from A to B, for example—the addition of GPS, Galileo, and other satellite constellations, coupled with the capabilities of multi-modal chipsets, is improving accuracy and helping drive a new category of applications. With its greater capacity and low latency, the advent of 5G introduces new use cases and commercial opportunities that could not be supported by 4G."

These applications include mobility-as-a-service platforms, like transport on-demand offering Via in Australia, Pickford notes. Via's technology enables partners to create end-to-end transit systems and plan better networks, including on-demand public transit, autonomous mobility, and logistics. Other applications include public transport optimization efforts, which leverage transit timetables and operational data, together with citizen location data to allow individual commuters to optimize their trips. The Berlin Transport system has one such system, known as Jelbi, and Ubigo provides a similar offering in Gothenburg, Sweden.

Cellular connectivity, Scania's Sandberg believes, is also key to enabling the expansion of e-vehicle deployments at scale and speed. "We simply need to deploy electrical vehicles as fast as possible in order to save the planet, and to do that we need to use something that is reliable and available today and helps vehicles to find and connect to chargers."

For existing and new transport service providers, reducing wastage and variation time are crucial to becoming sustainable, says Pickford. This means shorter wait times for trucks at shipyards or replacing empty carriages on subway lines with bus services. "This business needs more predictability," says Pickford. To achieve this, service providers need to be better connected. "Transportation services could improve the productivity of their services through collaborating with other nodes." But, for now, a large gap remains between mobility providers, automotive manufacturers, and infrastructure.

"There is a lack of collaborative innovation between infrastructure and vehicles. They're separated. Wireless fills that gap." Pickford notes that in many countries with advanced mobility infrastructure, 5G networks could become a facilitating platform to link disparate elements and communities—vehicle manufacturers, mobility providers, motorists, and public transportation networks—into harmonized and sustainable transportation initiatives.

06 Conclusion

Cellular infrastructure is a unique and fundamental enabler of decarbonization efforts. The intelligent systems digital mobile networks support are increasingly used by firms to closely monitor, manage, and lower their energy and resource consumption levels. Combining individual firms' analytics capabilities into system-wide solutions will allow these decarbonization benefits to scale exponentially across an industry. At both the individual company and the industry levels, cellular networks are often the infrastructure solution that best provision these resource management capabilities.

Mobile broadband infrastructure will specifically facilitate the decarbonization efforts among energy, industry, or transportation sector participants, through:

- **Remote intelligence enabled by cellular connectivity.** Organizations that manage remote and disparate facilities, people, and assets benefit from robust cellular communications connectivity. They are also finding that reliable, low-latency networks are critical to their ability to lower emissions. As WindAid's case demonstrated, using cellular-connected network management tools to remotely troubleshoot wind turbines can reduce carbon emissions by increasing uptime and reducing travel time to make repairs. Furthermore, as observed by RWTH Aachen University's Antonello Monti, 5G networks enable the incorporation of the millions of devices that are defining the networks of the future. Cloud-based edge networks facilitated by 5G allow enterprises to have their intelligence available close to where the devices are.

- **New ecosystems and platforms driven by rapid transformation.** Wireless-connected IoT sensor networks are easy and quick to implement and can be used to monitor electricity consumption in both legacy and greenfield infrastructure. Flexibility and scalability are particularly useful for fast-evolving new and digitally transformed environments, such as those of small entrepreneurial solar energy producers, or "dark" factories where remotely managed and automated vehicles or articulated robots require the rapid integration of many disparate, and mobile, parts. Another example is new digital ecosystems taking shape in transportation revolving around electrification, vehicle sharing, and last-mile distribution solutions driven by sustainability challenges. Digital platforms that monitor and report on the carbon content generated by raw materials, manufacturing, and transportation are required for industry players to quantify and reduce their environmental impact, which is increasingly demanded by customers, investors, and regulators.

- **New business models, from the bottom to the top.** Bottom-line business concerns have largely driven enterprise use of communication infrastructure to gather data and manage operational processes, which helps reduce carbon emissions. These efforts lower electricity and materials costs immediately and substantially, so sustainability benefits accrue whether or not emissions reduction is the primary objective. As consumers and regulators become more attuned to the carbon impact of firms, the ability to offer low-carbon products and services may become both a competitive and a compliance advantage. 5G network deployment will continue to be guided by economic and efficiency concerns, but meeting sustainability objectives will inexorably grow in importance alongside them. Continued deployment of cellular broadband capabilities is essential for those efforts to have optimal decarbonization impact.

Footnotes

1. IPCC, "Climate change rapid, widespread, and intensifying," Intergovernmental Panel on Climate Change, August 9, 2021

2. Exponential Roadmap Initiative, "The Exponential Roadmap"

3. The Working Group I, "IPCC Sixth Assessment Report," Intergovernmental Panel on Climate Change

4. Paris Agreement, United Nations

5. Working Group I, "Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty," IPCC

6. When referring to entities or organizations, the term "carbon neutrality" describes a state where a company has balanced yet-to-be-abated emissions through market measures such as carbon offsetting. In contrast, "net-zero" is a state where there are no, or almost no, emissions.

7. Visual Capitalist, "Visualizing the climate targets of Fortune 500 companies," Transport Energy Studies (blog), August 6, 2021

8. Cal Fire, "Stats and Events," California Department of Forestry & Fire Protection, October 1, 2021

9. Working Group I, "AR6 Climate change 2021: The physical science basis," IPCC

10. Sarah Connors and Roz Pidcock, "Frequently Asked Questions," IPCC

11. IPCC Sixth Assessment Report

12. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.)

13. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p. 52

14. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p. 62

15. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p. 88

16. "Special Report: Global Warming of 1.5 ºC: Summary for Policymakers", IPCC, 2018,c.22

17. "Renewables 2019 Global Status Report," Renewable Energry Policy Network, 2019

18. "World Adds Record New Renewable Energy Capacity in 2020," (press release) International Renewable Energy Agency, April 5, 2021

19. The Exponential Roadmap identifies that, overall, energy use is responsible for about two thirds of global greenhouse gas emissions, which is made up of 32 Gt of annual CO2 emissions, plus 3.3 Gt of CO2 equivalent emissions (CO2e) from other greenhouse gases. However, the report addresses the 18.46 Gt CO2e per year that the energy sector can "directly influence," which is 34% of total global emissions. This comprises 12.4 Gt of direct emissions from electricity and heat production for other sectors, and 6.1 Gt of the sector's own emissions associated mainly with extraction, refineries and distribution of fossil fuels. The remaining 17 Gt of emissions from fuel use in other sectors, such as gasoline use in cars or coal in industry, are not included here but covered in other sectors.

20. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p. 52

21. "Syncronization" is the process of reducing the amount of variance (in voltage output, frequency, and other factors) between the output of renewable energy generators and that of traditional power grids.

22. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.). p.52

23. SOGNO

24. International Energy Agency, "Global Energy Review 2021," IEA, 2021, p.24

25. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p. 12

26. Johan Falk and Owen Gaffney, "The Exponential Roadmap version 1.5," January 2020 (rev.), p.88

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