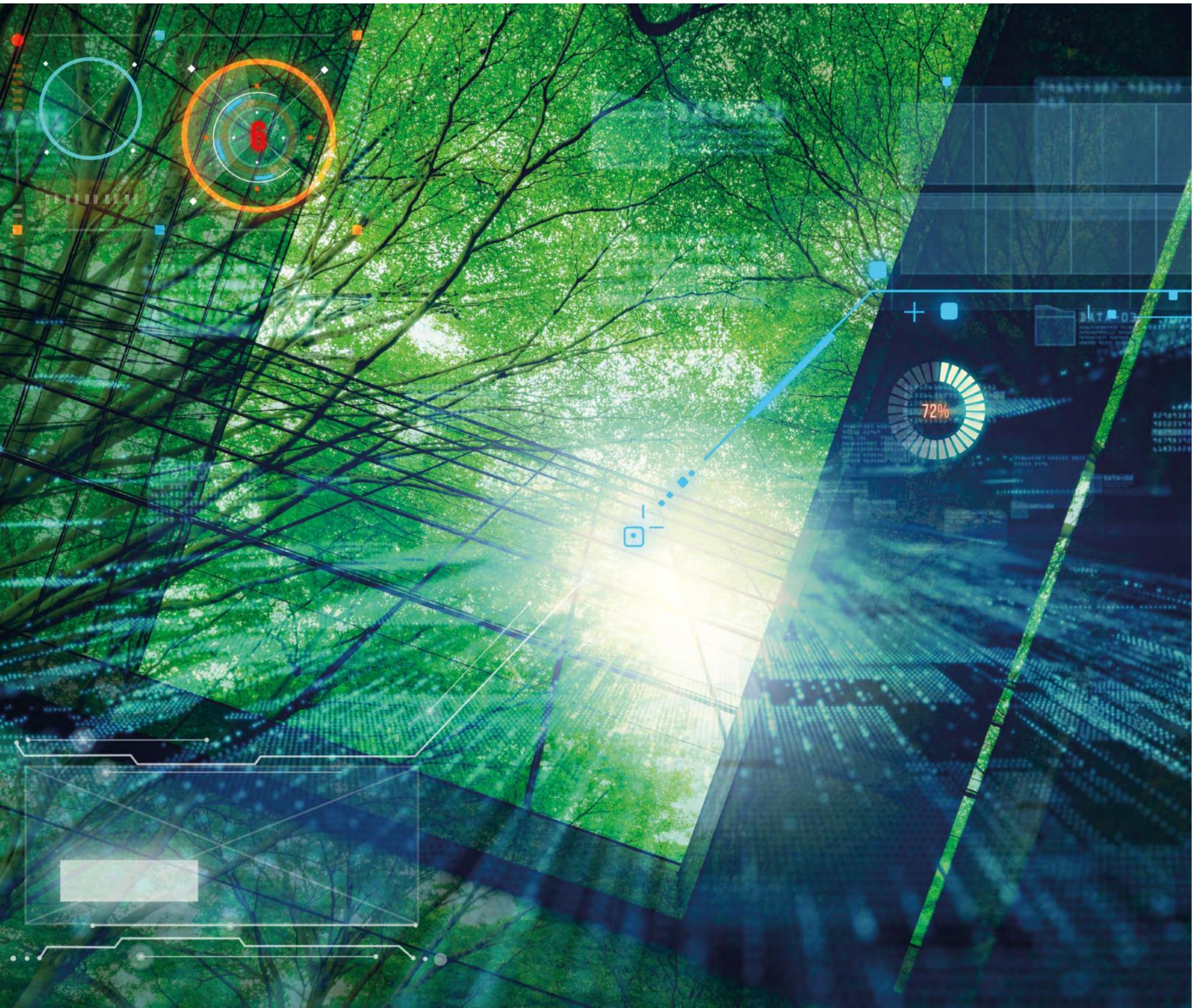
Powering sustainable IoT

The environmental cost of battery-powered IoT devices – and what to do about it



Introduction

IoT sensors can be deployed on people, objects, or within the environment. These smart sensors and beacons are capable of tracking an astonishing range of data—such as heart rates, lighting conditions, temperatures, locations, and equipment usage, to name just a few. This wealth of information provides valuable insights that help businesses optimize operations, improve efficiency, and gain a deeper understanding of the world around us. However, all this benefit presents a problem – how do we power this vast and growing number of devices?

It is predicted that there will be 50bn IoT devices by 2030. At present, almost all wireless IoT devices use batteries. Added to this, the typical real-world battery life for a wireless device sensor can be as little as a year, yet most devices have an operational life upwards of ten – meaning multiple battery replacements for each device.

That's a lot of batteries.

This has major environmental impacts, from the carbon footprint of device manufacture to the maintenance requirements of battery changes and the waste and toxic chemicals produced due to their disposal.

But what can be done to address these issues? This whitepaper examines the environmental impact of battery-powered IoT devices, presents a new study on the carbon footprint of an IoT sensor using various power sources, and demonstrates that there is a more environmentally friendly solution to the IoT power challenge.

A study of IoT sensor carbon footprint

Until recently, assessing the carbon footprint impact of various power sources for IoT devices has been difficult, with limited research on the effects of coin cell batteries, for instance. To tackle this gap, Lightricity partnered with Circular Ecology, carbon footprint experts, to model and compare the carbon footprints of an IoT sensor powered by an AAA battery, a coin cell CR2032 battery, and Lightricity's indoor photovoltaic (PV) cells.

The comparison was conducted using the same sensor with different power sources over a 25-year period, reflecting its expected lifespan. The findings from this study play a crucial role in the discussion presented in this paper.

The environmental cost of the battery-powered IoT

A lot has been discussed about the potential positive environmental benefits of IoT devices, and there are numerous examples. For instance, IoT devices can help save energy by turning on streetlights only when needed or notifying water treatment plants about leaks, thereby conserving valuable natural resources.

While IoT devices can contribute to saving energy, water, and other resources, they also have their own environmental footprint, largely due to their reliance on battery power. According to Statista, there were an estimated 22 billion IoT-connected devices worldwide by the end of 2018, with forecasts predicting that number could rise to 50 billion by 2030. If most of these devices are battery-operated, the environmental impact could be substantial.

Although low-energy IoT sensors can have a long lifespan—some lasting up to 25 years or more—batteries do not last as long. In our study, we used an AAA battery with a 2-year lifespan and a coin cell battery with a 1-year lifespan as the base cases (our internal market research revealed a wide range of quoted battery lifetimes, from a few months to 10 years). With a 1- or 2-year lifespan, this results in the need for frequent battery replacements throughout the device's lifetime.

But what exactly are the environmental issues caused by batteries? Let's take a look…

Batteries are a significant contributor to IoT device carbon footprint

The study on IoT device carbon footprint, carried out by Circular Ecology in accordance with ISO14067, showed the clear impact that battery power has on the carbon footprint of an IoT sensor.

In fact, when considering an AAA battery-powered device over 25 years, the battery – including emissions from manufacturing, materials, and replacement - was the largest contributor to carbon footprint at 51% (the rest comes from sensor components, especially the low power BLE wireless connection chip, and the replacement maintenance cycle).

In the model of the CR2032 coin battery, the battery – on a 1-year replacement cycle – was also a large contributor to the device's carbon footprint at 36%.

In comparison, an IoT photovoltaic (PV) cell can account for as little as 1% of the device's total carbon footprint (which we will examine in more detail later). The emissions associated with batteries stem from several factors, including the carbon footprint related to the extraction and production of raw materials needed for their manufacturing. Additionally, emissions arise from maintenance activities, such as the travel of professional engineers to replace the batteries.

However, the real lifetime impact comes from the compounding effect of having to use and replace multiple batteries over a device lifetime, to the point where a 25-year device would create more emissions from battery manufacture and maintenance, than from manufacturing the device itself.

The environmental cost of battery manufacturing

A variety of battery types are used in IoT devices, but due to the small size of the sensors, smaller batteries like AAA and coin cell batteries are most commonly used. Even within these categories, there are several variations available. The most widely used types include alkaline, lithium-metal, nickel-metal hydride (NiMH), and lithium-ion batteries.

While they are named after individual metals, these batteries often contain a mix of the same metals. For example, lithium-ion batteries contain nickel, and some nickel batteries contain lithium. Cobalt also tends to be present in most rechargeable batteries.

[1] https://www.statista.com/statistics/802690/worldwide-connected-devices-by-access-technology/

There are environmental implications to the extraction of the various materials required for these different types of batteries. The table below gives some examples.

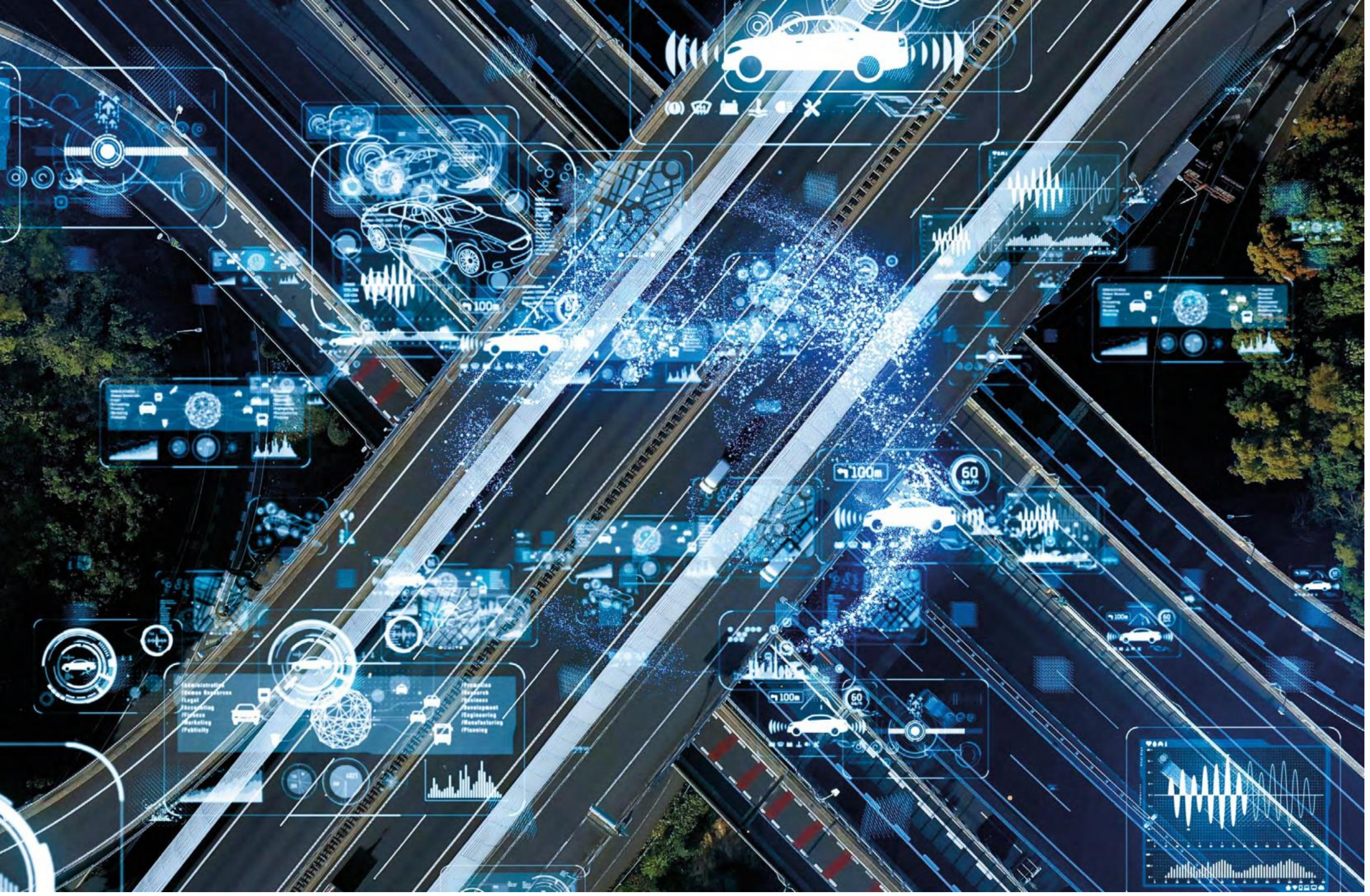
Metal	Environmental concerns
Lithium	Lithium is extracted from brine found under salt flats. Serious concerns have been raised by the Indigenous communities living in the areas where these salt flats are found – both about how much they share in the benefits from the operations on their land, as well as the possible environmental impacts. Mining activities for materials such as lithium can wreak havoc on the surrounding environment.[2] In addition, on land where water is already scarce, the amount being used by the mining companies can reduce access for local communities as well as contaminate freshwater sources with salt or chemicals.
Nickel	Nickel is a vital component of lithium-ion as well as NiMH batteries. Unfortunately, the extraction of nickel has been linked with high levels of environmental destruction and toxic pollution. In 2016, New Internationalist reported[3] on the devastating effects that nickel mining pollution was having on local communities in Colombia, with drastic increases in birth defects, miscarriages and cancer, as well as numerous other illnesses.
Graphite	Graphite is used as an anode in many batteries, including alkaline and lithium ones. Natural graphite mining can cause dust emissions, while the purification of battery-grade anode products requires high quantities of reagents such as sodium hydroxide and hydrofluoric acid, which may be harmful to both human health and the environment. Synthetic graphite production, on the other hand, is more energy-intensive, which has led operators to seek the cheapest power sources that tend to be coal dominant, generating a higher overall carbon footprint.[4]
Cobalt	Particles emitted during cobalt mining are damaging to human health in a number of ways. In addition, cobalt particles can also affect ecosystems through accumulation in fruit or plant seeds grown in contaminated soils. Cobalt mining can contaminate the environment through air-blown dust, surface water, and radioactivity – it also has a significant carbon footprint, due to the electricity used during extraction.[5]
Copper	Copper mining poses significant risks to communities on the ground, threatening everything from water access to air quality to Indigenous cultural sites. The heavy machinery used creates significant amounts of dust, polluting the air. While chemicals are used to leach the mineral out of ore and exposed water is forever contaminated. Some mining operations will have to pump water in perpetuity, even after there is no longer copper to be found, so that contaminated water from the mine site doesn't flow back into the wider water table.[6]

[3] https://newint.org/features/2016/11/01/we-are-slowly-being-killed-by-this-mine

[4] https://www.mining.com/climate-change-impacts-of-graphite-production-higher-than-previously-reported-study/

[5] https://doi.org/10.1016/j.jsm.2019.03.002

[6] https://www.theguardian.com/us-news/2021/nov/09/copper-mining-reveals-clean-energy-dark-side



These environmental issues associated with batteries are likely to grow as the demand for battery raw materials increases. The rise of electric vehicles is the main source of this increased demand. Recent research[7] has suggested that demand could be 18-20 times higher for lithium, 17-19 times higher for cobalt, 28-31 times higher for nickel and 15-20 times higher for most other materials from 2020 to 2050. This would require a drastic expansion of lithium, cobalt, and nickel supply chains and likely additional resource discovery. It's also likely to significantly increase the cost of batteries.

Battery disposal causes environmental harm

According to an EU-backed research project, about 78 million batteries powering IoT devices will be dumped globally every day by 2025[8]. While in theory, most batteries are recyclable, the reality is that many end up in landfill. In fact, only about half of the batteries used in Europe are recycled[9]. Recycling these types of batteries is a costly process, with its own energy requirements.

When batteries are sent to landfill and decay, or are burned, photochemical reactions can release greenhouse gases. In addition, improper or careless processing and disposal of spent batteries – which is not uncommon – leads to contamination of the soil, water and air[10].

Clearly, as our use of the IoT grows, the environmental impact of disposing of batteries in this way will continue to grow. That's why it's so important to consider alternative energy sources.

7 https://www.nature.com/articles/s43246-020-00095-x

8 https://cordis.europa.eu/article/id/430457-up-to-78-million-batteries-will-be-discarded-daily-by-2025-researchers-warn

9 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_recycling_of_batteries_and_accumulators&stable=0

10 https://pubs.rsc.org/en/content/articlelanding/2021/ee/d1ee00691f

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Sustainable IoT – what's the solution?

If we want to reap the many benefits of expanding IoT without damaging the environment, a radical rethink of power sources is needed.

Many proposed solutions to mitigate the environmental impact of batteries in IoT sensors have focused on extending battery life. While this would indeed reduce the carbon footprint by decreasing the number of batteries required and lowering maintenance needs, there are limits to how much size and weight improvements can be made. Additionally, manufacturing and disposal challenges would persist, even if at somewhat reduced levels.

A more sustainable solution, however, is energy harvesting, which involves converting energy from a device's immediate surroundings—such as light, heat, or movement—into electrical power. Unlike batteries, which store chemical energy, energy harvesting relies on environmental energy, making the source virtually limitless. The only environmental impact comes from the one-time production of the energy harvesting device itself. For more details on the various methods of energy harvesting, you can read our whitepaper, *Breaking the Battery Barrier*.

IoT power proven to lower your carbon footprint

Our own solution to the battery problem uses photovoltaic panels to provide everlasting power to IoT devices. They're specifically optimised to harvest power from indoor lighting but work well in other light conditions too.

Our off-the-shelf 4EverTrack sensor device is powered by an incredibly efficient PV panel that operates even in poorly lit indoor environments. This device was assessed according to ISO14067 by Circular Ecology to establish its carbon footprint over 25 years, which was compared to the same device powered by an AAA battery and a CR2032 coin battery.

Over the 25-year study period, the PV panel's carbon footprint was 0.07 kg CO2e[11]. In comparison, the AAA battery on a 2-year replacement cycle had a carbon footprint of 1.17 kg CO2e and the CR2032 battery on a 1-year replacement cycle had a footprint of 1.02 kg CO2e. This means that the PV power source reduces carbon footprint by 94% compared to an AAA battery replaced every two years.

At the device level, our 4Evertrack sensor, powered by PV had a carbon footprint of 0.87 kg CO2e, half that when powered by a CR2032 battery, and 45% that when powered by an AAA battery (*see table on page 8*).

This is a measure of the entire device lifecycle, including raw materials (which made up most of the total carbon footprint) and transportation.

These differences between total energy from battery and PV power over a lifetime are largely due to two factors. Firstly, this replacement cycle results in many batteries being used over the 25-year lifetime, which significantly increases the contribution of the battery raw materials and disposal to the overall carbon footprint.

Secondly, the battery-powered devices require maintenance for the replacement of the batteries. (In the base case used for the study, it was assumed a maintenance worker travels 10 km in a diesel van to the job site. It is also assumed that it takes 2.5 minutes per comparison device to change the batteries. This is of course, likely to vary significantly on a case-by-case basis.)

11 Carbon dioxide equivalent or CO2e means the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas

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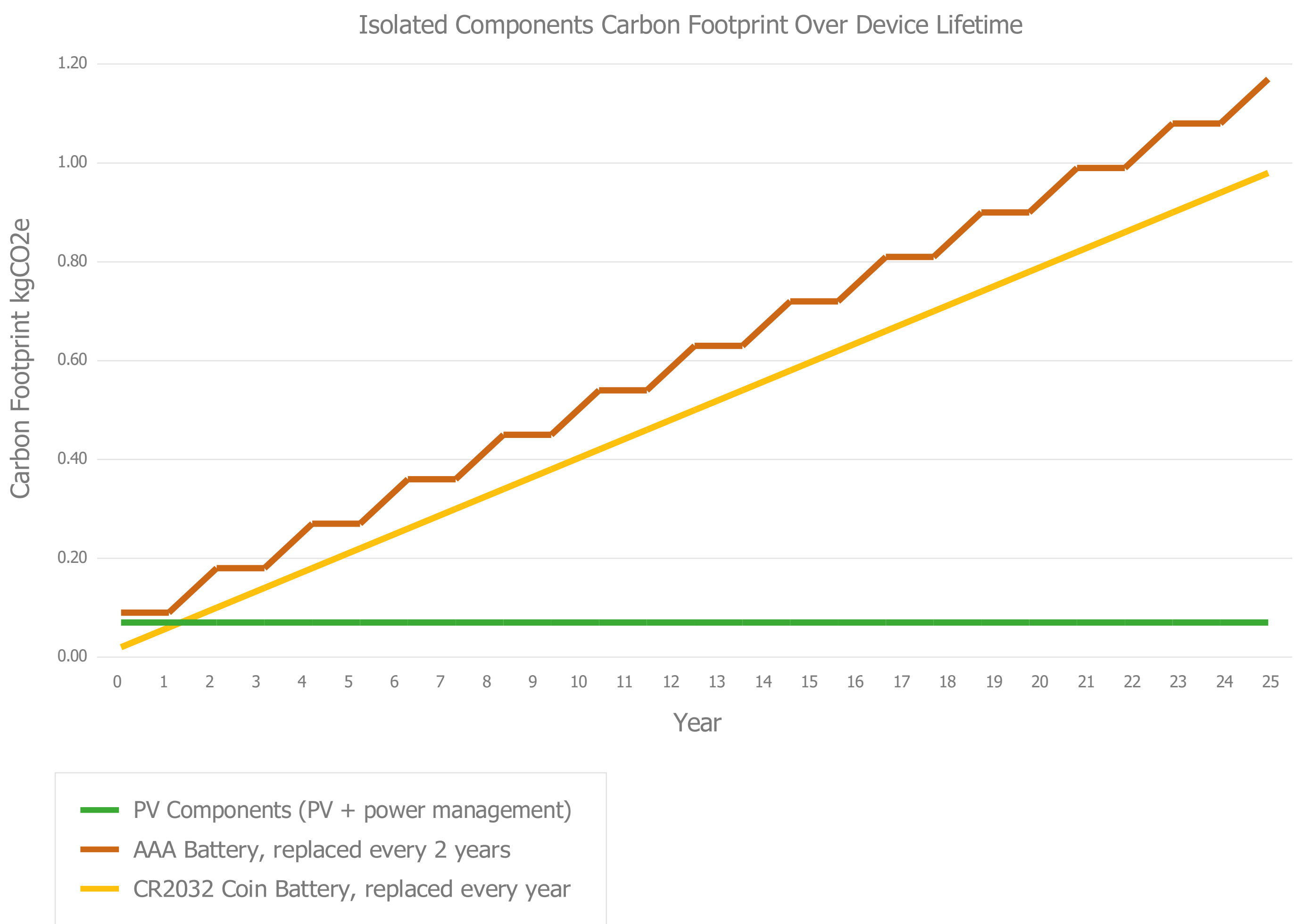
4Evertrack PV sensor carbon saving – a comparison of power sources for an IoT device over 25 years

	4Evertrack sensor (PV power)	AAA device (2-year battery replacements)	CR2032 (1-year battery replacements)
Total kg CO2e	**0.87**	**1.92**	**1.73**
Carbon footprint increase (compared to PV cell)	**–**	**121%**	**99%**

On the other hand, our light harvesting sensors are produced once and used for the device lifetime (and possibly beyond) with no replacements, disposal or maintenance costs between installation and the device's end of life.

An illustration of the comparative carbon footprints over time of the PV panel, AAA battery, and CR2032 battery is shown below. It demonstrates that the carbon footprint of an indoor PV-powered device is significantly lower than that of an equivalent battery-powered device even for shorter product lifetimes of 5-10 years.

In a 1,000 device deployment, with a battery change every two years, using PV power would save 500 batteries – and all their associated environmental costs – every year.



Lightricity PV technology

Our technology is the world's most efficient indoor PV technology (though it works outdoors too). It converts indoor light sources to energy with over 30% efficiency – a more than six-fold improvement on conventional PV, as validated by the UK's National Physical Laboratory.

A panel the size of your fingertip will power your IoT device forever. Even in extremely low indoor light. Our technology can be sealed in the device and operate at temperatures from -40 to +200 degrees, opening possibilities to power devices not previously thought possible with indoor IoT.

We offer two solutions. For those designing new connected devices, our customisable PV panels can be integrated into any low-power IoT device as an alternative to batteries. For IoT systems integrators, we offer off-the-shelf, easy-to-integrate, PV-powered sensors for many common measurement and tracking applications.

Want to know how light harvesting can reduce your products' carbon footprint? Get in touch today to find out more.

+44 1865 747711

info@lightricity.co.uk

+44 1865 747711
info@lightricity.co.uk