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Driving Sustainability *via* Technology Strategies

Deishin Lee
Guest Editor

Cutter Business Technology Journal

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Opening Statement

by Deishin Lee, Guest Editor

> It's not that we use technology, we live technology.
>
> — Godfrey Reggio,
> director of experimental documentary films

In our previous issue of *Cutter Business Technology Journal* (*CBTJ*) on technology and sustainability,[1] we concluded that there is no silver bullet to solving sustainability issues. Fundamentally, we need to change how we live — how we make things, how we use things, how we spend our time — to achieve a sustainable way of life. That requires changing many processes, from growing food to transporting people to providing entertainment. The hallmark of a sound process improvement effort is the ability to monitor and assess the current process and to use that information to make improvements. This ability is critical for the effectiveness and credibility of the improvement effort, and as we see in the articles in this issue, technology can play a key part.

To improve any process, we need to start with a process. In a manufacturing plant, process improvement always starts with mapping out the current process. For example, if an automobile manufacturer wants to reduce the cycle time of its paint operation, it would start by documenting the activities of the current process in a flow diagram and then move on to measuring the current cycle time. We need to start with an understanding of the current process in order to propose a change and be able to assess whether the change improved it. This seems obvious, but it's surprisingly difficult to do. Even this relatively contained paint operation problem in a manufacturing plant turns out to be quite complex when we factor in all the different models, trims, colors, and so on, not to mention the supply chain implications for input materials.

Now imagine the complexity if we are trying to improve the process of measuring the carbon captured by forests. How do we map that process, and how do we measure how much carbon is captured? What if a farmer wants to increase yields over hundreds of hectares of planted crops in an unpredictable environment dependent on weather and susceptible to pests? What if a municipality wants to improve water quality in a waterway accessed by many other cities, factories, and households? Sustainability problems are so complex, it's often difficult to even map out the process. And in the past, it has been virtually impossible to measure key characteristics in the process. But today's technology is changing all that. Using drones, Internet of Things (IoT) devices, sensors, cameras, and so forth, we are now able to collect data in settings previously (economically and physically) unreachable — and collect the data frequently. That information is essential for designing *effective* process improvements, an endeavor that itself is often aided by artificial intelligence (AI) and machine learning (ML).

Fundamentally, we need to change how we live — how we make things, how we use things, how we spend our time — to achieve a sustainable way of life.

The ability to monitor and authenticate is also crucial for providing *credibility* to many sustainability efforts. Sustainability problems often arise because of externalities generated by human activities. The canonical example is carbon emissions. When we drive our cars, we benefit from the convenience but we emit pollution, and that cost (i.e., adverse health effects, climate change) is borne by others. In the past, externalities have been difficult to control because market mechanisms typically don't work. However, the use of technology (e.g., blockchain, satellite imagery) to monitor and verify activities provides a method of ensuring accountability for actions, both good and bad. Once we have a credible way of authenticating who carried out what actions and the subsequent impact on the environment, we open up the possibility of using market mechanisms to internalize the cost of environmental impact.

In This Issue

The four articles in this companion issue of *CBTJ* on sustainability explore the ways that technology can be used to monitor and improve the sustainability of a wide range of processes, industrial and otherwise.

The ability to offset our carbon footprints is now a widely accepted notion. We can offset carbon emissions from a flight between Boston and San Francisco by investing in any number of carbon reduction projects, such as planting trees or providing solar-powered cookstoves to developing countries.

First up, we have an article from Cutter Consortium Senior Consultant San Murugesan, a frequent Cutter contributor and past *CBTJ* Guest Editor, who provides a broad overview of the many areas where we can use IoT to improve environmental sustainability, from energy management to food waste reduction. He explains that "the power of IoT lies in its efficiency, accessibility and controllability, and scalability in connecting disparate, distributed devices and appliances." Many of the applications Murugesan describes rely on sensors to collect data in settings where previously it would have been prohibitively expensive (e.g., collecting temperatures from each room in a house) or infeasible (e.g., attaching sensors to crops to support precision agriculture). These sensors then feed information to data analytics software that can optimize decisions. His article gives us a sense of how pervasive IoT already is, and how much potential it still has.

Our next two articles describe innovative examples of how technology can help provide a means for individuals and organizations to counteract their negative environmental impact. The ability to offset our carbon footprints is now a widely accepted notion. We can offset carbon emissions from a flight between Boston and San Francisco by investing in any number of carbon reduction projects, such as planting trees or providing solar-powered cookstoves to developing countries. However, as with all good ideas, the devil is in the implementation details.

It turns out that whereas planting a tree may be straightforward, verifying that it was actually planted and determining the magnitude of the environmental impact of that tree is anything but. In our second article, we continue the trend of the last *CBTJ* issue with an interview of a top-notch expert whose company is helping to make great strides toward sustainability. Cutter Consortium Fellow Lou Mazzucchelli talks with Carlos Silva of Pachama, named one of the world's "Most Innovative AI Companies of 2021" by *Fast Company*.[2] Pachama uses satellite imagery and ML to measure the carbon captured by forests and how it evolves over time. This measurement allows us to determine whether a carbon credit that is traded on an exchange represents a "real" reduction in emissions. The verifiability and accuracy of such measurements form the foundation for robust carbon markets. Silva explains how the technology works to ensure the integrity of forest carbon credits.

A Renewal Energy Certificate (REC) is another mechanism for offsetting carbon emissions. As explained in our third article by Claudio Lima, RECs are issued to accredited generators of renewable energy (e.g., solar, wind). These credits can then be traded in energy markets where consumers looking to offset their own fossil fuel energy consumption can buy the credits. Since a REC is essentially a record of a quasi-observable event (i.e., renewable energy fed into the grid), this data is susceptible to manipulation and transaction errors. Similar to carbon markets, or any

Upcoming Topics

Cyber Attacks & Strategies That Matter
Anjali Kaushik

Teams
Guest Editor: TBD

Healthcare
Guest Editor: TBD

market for that matter, lack of credibility can undermine the effectiveness of the market. Lima explains how blockchain, a distributed ledger technology, can be used to ensure the authenticity of RECs and improve their market credibility.

Finally, Cutter Consortium Senior Consultant Helen Pukszta returns to *CBTJ,* exploring the use of drones for sustainability. From the critical application of precision agriculture to whimsical light shows, drones not only provide new functionality, they do so with a low carbon footprint. In precision agriculture, we see again that the data collection capability of drones coupled with sophisticated optimization algorithms can help farmers use natural resources more efficiently. In an unusual application that most would not think of, Pukszta goes on to illuminate the unintended environmental consequences of fireworks and the benefits of using drones for light shows.

As we have seen in this issue and the previous *CBTJ*, technology can and does play a significant role in sustainability. These articles have covered applications of digital technologies in energy, agriculture, natural resource conservation and restoration, supply chain management, smart cities, and many other fundamental areas of society. But I'm glad we close out the issue with a look at celebratory light shows — it reminds us that art is also important. From what we need to survive (food, energy, water, clean air) to what we need to live (creativity, play, dancing light shows), technology is entwined in all aspects of our lives. When it comes to sustainability, technology's power and potential stem from its ubiquity.

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Leveraging IoT to Create a Sustainable Environment

by San Murugesan

We must reshape our environment now to be on the path of sustainability. In the past couple of years, we've witnessed devastating climate crises all over the world. The situation is worsening — lives are being severely affected and are in danger, and the costs of each crisis continue to mount. Indeed, the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) recently delivered its starkest warning ever about the world's climate.[1] Yet, the panel also claimed that there is still a narrow window of opportunity in which we can alter the Earth's climate path. The climate crisis is the defining story of our times. The actions we take today to reduce CO2 emissions and other heat-trapping gases will have a huge positive impact on our future.

Thus, the sustainability revolution has begun, and the climate crisis is a race that we can — and should — win.[2] The intensifying crisis demands urgent and sustained actions. Governments, corporations, and organizations around the world are increasingly recognizing sustainability and climate change as critical issues and are looking for ways to address them. We're at a crossroads; the conditions are ripe to build a truly sustainable planet. How do we get there?

There are many ways in which members of the technical, scientific, and business communities can help address this grand challenge. Embracing the promise of technology, particularly information technology, is an effective approach.[3] The Internet of Things (IoT), in particular, has vast potential to address sustainability in several ways. It can connect a large number of objects of interest, sense and remotely monitor their status, and control and manage them in real time. For example, it can make energy systems smarter and more connected and improve their operational efficiency. It can reduce the carbon intensity of buildings, manufacturing, transportation, and other key sectors such as heavy industry, aviation, and shipping. It can also lower energy consumption through smart operations and improve resource utilization.

In this article, we outline IoT's role in creating a sustainable environment. In particular, we discuss how IoT is being used — and can be used — in key business and industry sectors, buildings, and households to improve energy and operational efficiency, thereby minimizing environmental impact. Embracing an inward-looking approach, the article further examines how we can reduce IoT's own environmental impact. Finally, we cover IoT's cybersecurity risks and discuss how we can go about leveraging and benefiting from IoT's full climate-action potential and help create a sustainable environment.

The Power of IoT

IoT is effectively comprised of two entities: (1) *the Internet*, signifying connectivity and communication, and (2) *things*, representing a variety of objects and devices. However, there is no formally accepted single definition of IoT; in fact, a recent article outlined 12 "flavors" of IoT.[4] Nevertheless, all definitions share similar concepts and functionality. The following comprehensive description is good enough to help us examine IoT's potential and find ways to harness it to address climate change:

> Internet of Things [is a] network of objects embedded with sensors, software, network connectivity, and computer capability, that can collect and exchange data over the Internet and enable smart solutions.[5]

IoT adoption offers environmental and other benefits, such as resource optimization, cost reduction, convenience, and better operational reliability. For instance, according to the UN, digital solutions have the potential to reduce water consumption by up to 15%, energy consumption by more than 1.3 billion MWh from now till 2030, and food waste by 20% through smart agriculture and other measures.[6] According to the World Economic Forum (WEF) report, "Internet of Things: Guidelines for Sustainability," IoT is the largest enabler of digital transformation, estimated to add US $14 trillion dollars to the global economy by 2030.[7]

IoT's potential and power makes it a game-changer for sustainability. The same report from WEF states, "At its core, IoT is about measuring and remotely controlling previously unconnected 'things,' … [and] reaches people and objects that technology could previously not reach and in the process also supports sustainable development elements." WEF analysis also states that IoT can help attain the UN's 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs).[8] The WEF report outlines the UN's intentions, which include fighting climate change, ending global poverty, providing clean water, and improving education.

The power of IoT lies in its efficiency, accessibility and controllability, and scalability in connecting disparate, distributed devices and appliances, as well as the availability of a wide variety of sensors and data analytics software:

- **Efficiency.** Data collected by disparate IoT-enabled sensors help us synthesize a full picture of interest, extract usage patterns, and make and execute smart decisions, which reduces the consumption of energy, water, or other resources, and lowers waste. IoT data can also streamline workflow and cut down on costs.

- **Accessibility and controllability.** IoT sustainability solutions can give users access to their consumption or resource utilization data and empower them to control their consumption habits with the help of a smartphone or a specialized gadget. For example, smart thermostats like Google Nest allow individuals to monitor how much electricity they consume and adjust the temperature around their living space via an app to reduce energy consumption. IoT applications can show what-if effects; that is, the impact that can be made by making small changes, which can motivate users to adopt environmentally friendly practices. This also empowers individuals to make behavioral changes for a more sustainable lifestyle that helps the planet.

- **Scalability.** A good IoT infrastructure allows us to easily add devices to an existing network or application to accommodate alterations, such as building or facility expansion, and adjust the rate of data collection from devices without requiring additional engineering resources or major changes. Operations over a large geographical area, such as a solar farm, can be optimized with IoT-enabled devices deployed across remote locations with cellular network coverage.

- **Vast array of IoT sensors.** For sensing almost anything, we now have a vast array of miniature, low-cost sensors; some can operate on small batteries for several months.

- **Data analytics.** To get helpful insights and generate appropriate actions, we now have viable, effective systems for storing, retrieving, and analyzing large volumes of data. We could use cloud and software-as-a-service for different kinds of analysis of real-time and historical data.

In view of the above and other factors, such as lower costs, we are seeing greater interest in harnessing the potential and power of IoT.

> *The power of IoT lies in its efficiency, accessibility and controllability, and scalability in connecting disparate, distributed devices and appliances.*

Leveraging IoT

IoT is a powerful enabler and supporter of sustainability. Through various applications, IoT can help reduce greenhouse gas emissions and support adaptations to a changing climate. For example, it can:

- Reduce greenhouse gas emissions

- Monitor and reduce energy usage

- Reduce waste and improve resource utilization

- Reduce water consumption and wastage

- Assist in our sustainability efforts through an integrated environmental management system

The good news is that IoT is effectively being embraced in practice in several ways for enhancing environmental sustainability in diverse areas. This includes myriad applications for energy management, smart grids, air and water pollution control, water conservation, farming, transport, wildlife management, waste management, hotel housekeeping/maintenance, food waste reduction, and more. The following examples show how IoT is being employed in these areas to reduce carbon emissions, improve sustainability, and increase benefits to companies and individuals.

Energy Management

IoT presents several opportunities to reduce the energy sector's carbon impact. Examples include operational optimization in wind farms and power plants.

IoT sensors, along with home management systems, can reduce energy consumption, manage generation of onsite renewable energy, and measure the carbon footprint of energy consumption. For example, Samsung Electronics pursues energy efficiency at its workplaces by employing a smart monitoring system that uses IoT and active environment heating, ventilation, and air conditioning (HVAC) control. It applies an energy-saving algorithm that factors in outdoor climate conditions, HVAC load, and device capacity, for optimum operational control of the infrastructure equipment. As a result, Samsung Electronics in Ho Chi Minh City, Vietnam, was able to reduce energy consumption by 12.4%, and it plans to deploy a similar system at its other worksites.[9]

> *To make agriculture greener with a low impact on the environment, we can use IoT to monitor crops, hydration, and soil conditions.*

Smart Grids

Smart grids leverage IoT and allow for two-way communications between an energy provider and its customers, as well the ability to sense along transmission lines. This flow of information enables smart grids to respond more quickly to real-time changes in electricity demand or power disturbances and can improve the efficiency of energy distribution. It also presents several other benefits: automatically rerouting power during power disturbances, containing large-scale blackouts by isolating outages, adjusting outputs automatically based on usage data across geographic regions, and allowing strategic recovery of electricity (e.g., power can be provided to emergency services first). Finally, IoT facilitates data collection, reporting and analytics, optimization of smart grids, and automated maintenance.

Air & Water Pollution Control

We can monitor air pollution in real time using IoT air-quality sensors. This can also enable us to identify the source of this pollution in real time, allowing us to initiate swift action to control the pollution source (e.g., gas leaks and smoke can be immediately detected, and swift action taken, to contain them). IoT can also help reduce air pollution in the automotive and transportation sector, a major source of greenhouse gas emissions. Traffic could be monitored and smart adaptive systems of traffic lights in a stretch of a road can automatically adjust the traffic flow to reduce the number of idling cars or total idling duration.

Water Conservation

By installing appropriate sensors and collecting and analyzing collected data, we can monitor and assess activities that harm the ocean and waterways, such as illegal fishing, unlawful solid waste disposal, and the discharge of industrial effluents into bodies of water. IoT technology can also help sustain clean water by reducing leakages and monitoring water quality. For example, in the US city of South Bend, Indiana, IoT sensors in the sewer system monitor water levels and redirect wastewater. According to Indiana University, this system has prevented at least 3.8 billion liters of raw sewage from entering the St. Joseph River each year.[10]

Smart Agriculture

To make agriculture greener with a low impact on the environment, we can use IoT to monitor crops, hydration, and soil conditions. Sensors attached to crops allow farmers to monitor their growth and detect and address anomalies early, enhancing crop yield and quality. The collected data can be used to develop and implement smart adaptive irrigation systems that would follow the most efficient watering patterns. IoT-enabled irrigation systems optimize water consumption and minimize wastage of water. For instance, Agrisource Data claims to have saved more than 772 million liters of water and increased average yield by nearly 10% by adopting these practices.[11] In other example, Smart Watering Systems has been able to significantly reduce water use — and costs — for each of its growers through its proprietary technology.[12] In addition to reducing greenhouse gas emissions, IoT is already in place monitoring crops and soil conditions and screening and treating farm animals. Producing more and wasting less is the major objective of smart, data-driven agricultural solutions enabled by IoT, also known as "precision agriculture" or "smart agriculture."

IoT can provide important post-harvest analytics. Inadequate temperature management is a major contributor to the spoilage and waste of fresh food. In fact, each post-harvest hour spent in the field costs produce about one day of shelf life. Zest Labs is tackling this issue from the ground up to ensure that fresh foods make their way to temperature-controlled areas post-harvest.[13] IoT sensors embedded in pallets of freshly harvested food send data to a cloud-based data monitoring system, which sends real-time alerts that notify when pallets need to be cooled. Data from the journey along the supply chain is analyzed to pinpoint process inefficiencies that contribute to this premature spoilage so that it can be prevented in the future.

Maritime Cargo Shipping

Maritime shipping transports 90% of the goods traded around the world by volume and drives the global economy.[14] It consumes 300 million tons of fuel[15] and produces about 3% of the world's CO2 emissions,[16] giving the international maritime shipping industry roughly the same carbon footprint as Germany.[17] Moreover, adoption of IoT monitoring and rerouting of oceanic cargo shipping can reduce fuel consumption by up to 15%.[18] IoT also facilitates predictive maintenance, which can avoid week-long overhauls and advise timely repairs.

The shipping industry has deployed IoT devices and GPS offered by Traxens in its fleets for real-world commercial use. These devices can track geolocation, detect shock and motion, and check the temperature, humidity, and alarms on refrigerated containers, called "reefers." IoT technology and associated systems save the industry billions of dollars, reduce refrigerated goods damage by 30%-50%, and increase the utilization of containers by 10%-25%.[19]

An environmental intelligence (EI) system that uses IoT and other sensors can reduce consumption and costs in the shipping industry. Delays and inefficiencies that occur as a result of unanticipated environmental conditions, such as severe storms, rainfall, and ocean currents, directly impact the shipping industry and the supply chain. EI solutions are helping the industry manage these risks more effectively. An example of a company using EI is Maersk, a leader in the container shipping industry, which developed a proprietary EI system, Eco Voyage, to optimize its voyage routes.[20]

Wildlife Management

Species extinction and biodiversity loss have a devastating impact on our planet. By using IoT equipped with appropriate sensors, we can monitor and study animal behavior, such as migration, mating, and feeding habits, and determine factors that threaten particular animals or endangered species, such as deforestation and poaching.

We can also monitor and protect large areas of forest using drones equipped with high-resolution IoT-enabled cameras and other sensors. The collected data can then be used to map significant changes that take place and trigger an alert when uncontrolled deforestation takes place, for example. We can also reduce poaching activities significantly by monitoring known poaching paths using IoT-supported cameras or motion sensors.

Waste Management

Waste bins equipped with IoT sensors can collect and transmit information on fill level, temperature, waste type, and location. Based on the fill level and location, an automated route can be planned for waste collectors to clear the bins in a timely and efficient manner. This also helps address incorrect disposal practices and creates insightful long-term plans. For example, the city of Cascais in Portugal uses sensor-fitted rubbish bins that notify local authorities as the bins approach capacity, allowing for effective scheduling of rubbish-collecting trucks. Use of these sensors enabled Cascais to cut the number of refuse trucks by 20%.[21]

Hotel Management

Housekeeping and maintenance are critical and expensive components of hotel management. Washing linens and towels consumes large amounts of water and chemicals, contributing to environmental problems, while lighting and air conditioning rooms and verandas consume a lot of power. An integrated hotel management system (HMS) using IoT sensors for monitoring HVAC appliances, occupancy, lighting level, water leaks, and other parameters has huge potential to minimize the industry's environmental impact. HMS can also facilitate condition monitoring of HVAC and other critical equipment and proactive maintenance, which avoids major service disruptions and aids in better resource planning and utilization.

Food Waste Reduction

Though you may not readily realize, food waste is a major contributor to climate change. Its carbon footprint is estimated to be greater than that of the airline industry.[22] In fact, more than a third of food in the

US gets thrown away, which can be traced back to 4 trillion tons of water, in addition to the energy it takes to harvest, transport, and package that food.[23] According to the World Wildlife Fund (WWF), a few simple steps could help reduce the environmental impact of wasted food; cutting out food waste could reduce total greenhouse gas emissions caused by humans by 6%-8%.[24]

IoT food container tags help prevent waste. Chicago-based company Ovie has adopted a novel approach for food waste prevention at the consumer level, with its IoT SmartTag food sensors.[25] The solution minimizes the amount of food that ends up going bad in the fridge. Its Smarterware, equipped with SmartTags and a hub, connects to the cloud and sends notifications to users' smartphones and smart home speakers to notify them when the food in their fridges needs to be consumed.

> *Digital twins use real-time and historical data to represent the past and present and to simulate predicted futures, helping us with holistic understanding, optimal decision making, and effective action.*

Other Applications

IoT is being used to support sustainability in several other applications, for example:

- To facilitate sustainable manufacturing, reduce energy usage in manufacturing,[26] remove inefficiencies on the factory floor, and cut supply chain costs.
- To check water quality, watch for intruders, and detect structural damage, 100,000 IoT sensors monitor a 1,400-kilometer canal in China.[27]
- To track air pollution, spot parking spaces, and enhance safety by listening for gunshots, smart sensor–laden streetlights monitor the metropolis of San Diego, California.[28]
- To provide valuable intelligence to firefighters before they get to an emergency by using sensors and an IoT gateway with provisions to send data in real time to cloud computing.[29] Simulation studies confirm that drones and IoT sensors can help detect wildfires early with 99% accuracy.[30] Such a system can also be used for monitoring oil spills.
- To create smart roadways connecting highways, street lights, and vehicles for adaptive real-time traffic flow and parking management.[31]
- Other case studies further reinforce how IoT can be harnessed to reduce emissions and enhance sustainability.[32]

Digital Twins

A digital twin, also known as "virtual twin," is an exact digital or virtual representation of a person, place, process, or thing in the physical world. It is used to analyze operations and receive insight into complex processes that exist in the physical world. Information channels connecting physical and digital assets are known as "digital thread." The digital asset is a synchronized copy of the environment that the user interacts with, realized through the use of IoT sensors to collect data in real time about a physical object. The digital duplicate of the physical object in question helps us better understand, optimize, and simulate possibilities, and predict its future. Digital twins use real-time and historical data to represent the past and present and to simulate predicted futures, helping us with holistic understanding, optimal decision making, and effective action.

Scientists are building a digital twin of the Earth, and it will be an important tool in understanding and addressing climate change.[33] It will continuously incorporate observational data in order to make the digital Earth more accurate for monitoring its progression and predicting possible future trajectories. The new "Earth system model" will represent virtually all key processes on the Earth's surface as "realistically as possible, including the influence of humans on water, food, and energy management, and the processes in the physical Earth system."[34] It will help develop and test scenarios that show more sustainable development and thus direct strategy and policy creation. Digital twins are already being used for predictive maintenance, to mitigate carbon emissions in the construction industry,[35] and to help enable green recovery.[36]

Reducing IoT's Environmental Impact

If not designed, operated, and scaled in a sustainable manner, IoT could itself have unintended negative consequences for the planet. For instance, IoT consumes electrical energy to sense parameters of interest and fetch and transmit data in real time. When a large number of devices are interconnected and huge volumes of data are transferred over the network, and processed using a variety of processors, the overall energy consumption of IoT becomes high, resulting in higher carbon emissions. Like other electronic devices, IoT devices pose environmental problems during their manufacture and disposal. This impact, though, is very small compared to the positive impact on sustainability achieved by harnessing the technology in several applications. Nevertheless, we should reduce the environmental impact by "greening" IoT.

The greening of IoT encompasses a set of approaches intended to minimize environmental impact by reducing energy consumption through the use of lower-power sensors, communications protocols, and energy-optimization procedures. For instance, using narrowband communications to transmit data at low rates. Devices may also draw power from alternate sources using energy-harvesting techniques.[37]

IoT presents a major e-waste problem, as a large number of IoT devices become obsolete, faulty, or unusable once built-in batteries die. The industry must consider recyclability and sustainability issues when designing IoT devices. For example, disposable devices can be made of paper. Decisions that manufacturers make now could mean much less e-waste in a decade.[38]

Addressing IoT Security Risks

While IoT presents several significant opportunities to address climate change and sustainability, it also presents potentially serious cybersecurity risks that need to be assessed and mitigated. Since IoT interacts with the physical world, when it is hacked or compromised, it could create disastrous consequences that affect the object in the physical world that is being monitored or controlled.

The primary security concern is that each device connected to the Internet is an entry point for hackers. Hackers could connect to a device and use it to reach the network and application, compromising them. Many current IoT devices are not particularly inherently secure.[39] An IoT device such as a smart lightbulb can easily be hacked and infected with malware, which could then spread to other devices on the network. Simple IoT applications might have poor password requirements, or the vendor might not keep the software or firmware up to date. And if a device stores data, it could be easily readable to anyone. Hence, application developers — and IoT makers and service providers — must endeavor to secure IoT.

Securing IoT, however, is more difficult than traditional IT security due to a few key differences.[40] When it comes to hacking a critical IoT application, the adversaries are often professional, sophisticated, and well-equipped nation-state strikers. Their hack could lead to total failure of an operational system causing more dire consequences than an organization's data leak. And many IoT vendors don't offer good long-term support and updates or patches over a long period of their products' use. Many connected devices are built with software, hardware, and firmware that are created by different companies and pieced together at the end.

It takes only one weak link to create a vulnerability; hence, IoT is more vulnerable and more difficult to secure. For simple, relatively noncritical applications such as smart farmland irrigation, we can't afford to have dedicated, knowledgeable IT personnel to properly configure systems and to monitor potential emerging security attacks and take timely action.

The IoT threat landscape is continually evolving, and encryption could protect IoT data. When done effectively, encryption renders data unreadable to anyone without authorized access. Encryption, however, presents obstacles such as demand for increased computing resources and power consumption. The better and stronger the encryption, the more computing power is needed to run it. Traditional mechanisms used to keep computers secure are not suitable for IoT as most of those protections consume significant amounts of power. They won't work for a tiny device, such as a watch or sensor node, which must operate using very little energy.

Organizations that use, or are considering using, IoT devices must first do their due diligence on their vendors to ensure that any data stored and transmitted is properly encrypted.

Future Prospects

The future of IoT in support of sustainability is bright. The potential of IoT to enhance sustainability, supported by data analytics, artificial intelligence, machine learning, and smart adaptive decision-making capabilities, is huge. To realize this potential and broaden the use of IoT on a larger scale, sustained actions are needed: raising awareness among professionals and executives, recognizing the importance of sustainability issues and IoT's potential to address them, training, further R&D, standardization of IoT, and public-private investments to further advance IoT. This will generalize use of IoT, lower implementation costs, expand its use, and help create a sustainable world.

> *It is everyone's ethical and social responsibility to do their part to decrease global warming and its disastrous consequences.*

Without a clear use case and plan for the collected data, any IoT sustainability project is destined to fail. Adopters need to formulate and execute sound strategies for ensuring their IoT projects come to fruition and yield the intended sustainability and other benefits. To facilitate and simplify development and deployment of real-world IoT-enabled sustainable solutions, major IT service providers offer cloud IoT platforms (e.g., Microsoft's Azure IoT, Amazon's AWS IoT, and Google Cloud IoT Solutions).

Green issues are becoming a priority for many companies. Rising energy consumption and energy prices, growing consumer interest in green products and services, higher expectations by the public regarding environmental responsibilities, and upcoming stricter compliance requirements are driving this priority. Furthermore, it is everyone's ethical and social responsibility to do their part to decrease global warming and its disastrous consequences. IT professionals, executives, and policy makers should maximize the promise of IoT and other technologies to deliver significant environmental, social, and economic sustainability. Moreover, we — as citizens, consumers, or users — can make a huge impact by effectively embracing smart, environmentally friendly products, applications, services, and practices.

We hope we have inspired you to examine and embrace the potential of IoT in your area of interest. We also hope you find this article useful in crafting and successfully executing an IoT-enabled sustainability strategy that benefits your business and helps create a sustainable world while promoting growth and progress.

> The opportunity we have is to build a secure, intelligent platform that solves some of the world's greatest problems at scale. That's what's possible with hundreds of billions of connections and the capabilities that we can deliver together.
>
> — Chuck Robbins, Chairman and CEO, CISCO Systems

> If you think that the Internet has changed your life, think again. The Internet of Things is about to change it all over again!
>
> — Brendan O'Brien, CIO and cofounder, Aria Systems

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Seeing the Trees Through the Forest: A Q&A with Pachama

by Lou Mazzucchelli and Carlos Silva

Carbon credits, when used effectively, are a critical tool to address climate change. These credits are purchased as a means to compensate for carbon emissions produced elsewhere and drive necessary funding for things like renewable energy and forest conservation. But voluntary carbon markets, which facilitate the exchange of these credits, have several flaws.

Particularly in the world of forest conservation, a proven method to capture carbon today, impactful projects are often mixed in with questionable ones. Some projects shouldn't have been issued credits to begin with, others were issued too many credits, and some, while valid initially, failed to maintain their value over time. These issues have arisen as a direct result of evolving and opaque standards. But as companies set increasingly ambitious climate targets, they are flocking to these markets — even in the absence of oversight.[1]

Pachama is a technology company that uses satellite imagery and machine learning (ML) to measure the carbon captured in forests and monitor them over time. Named in honor of Pachamama, a Mother Earth goddess for the indigenous people of South America, the company's goal is to restore our planet's forests and ecosystems by creating a technology-verified marketplace that drives finance only to the highest-quality forest restoration projects. Cutter Consortium Fellow Lou Mazzucchelli (LM) spoke with Pachama's Head Remote Sensing Scientist Carlos Silva (CS) to learn more about how the company is using technology to achieve its mission.

LM: What are carbon credits — and how can technology improve them?

CS: Companies buy carbon credits to compensate for the emissions they cannot reduce. As witnessed in the recent *26th UN Climate Change Conference of the Parties* (*COP26*) in Glasgow, Scotland, many companies and countries have set ambitious targets to reduce emissions. And it is clear that they must do everything in their power to reduce emissions as quickly as possible. But, even if they do, they won't be able to reduce them entirely overnight. Along the way, they can compensate for the emissions that remain. Companies can do this by purchasing carbon credits, which will funnel their investment toward projects like forest conservation that sequester the carbon they can't reduce today.

The carbon markets, however, *must* guarantee that each credit purchased represents a "real" net reduction in carbon emissions that exactly cancels the purchaser's emissions. These calculations are hard, and the tools used to do them today are far from perfect. To prove this real net reduction in carbon emissions, you need to demonstrate that a forest you saved was at risk of being cut down, or that trees you planted would not have been planted otherwise. If you saved a forest, you would need to also prove that the deforestation didn't just shift to another place nearby.

The only way to validate these offsetting claims with any rigor is to have a bird's-eye view of how forests evolve over time. Satellites and other remote sensing bring you that unparalleled view going back decades and can monitor these forests on a regular basis. That technology is absolutely game-changing for the credibility of these carbon credits.

LM: I think there's certainly a need for credibility because there are some effectively junk credits floating around out there, and nobody knows the underlying basis of them.

CS: Exactly. In fact, there has been a lot of criticism from media outlets like ProPublica,[2] Bloomberg,[3] and others, that have called out carbon offsetting — and the high-profile companies investing in them — for questionable projects and crediting practices. The above Bloomberg piece, for example, highlights a patch of forest that had been preserved for decades; there was no evidence it was at risk. Yet, this project was able to get approval because it seemed like a reasonable claim to the verifying body at the time. There was no satellite view; they just had tree measurements and an Excel spreadsheet.

The important media scrutiny generally demonstrates that we need higher-quality projects. But we can't write off carbon offsetting entirely because the methodologies need advancement. So it's absolutely critical that we drive funding toward forest restoration projects. If we're going to do it with carbon credits, we need robust quantitative models, transparent for all to see, to bring integrity to these markets. Technology — and remote sensing, in particular — can play a major role in ensuring that these credits are of high quality and that these forests continue to sequester carbon over time.

LM: What can satellite images detect that traditional methods can't?

CS: Today, most measurements are collected by hand. Forest inventory crews are sent out into the forests with tape measures to record tree diameter. From there, they calculate the potential carbon credits, which are verified by a third party. This method is expensive and time-intensive, costing roughly US $30,000 for a multiday measuring expedition. As you can imagine, these teams can't measure the entire forest, and they certainly can't afford to make these trips often. There are three main issues with this approach:

1. Measurements are captured infrequently.
2. Measurements may not be reflective of the entire project area.
3. There's a lot of ambiguity in how those tree measurements ultimately get translated into credits.

So the satellite imagery helps ensure that we can see not only the entire project area, but actually look at that area over the past 20-30 years *and* all the other areas nearby, to get a better sense of what would have happened if the project didn't exist. The counterfactual, "What would have happened?" is really the core question when determining whether a project should be eligible for carbon credits and how many it should get. Satellites and remote sensing can deliver the missing inputs needed to make those calculations and monitor those forests over time.

LM: How did Pachama start with remote sensing technology and, specifically, with ML, to attack this problem? Where did Pachama get its initial data sets?

CS: The satellites don't directly measure carbon, but they do provide us with crucial data on forests across the globe and over time. Some satellite data goes back to before 1980, giving us historical patterns we can use to understand deforestation trends. Our ML technology takes those observations and turns them into estimates of carbon.

To build and train these models, we use a few different data sources: the field plot data from those tape-measuring scientists mentioned earlier and the remote sensing that we gather from aircrafts or drones, such as LiDAR (light detection and ranging) and radar. While satellite data can give us 30-meter resolution, data sources like LiDAR and radar can give us even more granular information, like the height and branch structure of a tree (see Figure 1).

Much of the satellite data we use is publicly available through NASA or other national space agencies and, for the rest, we partner with government institutions, research groups, or private companies. And there is a new LiDAR instrument on the International Space Station called Global Ecosystem Dynamics Investigation (GEDI),[4] which has been acquiring forest measurements since early 2019. GEDI, which was specifically designed for forest measurement, measures tree height as well as the vertical distribution of vegetation in the forest canopy.

Using these spaceborne observations for forest monitoring is an active area of research, even in the academic community. We closely follow this research to ensure we remain on the cutting edge of best practices. Simultaneously, we're building our team with these disciplines in mind; today, a number of our team

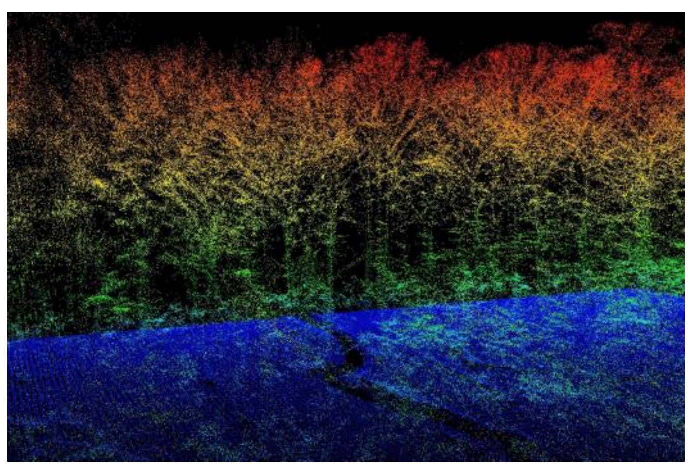

Figure 1 — LiDAR point cloud used to detect the height and structure of trees to measure carbon sequestration.

members bring along research experience with NASA, SpaceX, Microsoft, OpenAI, and others. The scientific approach we are taking here, using three-dimensional observations, really goes above and beyond what anyone else is doing right now, and reflects the extent to which we care about bringing integrity to these markets.

LM: How do you go from this multi-spectral geospatial data to "this forest is going to perform in the carbon environment in this way"?

CS: The objective of any forest carbon project is to demonstrate the project has produced a net decrease in deforestation or a net increase in reforestation. What do we mean by that? The key idea here is, if you were going to protect the forest anyway *even if there was no carbon market*, then you're not producing an additional net reduction in deforestation. So we need to be able to quantify the background amount of deforestation and reforestation going on in a region every year in areas without any carbon projects. The only way to get a handle on background deforestation and reforestation rates is to have that bird's-eye satellite view. The market doesn't have that at present. As a result, a lot of projects on the market are over-credited. Satellite observations are crucial to substantiating project claims that forests were at an imminent risk of being cut down.

> *The objective of any forest carbon project is to demonstrate the project has produced a net decrease in deforestation or a net increase in reforestation.*

LM: Can you elaborate on the value of these satellite observations in monitoring for, and detecting, disturbances in forest projects?

CS: Absolutely. Imagine a company recently bought carbon credits to preserve a patch of forest in the Amazon that was at risk of deforestation. Today, after they buy those credits, they have no way of knowing whether the project was successful in preventing deforestation. Unless someone on the ground observes the activity, they simply have to trust that it's not occurring until it's confirmed during the next credit issuance, which could be years later.

This is the second core capability we've developed: deforestation detection on a regular basis. We're developing this detection capacity so we can automatically alert both project landowners and credit buyers of unexpected deforestation in a project area so they can take appropriate action. If there is an unexpected loss, these markets have credit reserves set aside that can be activated to compensate for the credits that have been rendered null and void. The market currently has no system for detecting deforestation and activating these withdrawals, so deforestation could be occurring for years without the buyer or the landowner knowing.

LM: How can Pachama deal with the latency problem?

For example, something happens locally in one of these forest areas and Pachama might not find out about it until it's too late. Do you expect that to get better, or are there other ways to get at that?

CS: This is exactly what we focus on for our clients, providing regular reporting on deforestation activity every few months. At a certain point, you become constrained by the satellite patterns: has the satellite flown over this region enough in the past few weeks to get data to make this judgment with certainty?

The biggest challenge to frequent monitoring, particularly in the tropics, is cloud cover. If you're using satellite imagery to detect deforestation, when you have clouds, you can't see anything; you just see the clouds. So you're stuck. It can take several months to a year to build up enough data to make a confident detection.

That's why our deforestation detection model uses satellite radar, which penetrates clouds. Any deforestation detection, even if on an annual basis, is a massive step relative to the status quo. At the moment, the market has no deforestation detection capacity other than on-the-ground observations through word of mouth or someone walking around an area and observing trees being cut down.

LM: So this technology ultimately helps you verify and audit projects?

CS: Yes, at the moment. What we primarily do now is add another layer of scrutiny to projects that are listed on the main carbon registries. With so much at stake, many companies are looking for this additional due diligence. They want to ensure that the projects are high quality and that the credits actually represent what they claim to represent. But a key outstanding issue is that there's simply not enough of these high-quality projects out there at the moment.

LM: Will you ever work to develop new projects yourself?

CS: We're getting incredibly valuable intelligence as we improve and validate our ability to estimate the carbon stored in forests. We believe this insight will be critical to the future of carbon markets, helping not only evaluate projects that exist today, but helping better estimate the potential of future projects to ultimately bring more high-quality projects to the market faster.

In the future, we envision that we would be able to say "Look, according to our computing, based on our rigorous, audited methodology, this project is 50% over-credited. It should have gotten 50 credits and there are 100 out there on the market. So, be aware. You need to buy 100 to offset 50." That kind of quantitative information is very valuable; it's not just qualitative due diligence or thresholds.

Today, we're in the pilot phases of originating forest projects. For example, we're already partnering with Mercado Libre on an original reforestation project in the Atlantic Forest in Brazil. There, we're planting trees that connect disparate patches of land together, creating corridors for wildlife to move between forests.

LM: How has Pachama tested its models? Is automation in place to help? Are there tools Pachama can buy, or do these tools have to be made in-house?

CS: Today, we are conducting a lot of our own validation because we're dealing with data that's not common in the general ML community. There's no academic ML benchmark on image classification in this area.

It's also worth noting that we explicitly model the uncertainty of our estimates and produce confidence intervals around them. We use state-of-the-art uncertainty estimation methods, which we're quite proud of. We also have scientists at Pachama who provide domain expertise and visually examine maps we produce to locate obvious errors or ensure that our outputs can, for example, faithfully capture complex timber harvest activity.

LM: How will you get the rest of the market behind your models?

CS: We're already partnering with a number of leading companies like Microsoft, Salesforce, and Shopify. We're also currently in conversations with several organizations, from registries to standard setters to advocacy groups, to further vet and adopt some of these models. Our hope is to bring more precision to the market. Clearly, there is broad acceptance of the important role that remote sensing will play across many major market players.

Another important element of what we're pursuing is visualization — to bring transparency to all these calculations. Our vision is to plot these validations and allow buyers to see these maps dynamically on our website so people know what they're buying and how we go from these images to biomass estimates and to crediting estimates.

LM: Can you imagine a future scenario where we get to an instrumented forest, where we have decentralized, cheap sensors — maybe drones — where cloud cover isn't an issue and we can get near-real-time data?

CS: It's easy to understand the appeal of decentralization, but the biggest constraint is scalability. For example, there are NGOs [non-governmental organizations] and research groups out there that have put up microphones in the forest to detect illegal deforestation via chainsaw noise (obviously, in a highly localized area). A group called the Open Forest Protocol[5] is trying to crowdsource auditing of forest carbon projects, using on-the-ground photos, for example, to confirm whether sites within a forest are still standing.

In this conversation, I've tried to emphasize the paramount importance of the bird's-eye satellite view to ensure the integrity of forest carbon credits. For example, we haven't even talked about the concept of leakage. Imagine you've protected a forest somewhere, but the deforestation has just moved somewhere else, so on *net* you haven't produced the purported reduction in deforestation. This is why we've invested so much in computing infrastructure and R&D to build a truly global forest monitoring system. Admittedly, it is highly centralized, but our view is that fixing the shortcomings of the market does not require better rules or better auditing. It requires accurate forest monitoring over large spatial scales, ideally globally.

LM: Is there a role for carbon beyond forests at some point for Pachama?

CS: At Pachama, our mission is to restore nature, not just forests. The science tells us that forests are an incredibly important lever to mitigate climate change and, by restoring forests, you support biodiversity, local indigenous communities, and so much more. Given the size of the impact, we've started with forests. Today, we are building and training our models to measure the carbon stored in these forests incredibly well. Doing so is a nontrivial scientific and technical challenge. Many organizations can stand up a nice website and trading platform, but in order to have a real impact on the climate, the credits traded must be of the highest quality. So we are hyper focused today on building the most robust models possible for forests, specifically. That said, there are myriad technologies emerging today that have tremendous potential to restore nature and we're keeping a close eye on the next wave.

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The Value of RECs on Blockchain

by Claudio Lima

Renewable energy certificates (RECs)[1] are becoming an important mechanism for energy commodity trading. These market-based instruments are used as an economic incentive for sustainable electricity generation and consumption and to support the development of the renewable energy market.

A REC is created when a renewable generator feeds energy into the grid. It provides documentation for the electricity delivered or consumed and is issued as proof that the power came from an eligible renewable energy source. When this happens, RECs become a tradeable commodity on the open energy market and can be sold or purchased from qualified market participants.

Consumers who want to offset the carbon energy footprint generated by their electricity consumption can purchase RECs, which certify that the bearer owns 1 megawatt-hour (MWh) of electricity produced by a renewable energy generation facility. This means that the REC has effectively offset the carbon footprint generated by the owner's nonrenewable electricity consumption, equivalent to the same amount of energy produced by a qualified renewable energy source.

Figure 1 depicts fossil fuel and renewable generators injecting energy into the grid. These forms of energy are mixed together; there is no way to distinguish where they come from and what type of energy source generated the electricity. Typical renewable sources (solar, wind, biomass, geothermal, and hydropower) are the ones entitled to generate renewable certificates, which embody green environmental and economic benefits for REC participants.

RECs are measured, validated, and issued at the green energy point of origin (e.g., at the meter level), as shown in Figure 1. Each REC issued shows proof of this green energy and is equivalent to 1 MWh of energy generation.[2] On the consumer side, businesses, manufacturers, and governments buy RECs to offset their carbon footprint or promote green energy usage. RECs are also used by federal, state, and municipal governments to create renewable energy programs and comply with renewable energy mandates. Utilities and retail energy

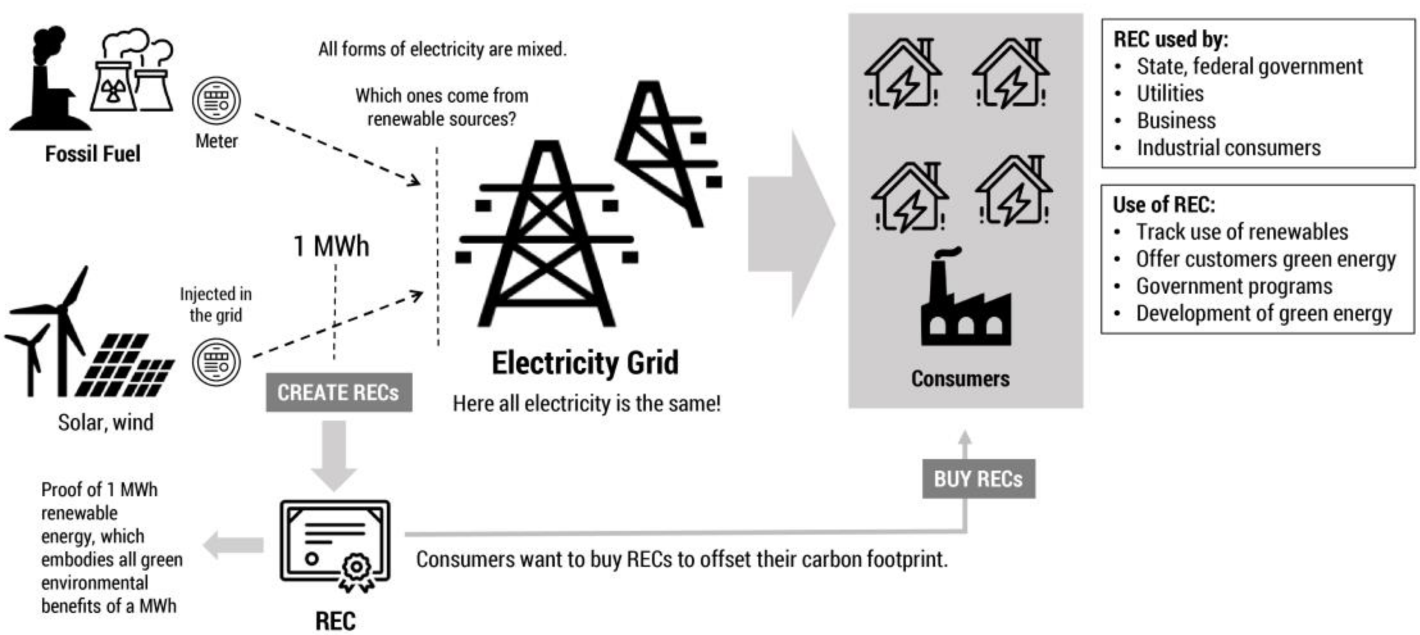

Figure 1 — REC generation and trading. (Source: Blockchain Engineering Council [BEC].)

providers can use RECs to offer green energy programs to consumers, and developers can benefit from REC programs to incentivize the construction of solar, wind, and other renewable energy sources. RECs can be tracked and managed to ensure compliance and authenticity.

The Challenges of RECs

REC registration, validation, and tracing are not completely automated or digitized, and they lack the proper mechanisms to eliminate double counting, ensure transparency, and prevent fraud. Once a REC is sold to a customer, it must be retired, which means it is no longer available to be commercialized as it was consumed to offset a certain amount of electricity. However, there are still risks of fraud, or double counting, since RECs are electronic data records on IT cloud solutions that can be tampered with or modified.

Therefore, transactions involving any certified data, including RECs, are rife with challenges. These transactions are also potentially subject to data manipulation and cyber attacks. Any type of data manipulation or error can compromise the authenticity and validity of the issued and traded RECs in open energy marketplaces, particularly if there is no oversight to track and trace the step-by-step process of validation, identify the provenance, and so on.

Figure 2 lists some of these issues. The most important aspects of RECs and market trading are transparency, accountability, and settlement of the REC transactions. For instance, when a company buys them, those RECs must be cancelled in the registry. In some cases, this won't happen due to a lack of accountability and transparency, and in other cases, a lack of proper transaction tracking and tracing. This process creates double counting, which is an important issue when generating, tracking, and retiring RECs.

Blockchain: What Value Does It Bring?

Blockchain is a distributed ledger technology (DLT) that enables a decentralized, trusted, immutable, and transparent data service layer model.[3] Permissioned, enterprise-, consortium-based DLT blockchain is a special type of blockchain that has emerged as a new

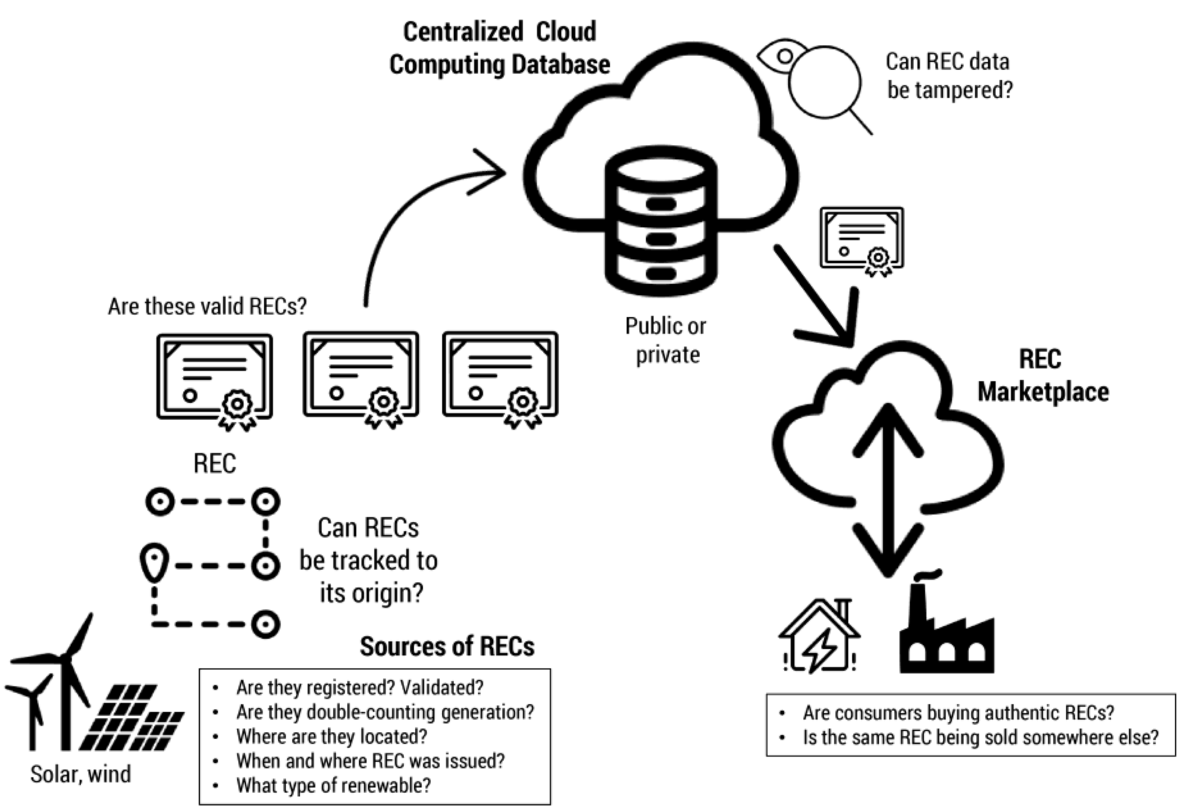

Figure 2 — The potential challenges of using centralized cloud databases for REC traceability and provenance tracking. (Source: BEC.)

IT layer to be added to future enterprise systems and processes to improve IT operations, security, and efficiency. Bitcoin, Ethereum, and other cryptocurrencies that run on public permissionless networks and use advanced cryptographic mechanisms rely on blockchain as their underlying technology.

Blockchain uses consensus-based, immutable, and transparent distributed ledgers to secure digital assets and transactions. Its key properties include:

- Data decentralization
- Encryption
- Traceability
- Validation
- Authentication

Blockchain can coexist with any centralized cloud computing service and integrate with legacy enterprise database systems. It can also be used in enterprise-grade applications to reduce reconciliation costs, improve settlement, tighten business and network security, speed up transactions, register and authenticate both physical and digital assets, and improve supply chain operation. Blockchain can also disintermediate and automate business process workflows, creating a distributed record of immutable, transparent, and auditable ledgers. In the next section, we explore how blockchain DLT is applied in the energy sector, and particularly to RECs.

Blockchain in the Energy Sector

Blockchain DLT in the energy sector has been used and tested in several pilots and demonstrations worldwide, becoming an important application for this new technology. In addition, standards for blockchain DLT in energy are underway, particularly driven by the IEEE P2418.5 standards. REC on blockchain is one of the main use cases for the standardization in the energy space, and several market participants have been implementing or testing blockchain DLT on RECs, including the power energy utilities.[4]

> *Blockchain can coexist with any centralized cloud computing service and integrate with legacy enterprise database systems.*

Figure 3 shows how smart contracts interact with different segments of the grid, automating flows and processes. The grid infrastructure can interface with the DLT digital layer, the consumer, and the prosumer (a consumer who also produces electricity [e.g., via a rooftop residential solar panel]) to provide a trusted,

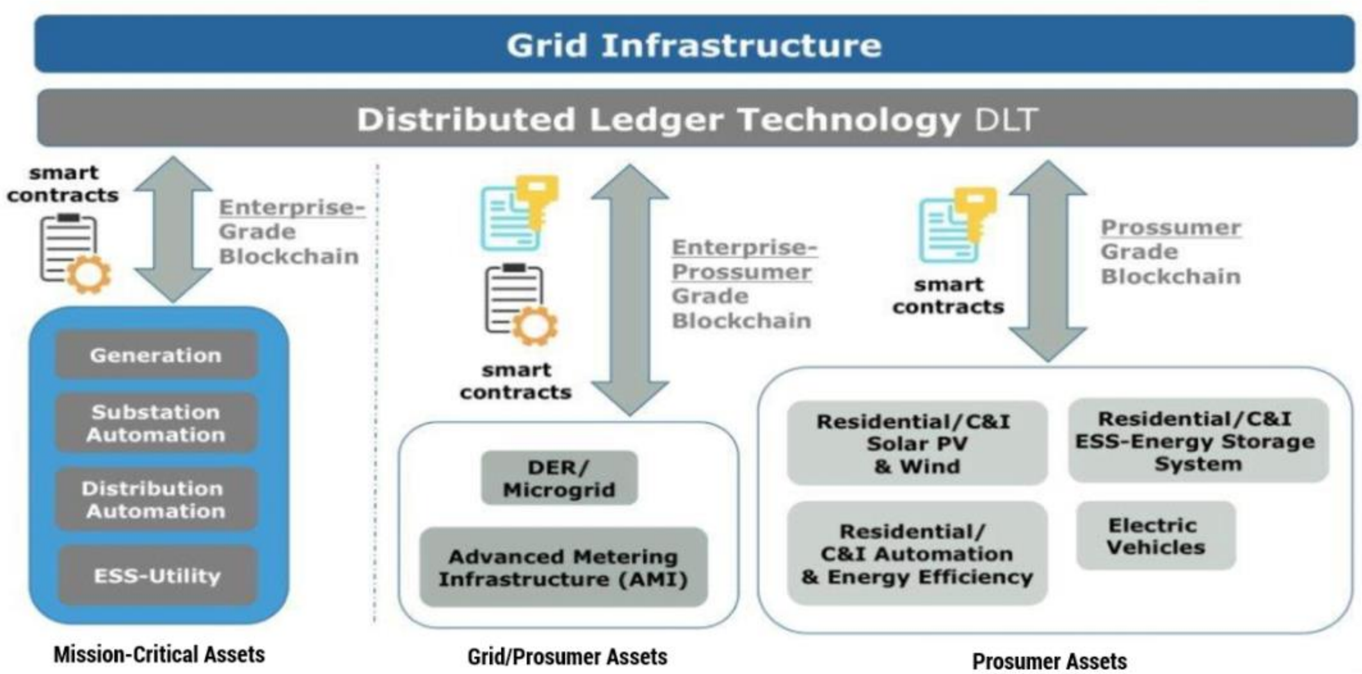

Figure 3 — Blockchain DLT on grid infrastructure. (Source: BEC.)

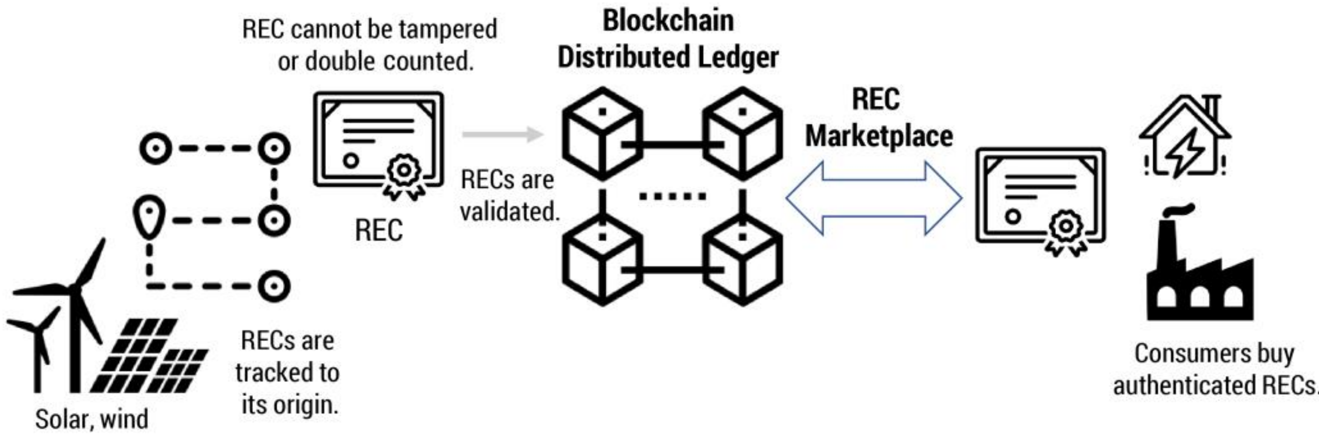

Figure 4 — Blockchain DLT–enabled REC registration, tracking, and trading. (Source: BEC.)

decentralized, and record-keeping IT layer environment. Smart contracts are used in the entire grid segment and are essentially computer script automation, triggered by conditional events, which embed the business workflow logical rules. A REC smart contract has similar characteristics, where grid participants (consumer and prosumer), and energy producers use business workflows to register, track, and trade RECs using blockchain DLT smart contracts.

> *Adding a new blockchain DLT layer to the existing REC process enhances the overall end-to-end operation, credibility, and accountability of certificates at the issuing, onboarding, registration, tracking, and trading stages.*

Blockchain DLT–Enabled REC Registration, Tracking & Trading

Blockchain distributed ledger is the technology of choice that addresses most of these issues, creating a new layer that registers, secures, tracks, and validates RECs along the entire process workflow, while enabling blockchain-based transactive REC marketplaces.

Adding a new blockchain DLT layer to the existing REC process enhances the overall end-to-end operation, credibility, and accountability of these certificates at the issuing, onboarding, registration, tracking, and trading stages. Both REC generators and end consumers can benefit from the blockchain properties of a new DLT-enabled REC solution. These include provenance validation (by the issuer); a tamper-proof, immutable data layer; decentralization enabled by a strong consensus algorithm; and transparent data exposure to auditors, regulators, and third parties.

The solution shown in Figure 4 benefits the end-to-end REC track and trace that validates the REC retirement and usage, and thus avoids double counting. A blockchain-based REC tracking-and-tracing system can benefit regulators and market participants by validating and checking the authenticity of the RECs being traded, retired, and so on; third parties can use a transparent public ledger database to verify the trading information. This platform can also increase accountability as a means of verifying compliance with renewable portfolio mandates and standards.

Recommendations

RECs are well-known, market-based economic incentive instruments used by the energy sector for generation, consumption, and development of renewable resources. The REC process is still very manual and prone to failures and manipulation by malicious actors, and if not properly managed, susceptible to double counting. This may eventually create credibility issues for the whole process. Tracking and trading the REC on a blockchain DLT throughout its supply chain is important, particularly if all steps along the process are registered and validated by the distributed ledgers and can be audited later by a third party, like regulators.

Validating the REC provenance to its issuer of origin, geographic position, and time of generation, as well as the type of renewable source used, is essential to increase REC trustability, value, and therefore market credibility. Blockchain DLT technologies solve all these issues and create a new "trusted-REC" solution that enhances the centralized cloud-based IT processes used in the industry today, adding a valued and trusted data layer validation mechanism. Blockchain DLT–based REC solutions is an emerging area of research and exploration. The Blockchain Engineering Council (BEC) is providing leadership in its design and implementation.[5]

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Drones for Sustainability

by Helen Pukszta

Drones count citrus trees in Florida[1] and penguin chicks in Antarctica,[2] detect invasive species in Illinois[3] and shore erosion in coastal Australia,[4] and can plant trees and help restore degraded habitats. In all our civilian endeavors, public and commercial, it seems no idea for a drone application is off the table, and we learn of new ones that help people and our planet daily. Their relatively small environmental footprint, maneuverability, task versatility, accessibility, and ease of use make drones great tools in the drive for sustainability.

Drones, also referred to as unmanned aerial vehicles (UAVs), are aircraft with no pilot to carry aboard, no cockpit, and not much need for special materials, instruments, or safety-critical systems normally required of manned aircraft. Because drones are unmanned, their size can fit the purpose without the need to accommodate humans onboard. Unlike today's airplanes and helicopters, most drones run just fine on batteries. By nature of their design, they are inherently energy-efficient.

> *The future positive impact of drones on the environment has been predicted mostly in two areas related to advanced air mobility: package delivery and passenger air taxis.*

The two areas selected and highlighted in this article, precision agriculture and drone light shows, are already here and thriving. Although quite disparate, both illustrate how adaptable and accommodating drone technologies can be to applications where saving the environment and creating economic value are not inversely related.

How Energy-Efficient Are Drones?

The future positive impact of drones on the environment has been predicted mostly in two areas related to advanced air mobility: package delivery and passenger air taxis. The latter is still a few years out. The technology has not solidified enough — not only of the vehicles themselves but of the infrastructure needed to fly them safely and efficiently — to closely evaluate its effect on sustainable development, though the benefits will likely be immense. Package delivery on a commercial scale is not quite here yet either, but it is much closer, and studies conducted in this area can serve as a good baseline to approximate the energy efficiency and environmental impact of commercial drones in general.

Most drones use lithium-polymer (Li-Po) or lithium-ion (Li-ion) batteries. One study, funded by the US Department of Energy and the RAND Corporation, analyzed the lifecycle greenhouse gas (GHG) emissions per one-pound package delivered by a battery-powered drone as compared with current systems of delivery. The GHG estimates included battery production, transportation electricity, upstream transportation fuels, transportation fuels combustion, warehouse electricity, and warehouse natural gas. The study showed that the total energy used by a small drone is far lower than with any other ground-based transportation.[5]

Battery-powered drones typically last in the air for 20 to 30 minutes and need to be recharged frequently; their relative advantage in low carbon footprint is closely tied to how green the energy is that charges them in the first place. As US and worldwide electricity industries transition to generating fewer GHG emissions, carbon intensity of electric power varies from region to region (see Figure 1). For example, according to the aforementioned study, if a small drone was charged in California, the lifecycle reduction in GHG emissions was an impressive 54%; if it was charged in Missouri, which uses mostly coal to produce electricity, it would be a still impressive but much lower 23%.

As is the case with other lithium battery-powered products from personal electronics to electric road vehicles, drones' environmental footprint increases when their impact on natural resources and end-of-life disposal is considered. The demand for raw materials used in lithium battery production for all types of applications is expected to increase annually by 30%, resulting in significantly higher consumption of lithium,

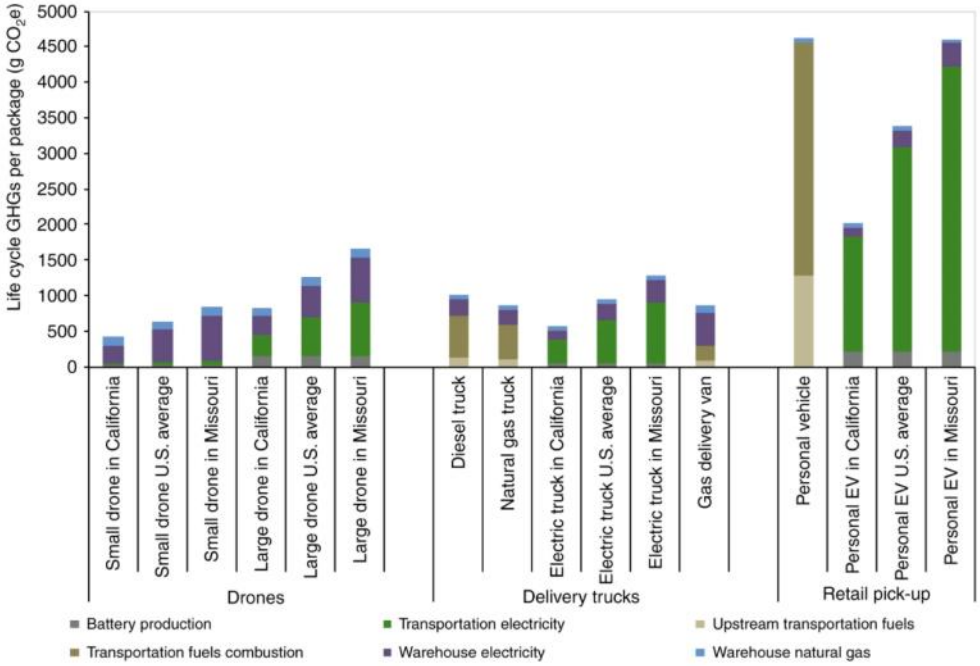

Figure 1 — Lifecycle energy use of drones. (Source: Stolaroff, J.K., et al., *Nature Communications*, 2018; http://creativecommons.org/licenses/by/4.0, reused as is.)

graphite, cobalt, nickel, and manganese and in associated resource-intensive mining.[6] Globally, it is estimated that only 5% of all lithium batteries are recycled, as mining is still the cheaper option and recycling requires energy-intensive processes to recover the materials in a usable form.[7] For drones and their batteries to firmly enter the circular economy, they need to be recycled, and the extraction of the reusable materials will best be accomplished through robotics and automation.[8]

In the context of deliveries, drones are in the lead for energy-efficient delivery of packages and goods. This conclusion is based on the combination of smaller electric drones charged by low-carbon electric power, small packages to deliver, and expected improvements in battery life and efficiency that will accommodate heavier loads in the future.

But comparisons with ground transportation cover only part of drones' lower energy consumption advantage. When a task can be performed only from the air, the primary competition is non-drone, manned aircraft. Such aircraft, having to accommodate the pilot in its size and design but all else being equal, are less efficient. Longer-endurance UAVs that use gasoline or hybrid gasoline-electric propulsion systems to extend the range and flight time are available.

Hybrid designs, in particular, hold a lot of potential by combining a practical level of endurance with payload capacity, using increasingly more efficient power systems. For example, some models use the gasoline engine not to power the aircraft but to generate electricity in flight that is used to power the UAV in a high-efficiency, gas-to-electrical power conversion. Their lithium battery also acts as backup to safely land the drone in case of engine failure. By taking advantage of gasoline's higher energy intensity and electric power, this design can be more efficient than powering with a battery alone on longer, heavier flights.

Wherever drones are used — in mapping, inspections, research, public safety, or spraying of crops — similar efficiencies apply. Drones can be used to enable sustainability while at the same time leaving a relatively small environmental footprint themselves.

Growing More with Less: Drones in Precision Agriculture

Precision agriculture is a set of farming management practices that produces higher yields through more efficient use of critical resources such as land and water, as well as lowered consumption of fossil fuels, fertilizers, and pesticides. Precision agriculture benefits crops, soils, groundwater, and the entire crop cycle and is now considered a cornerstone of sustainable agriculture.

The technology that made precision agriculture possible enabled farmers to locate an exact position in the field, and then gather data and apply crop management strategies specific to that location. The core technology is GPS (Global Positioning System, owned and operated by the US government) and, more broadly, GNSS (Global Navigation Satellite System, comprised of satellite navigation systems owned and managed by individual countries). GPS enabled the auto-guided systems used on the ground with tractors (pioneered by John Deere in 2001), sprayers, and other equipment to help avoid mistakes, such as missing patches of land or covering the same area twice. Adoption of satellite imaging, GIS (geographic information systems), Internet of Things (IoT) devices, and drones soon followed.

> *By using drones to help reduce the cost of water, fertilizers, and pesticides, farmers are getting a better return on their investment, while also contributing to environmental stewardship.*

What Farm Drones Do

Drones help carry out many farm management activities: crop scouting, weed detection, soil assessment, plant counting, harvest planning, drainage and irrigation assessments, and anything else that an aerial view can inform.[9]

Aerial imagery for agricultural use has long been accomplished with satellites and manned aircraft. However, satellite images lack the spatial (i.e., image quality) and temporal (i.e., image frequency) resolution that a regularly scheduled airplane outfitted with a sophisticated camera could provide. Compared to these traditional methods, drones are a low-cost option that can provide superior resolution of images without producing gas emissions, or significantly lower emissions if a gas or hybrid UAV is used. It is a safer option that does not put a pilot at risk when flying over difficult terrain, particularly when the flight needs to be conducted close to the ground. Provided there is a remote unmanned aircraft systems (UAS) pilot on hand, the drone can be deployed at a moment's notice, weather conditions permitting, with none of the overhead normally associated with manned aircraft. And, unlike satellite images, drones capture data at low altitudes and are not affected by cloud cover.

Drones used in agriculture can carry RGB (visible light), multispectral, thermal, LiDAR (light detection and ranging), and hyperspectral sensors, each with a different purpose for capturing aerial data. Multispectral analysis, for example, looks at how strongly plants absorb or reflect different wavelengths of sunlight, and drones help identify which crops are flourishing and which need help.[10] Aerial images of crops taken using red, green, blue, red edge, near-infrared, and thermal image bands are used to create normalized difference vegetation index (NDVI) maps, which are graphical indicators based on a mathematical interpretation of color and near-infrared data. NDVI maps can show whether the target area contains live vegetation, point to differences in crop performance (one area may have too little fertilizer and another too much), and help assess plant vigor and health. Any variability may point to issues with irrigation, pest invasions, soil or seed quality, or disease.[11]

Drone-collected images also produce orthomosaic, thermal, or digital surface maps that can be used for crop planning or to identify areas of drought or flooding. Advanced agronomy solutions combine drone, satellite, weather, and field operations data with artificial intelligence for early pest and disease detection and provide insights that help farmers make optimized decisions about how and when to intervene for optimal yields.

Data from drone missions can promote better timing and precision of variable-rate seeding and chemical applications. Drones themselves can be outfitted to spray fertilizers, herbicides, fungicides, and pesticides. They follow the terrain precisely to maintain a constant altitude above the crops and are uploaded with variable-rate maps to help adjust the volume of chemicals sprayed based on the location derived through GPS positioning. Although the efficiencies aren't always there when spraying large areas — drones have limited payload capacity, the weight of which more quickly depletes batteries — they can apply seeds and chemicals with precision that only UAV maneuverability can support, which in turn results in less drift and environmental impact.

By using drones to help reduce the cost of water, fertilizers, and pesticides, farmers are getting a better return on their investment, while also contributing to environmental stewardship.

How Farm Drones Perform Their Jobs

A wide array of agriculture drone platforms is now available. Some are highly specialized solutions tightly integrated with post-processing and analytical software; some cover a part of the workflow,such as high-end sensors that can be mounted on a variety of drones; and some are simply prosumer-grade UAVs that get the job done with an off-the-shelf drone equipped with a camera.

That last category is making UAVs a viable option to small farmers globally, allowing them to spot issues sooner than with the human eye. However, the large monoculture systems we are accustomed to in the US are easier to analyze and diagnose using aerial data than the smaller, diversified crops grown together that are more prevalent in developing countries.[12]

A readily available drone addresses both the spatial and the temporal resolution of captured data. The state of the crop can be assessed, and any issues addressed, at precisely the right time, and at meaningful and adjustable intervals corresponding to each crop's growth pattern that, although generally predictable and consistent, will vary from season to season. For example, there may be a small window of opportunity after a storm to assess the extent of a flood or other damage in a part of the field that may be difficult to access by foot.

An automated drone mission that canvasses an area in a consistent and efficient flight pattern can be planned quickly with a few clicks. The flights can be repeated, or adjusted as needed in the field for area size, flight altitude, and other parameters. Drone missions can produce and present results quickly and lead to faster decision making.

The long-range connectivity and endurance needed to gain efficiencies when covering a large area is no longer reserved for fixed-wing drones, which generally last longer and can cover more ground. Smaller, multirotor UAVs tend to be the most energy-efficient per mile traveled, but they only last for about 30 minutes before needing a battery change. Their payload capacity is also limited. For example, they do not easily accommodate heavy tanks of chemicals for large-area spraying. However, there are more drones available now that offer the benefits of a multirotor — hovering in place, making quick turns, needing only a small space for takeoff and landing — and possess the endurance of a fixed-wing UAV.

An automated drone mission that canvasses an area in a consistent and efficient flight pattern can be planned quickly with a few clicks.

Limitations & New Directions

Despite the benefit of a low carbon footprint, drones are not the answer in every case. Satellite images are still required for big-picture aerial analyses, and surveys and applications covering very large areas are still best accomplished with a manned aircraft. But the boundaries of these limitations continue to be challenged by accelerating innovation in drone technologies.

Internet connectivity and bandwidth limitations in rural areas can hamper the speed at which farmers get their insights. The simplest case of retrieving images from a drone's secure digital (SD) card after it lands may meet the needs of a smaller farm but is no longer sufficient with larger operations, particularly when drones are integrated into the farm's IoT ecosystem. Data can be uploaded to the cloud so processing can start in flight, but networking bottlenecks and reliability issues can slow the process. This is changing as more processing is taking place aboard the drone itself and alternative and proprietary networking solutions can now be deployed in the field. Once 5G networking becomes broadly available, it will provide the capacity to take what today's drones offer to a new level.

Complete automation of drone operations is also within reach. Drone-in-a-box capabilities of autonomous flights that consider weather conditions, automatically recharge drone batteries, initiate continuous flights, and house the drone between missions are becoming available. They are subject to regulatory restrictions (e.g., for BVLOS [beyond visual line of sight] missions), but relevant Federal Aviation Administration (FAA) waivers can be obtained for safe operations in rural areas in the US.

The availability, ease of use, and just-in-time precision of a drone are hard to match. Drones will continue to be a cost-effective and energy-efficient enabler of precision agriculture and many other sectors and industries, and trusted tools for sustainability.

Less Boom, More Wow: Reusable, No Pollution Drone Light Shows

Fireworks are a staple of centuries-old traditions and celebrations worldwide. Yet the environmental impact and the risk of fires from pyrotechnic displays are significant (see sidebar). A budding industry based on the innovation of using choreographed swarms of small drones carrying lights, or other special effects devices,

Beautiful & Fun, Fireworks Sparkle at a Cost

On New Year's Eve 2010, the city of Beebe, Arkansas, witnessed the death of 4,000 to 5,000 red-winged blackbirds after a series of loud detonations of professional-grade fireworks were set off near the birds' winter roost. Blackbirds have poor eyesight and don't fly at night. Roused from their roost and disoriented, they crashed into houses, cars, chimneys, and each other. Necropsy reports showed trauma primarily to the chest, consistent with crashing, rather than falling.[1] Studies of birds erupting into panicked flights en masse as a result of noise from fireworks have been reported with waterfowl and other birds as well; in some cases, birds abandon their young in their nests.[2] In the summer, birds are generally dispersed and not as affected as during winter displays when they roost together.

Aside from traumatizing wildlife, pets, and many humans, fireworks, mostly the consumer type, present a significant risk of fires. The origin of the El Dorado fire in California in September 2020 is one terrifying example. The fire, which burned more than 22,000 acres, required the expenditure of nearly US $40 million in suppression costs, and took the life of a firefighter, was started by a pyrotechnic device at a gender-reveal party at a park in Yucaipa, California.[3] Today, in areas that experience extreme dry conditions, which are increasing in number and duration, all fireworks, even prescheduled professional ones, are being banned or cancelled.

Although pollutants released in pyrotechnic explosions, in aggregate, are not significant compared to the volume produced by burning fossil fuels, they do contribute to air pollution and pose health risks.[4] For example:

- Fireworks produce a surge in fine particulates, microscopic particles that are 2.5 microns in diameter and can travel deep into the lungs. Particulate matter is among the top global environmental health concerns.[5] On 4 July 2021, one Indiana city reached an hourly average of 154 micrograms per cubic meter; the US Environmental Protection Agency (EPA) threshold for unhealthy air is 35.[6] The EPA allows states to discount exceptional events, such as community fireworks, in reporting their air quality statistics.
- Perchlorate salts that provide oxygen for the combustion (although cleaner fireworks operators, including Disney, claim to no longer use them) dissolve in water and can contaminate groundwater, rivers, and lakes. Ingested perchlorate ions can interfere with iodide uptake into the thyroid gland.
- Sulfur dioxide, which gives fireworks the distinctive smell of burnt matches, can be toxic at high concentrations.
- Metals such as barium, copper, lead, titanium, and aluminum that give the blasts their color and sparkling effect can also have negative effects on the health of humans and animals and damage cells and lungs.

It is important to point out that most of the pollution from fireworks, and ER visits due to related injuries, is caused by the volume of backyard amateur displays. Professional shows at large community events are run by firework technicians who have years of experience and safety training. These shows pose much less immediate risk because there are fewer of them, and they are launched far enough into the sky to dissipate before reaching spectators. Still, pollutants can be blown around for miles in atmospheric wind currents and affect the wildlife and the environment in the sky and below.[7]

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has been putting on shows for public viewing in place of, and alongside, fireworks.

Drone light shows have the potential to disrupt how the live events industry and corporate departments responsible for event planning deliver the optimal package of entertainment, special effects, advertising, and messaging. The public is likely most familiar with light shows performed by Intel during the Superbowl 2017 half-time performance in Houston, Texas, and recently at the Tokyo 2020 Olympics. But there are a number of other providers in the US and globally delivering spectacular drone shows of all sizes.

> ***Drone light shows can easily run the gamut from large, sophisticated displays that can be integrated into a broader entertainment or advertising experience, to small celebrations among friends and family.***

Drone shows use swarms of small drones, from a handful to a thousand or more, each equipped with an LED light acting as a pixel in a choreographed set of images in the sky. Think of them as points in a low-resolution Georges Seurat painting or elements in a photomosaic that blanket the sky — the mind fills in the gaps and mixes the colors — but in a three-dimensional, immersive viewing experience. UK-based Celestial, a self-described "drone art company that fuses technology with soul" illustrated the technology's capabilities by creating a video in conjunction with Greenpeace.[13] This production used 300 illuminated drones to create images of iconic animals to send a message to world leaders attending the 2021 *G7* summit in Cornwall, England.

Flown at a safe distance from audiences and over one meter apart from each other, drones used in light shows are equipped with technology (including real-time kinematic positioning (RTK)–enhanced GPS for outdoor performances) that allows them to follow positioning precise enough not to collide with each other and ensure they can quickly enact dynamic 3D animations by forming eye-pleasing shapes and lines. The drones tend to be very small in size. With no payload to carry anything other than a small LED light that changes colors based on preprogrammed choreography and a battery that limits how long they can fly, the drones can be tiny, but the size and design also reflect the tradeoffs in ensuring that the UAVs can withstand some wind gusts without collisions or flyaway incidents.

The show itself, or the dance, is designed either in proprietary software that is part of an integrated system, or in standard 3D applications familiar to animation designers, in which case the animation is then validated and imported into the software that runs the show. The swarm performance is automated and centrally controlled; the drones in the swarm generally do not communicate with each other and do not perform any autonomous actions. The UAVs are managed as a group, but the operator has visibility into each drone's status and performance, and the overall setup employs varying degrees of hardware, software, and networking redundancies and controls.

Intel's drones and software are proprietary, and the majority of other providers, such as Pennsylvania-based Verge Aero and Michigan-based Firefly Drone Shows, have used their own custom systems. They pair the software they developed either with UAVs they also developed in-house or with modified, off-the-shelf consumer drones.

A Latvia-based company, SPH Engineering, which develops and markets commercially available drone show software, has pioneered a different approach. Its software can be paired with a number of drone models available on the market, creating an opportunity for new entrants to deliver drone shows without the need to build the drones or develop the software to run them, or even to integrate them.

SPH Engineering has been on a mission to lower the barriers to entry for drone show providers, whether established companies or new industry participants, by building flight path precision and layers of safety into its software, partnering with UAV manufacturers that make compatible drones, and spearheading an international community of drone show enthusiasts. Other independent makers of drone show software are beginning to appear on the market as well.

In any drone show endeavor, the learning curve tends to be steep, depending on skills and capabilities already present; safety and operational risk management are always front of mind. But a well thought out drone show enterprise can acquire the drones and the software and, in the US, for example, apply for the FAA 14 CFR § 107.35 waiver, assuming flight operations will be performed under the Part 107 rules, which is almost always the case.[14] This allows a pilot in command (PIC) to operate more than one drone at a time. The waiver is a key prerequisite to legally performing drone shows in the US and, like all FAA waivers to Part 107 rules, requires documentation of possible operational risks while flying, and the methods used to mitigate them.

Drone light shows can easily run the gamut from large, sophisticated displays that can be integrated into a broader entertainment or advertising experience, to small celebrations among friends and family. International mega-events will likely continue to be dominated by large players with deep pockets like Intel or China-based EHang. But the technology itself should no longer be the barrier, and it will be the creative and operational capabilities of drone show providers that will define winners in this space. The size and rate of growth of the drone show market will be tied to safety records, technical reliability, and overall cost. Maybe that next gender-reveal party will use a small drone show instead of fireworks, and someone's family reunion entertainment will feature a DJ who lights up the sky with a small fleet of drones.

Drone shows can't exactly match what traditional pyrotechnics produce, but they can complement (and even carry) fireworks, replace them with a different, environmentally cleaner experience, and easily surpass the level of customization, targeted messaging, and creative expression that pyrotechnics can offer. Although it is a niche industry, the application of drones in live events and entertainment demonstrates the versatility of drone technologies in creating new opportunities as well as new paths to sustainability. Watch for more such applications to appear and dazzle.

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