Exploring the Potential of Ambient Internet-of-Things as a Novel Tool for Carbon Management

A report by

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Title:	Exploring the Potential of Ambient Internet-of-Things as a Novel Tool for Carbon Management
Version:	1.1
Status:	Final
Dated:	29 January, 2025
Reviewed by:	Mike Berners-Lee

Document Details

Reference:	SWC Wiliot Thought Piece .docx
No of pages:	14

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1. Introduction

Despite increasingly widespread and ambitious efforts to manage greenhouse gas emissions, they continue to rise, making action in the climate crisis more urgent than ever. Governments are signing treaties and ratifying reduction targets into law, some individuals are altering their lifestyles to manage personal carbon footprints, and more businesses are reporting annual emissions and setting targets.

The first step in tackling the problem is measuring emissions, a relatively new area of expertise. Carbon footprints are calculated through a wide variety of different, non-standardised methodologies, relying on generic emissions factors that are often based on historical averages or Life Cycle Assessments (LCAs) with limited sample sizes and scope. While 'hotspot' areas can be successfully identified, this does not always lead to meaningful carbon reduction strategies from governments and businesses. The inability to verify exact carbon reductions, accurately track progress and communicate efforts clearly can cause governments and businesses to hesitate when investing in ambitious carbon reduction activities.

There is a question as to whether a higher level of accuracy across carbon accounting of goods and services could accelerate action. For example, knowing the precise journey individual products take from production to consumption (including real-time data on transport mode, speed, weather conditions, and storage times) could aid our understanding of potential reduction opportunities. Additionally, as our climate changes around us, an increasing amount of variables might need to be accounted for. For example, the impacts of changing weather conditions on the transportation of goods. Is travelling through a major storm worse for a load of bananas (through bruising), is heat and humidity more significant, or does it all come down to speed? What is the trade-off between the carbon cost of food waste of slower transport compared to the reduction in transport emissions? These data insights could allow optimisation of supply chains for carbon efficiency and cost and empower businesses to make more informed decisions about their environmental impact.

Wiliot is a technology company pioneering Ambient Internet-of-Things (IoT). Its 'IoT Pixels' are mass-producible, cheap, postage stamp-sized devices that allow real-time monitoring of location, temperature, light, and humidity. They are battery-free, harvesting power from radio waves, and transmit data by Bluetooth Low Energy to a nearby receiver or mobile device, automatically uploading to Wiliot's cloud, their Ambient Intelligence Platform. Wiliot has contracted Small World Consulting to produce this thought-piece on the potential role that its technology could play in tackling the climate crisis. While Wiliot have provided input, the opinions in this thought-piece are those of Small World Consulting, and the discussion is broadly applicable to any Ambient IoT technology.

In this article, we explore how the nascent technology of Ambient Internet-of-Things (IoT) could enhance carbon accounting and lead to efficiency improvements through real-time, item-level analysis. However, when evaluating the potential of such a technology we must not only establish that it can be deployed for good purposes, but also that it will not be deployed in a harmful way. Hence, we also consider risks that the same technology could reinforce harmful business-as-usual practices and increase net carbon emissions, while also addressing ethical risks related to data privacy.

2. The current state of carbon accounting

Carbon accounting estimates the greenhouse gas emissions associated with activities, products, or organisations. Producing a carbon footprint allows the identification and monitoring of the most effective carbon reduction actions. It has underpinned many climate actions, providing governments, businesses and individuals with estimates of the relative impact of different actions, from the identification of electric vehicles as lower-carbon than combustion alternatives, through to guiding low-carbon diets. Ambient IoT has the potential to be a useful tool for carbon accounting, but first, we should consider the current state of carbon accounting and its limitations.

Carbon accounting limitations

While carbon footprint figures are widely utilised, today's organisational carbon accounting and product life cycle assessments (LCAs) are fragmented, inconsistent, and can fail to capture the level of granularity required for precise, meaningful action on climate change. The current landscape resembles a "Wild West" with widely varied standards, methodologies, and reporting practices in a largely unregulated space.

Additionally, diverse methodologies, generalisations in data, and outdated information limit precision and comparability. Average emissions factors overlook geographical, temporal, and industry-specific differences. For example, food emissions factors typically use an average of farming practices, country-of-origin, seasonal variability, and transport scenarios. This means that the end numbers cannot reflect product-level variability, hiding potential improvements and quick wins for those responsible. In addition, the resource-intensive, typically annual basis of organisational carbon accounting, or even lower frequency for LCAs, results in delayed feedback that hinders timely action.

Carbon accounting is a balance between producing data of sufficient quality to allow successful carbon management, and the resource requirement to achieve further improvements in accuracy. All carbon footprints are estimates, and given that carbon accounting is essentially a means to an end – enabling, rather than achieving carbon reductions – improvements are only valuable as long as they enable meaningful actions that would otherwise remain hidden.

Carbon accounting best-practice

While there are challenges with how greenhouse gas emissions are estimated in both product LCAs and organisational footprints, by following best practice carbon can be effectively managed.

Carbon accounting, whether of products, processes or organisations, should:

Include everything – avoid exclusions wherever possible. Organisational carbon footprints should always include Scope 1, Scope 2 and Scope 3 emissions.

Be transparent – methodology, data sources, assumptions, and uncertainties should be clearly documented and shared so others can fully understand and trust the data.

Be suitably specific – specific enough to facilitate successful carbon management – more specificity opens up a wider range of actions that are specific to the context of an organisation or product.

Allow cross-compatibility – using comparable methods allows companies to use each other's results in their own carbon accounting, allowing greater specificity to real supply chains. For LCAs, this means adopting standardised frameworks and datasets to ensure consistency and comparability across studies.

Any new tools for carbon accounting should meet these best practice requirements and, where possible, address existing limitations. The key question is whether Ambient IoT can achieve this and enable carbon reductions that are otherwise hidden.

3. Ambient IoT as a carbon accounting tool

Ambient IoT technologies have potential to provide a step-change in the specificity of product carbon footprinting. They enable real-time item-level product carbon footprint estimates for transportation emissions through the data they collect and can increase specificity for other lifecycle stages through data shared to them.

The size, portability, and capacity of Ambient IoT devices to transmit their location enables a higher degree of accuracy when estimating carbon footprints of travel, down to the individual product. With location data incoming at frequent, regular intervals, accurate measurement of distance, speed and acceleration can be received by a gateway where additional factors can be applied e.g. the type of vehicle and its fuel efficiency. The number of IoT Pixels in each vehicle can also be communicated, to allow allocation of the vehicle's emissions amongst the units within it. External variables, such as weather, can be applied and the process as a whole could also be used to analyse other transport types (sea and air).

Additionally, Ambient IoT tags could be used to collect and record additional data that is shared with them. A tag attached to a tray of fruit, for example, could be supplied with carbon footprint data specific to the farm it was grown on. This data could be relayed to supply chain partners downstream, or combined with the carbon data for the rest of the lifecycle to give a product-specific carbon footprint. Likewise, a supplier-specific LCA for aluminium about to be used in a car component, shared to a tag in the shipment, could allow the carmaker to refine its whole vehicle carbon estimates. This additional data would be subject to the limitations of normal LCAs (as discussed in section 2), and introduce additional challenges of allocating emissions from things like losses, however, it still has potential to improve product specificity compared to industry averages. Wiliot could also use this as an opportunity to demonstrate leadership in this area by facilitating LCA standardisation.

Applications of real-time item-specific carbon accounting

Building on the benefits of data exchange, Ambient IoT could help further initiatives such as digital product passports by facilitating data exchange up and down the supply chain, leading to a level of transparency previously unattainable. For consumers, this could manifest as product-level carbon footprint information available at the point of sale, detailing the environmental journey of the product from conception to shelf. While carbon labelling has shown mixed results in influencing consumer behaviour, sometimes having greater influence through stimulating retailer action[1], there is more exploring to do in this area regarding the benefits of education and influence.

Another real-world application of item-level data could be carbon pricing, where the cost of products reflects their environmental cost. For instance, a carbon price could be applied to food items, accounting for whether it was transported via low-carbon shipping or grown locally using energy-intensive methods like hothouses. Such granular data could refine what is currently possible, moving beyond other blanket solutions like seasonal price adjustments.

Moreover, real-time data collection could allow businesses to establish, evaluate and refine their decarbonisation actions more effectively, making course corrections without waiting for annual reviews, and testing different approaches, with real-time results. Employees could be provided with data on the carbon impacts of their day-to-day decisions, and empowered with data on the positive impact changes they make could have. It could also enable more corporate transparency and accountability, as companies could substantiate their sustainability claims with verifiable data from their own operations. This could act as a powerful deterrent to greenwashing, an increasingly pressing issue as businesses face scrutiny over exaggerated environmental claims. By providing a clear, evidence-based picture of emissions reductions, companies could build trust with stakeholders while fostering greater accountability.

Ultimately, if applied widely, the specificity and accessibility of Ambient IoT-generated carbon footprint data could normalise the integration of carbon considerations into decisions at every level, fostering transparency and accountability. By making carbon data as ubiquitous and actionable as financial data, it has the potential to shift mindsets and priorities across industries. We discuss two use cases in more detail in sections 7 and 8.

4. Wider sustainability opportunities

The primary purpose of ambient IoT in industry is to improve efficiency and visibility in supply chains. This presents opportunities to also achieve sustainability improvements, even if they are not the primary objective. It is worth noting, however, that when the sustainability improvement is not the primary objective, there is a risk of negative impacts when pursuing other objectives.

Supply chain efficiency

Efficiency improvements in supply chains have potential to reduce emissions by reducing wastage, whether of energy or products. Ambient IoT-equipped supply chains will increase the visibility of inefficiencies; the real-time nature of the data collection on where products are located, and their conditions, can allow out of control processes to be rapidly resolved; and the data generated has the potential to identify improvements that are not otherwise apparent.

The specific monitoring of temperature and humidity that Wiliot IoT Pixels can provide has particular applicability to reducing wastage in perishable goods supply chains. Food waste is

[1] Taufique, K.M., Nielsen, K.S., Dietz, T., Shwom, R., Stern, P.C. and Vandenbergh, M.P., 2022. Revisiting the promise of carbon labelling. Nature Climate Change, 12(2), pp.132-140.

responsible for around 15% of global food system emissions[2], with poor storage and transportation conditions a contributing factor. Real-time monitoring can reveal when and where food spoilage is being accelerated by suboptimal conditions, allowing targeted interventions to improve them. For example, if a food crate has been unintentionally left out of refrigeration, there could be real-time feedback to staff, to avert the issue immediately, and the data could reveal longer-term trends that resolve the core of the issue. However, a potential unintended consequence of this could be *increased* food waste when items that could still be consumed, perhaps with a shorter shelf-life, are discarded if the monitoring data fails a threshold that has been set. This points to how important the accompanying data and assumptions are that must be combined with Ambient IoT data to maximise the positive sustainability impacts while minimising negative impacts.

Initial indications from Wiliot's industry applications have revealed considerable inefficiencies that can be addressed, particularly in industries where previous data collection was manual, or even paper-based.

While efficiency improvements have potential to reduce emissions, they do not guarantee them, particularly when rebound effects are considered i.e. The Jevons Paradox[*]. Hence, sustainability objectives must be set alongside efficiency objectives from a pure cost perspective, to ensure the sustainability opportunity is realised.

Specific applications

Further specific applications of Ambient IoT in industry can facilitate positive impacts beyond efficiency improvements, on a case-by-case basis. Positive health impacts can come, for example, from using tags to monitor vaccine vial cold chain adherence on delivery to remote locations, particularly in developing countries. Circular economy improvements could be achieved by labelling how specific products should be disposed of, tracking whether their disposal is appropriate, and using this data to inform actions.

5. Limitations to the sustainability opportunity

While Ambient IoT holds promise as a carbon accounting tool, for improving supply chain efficiency, and in advancing supply chain transparency and accountability, several limitations may prevent it from realising its full potential for sustainability, unless managed appropriately.

Device impact

Ambient IoT devices come with their own direct and indirect environmental impacts. While the low weight and cost suggest a minimal impact per device, the cumulative environmental impact could be significant, particularly given projections of an addressable market for 10 trillion Ambient IoT devices[3]. Consequently, manufacture, disposal and circularity need to be

[2] Scherhaufer, S., Moates, G., Hartikainen, H., Waldron, K. and Obersteiner, G., 2018. Environmental impacts of food waste in Europe. *Waste management*, *77*, pp.98-113.

[*] The 'Jevons Paradox' describes where the reduced cost after an efficiency improvement leads to an even greater proportionate increase in total demand, with the result that resource requirement goes up rather than down.

[3] 2023 Bluetooth® Market Update (2023): https://www.bluetooth.com/2023-market-update/

considered to mitigate problems stemming from electronic waste. The more indirect impacts of the devices should also be considered, for example, whether the tags hinder the recyclability of the products they are adhered to.

Beyond the impact of the devices themselves, there is also the underlying network of receivers, processors, and data centres, each with its own carbon footprint and energy demands. Any large-scale rollout would need to ensure the environmental benefits of the technology significantly outweigh the impacts of the whole system.

Deployment in a growth-dependent system

Focusing solely on efficiency improvements within existing supply chains risks obscuring the larger issue: the need to fundamentally rethink and reduce what is produced and consumed. Tackling climate change effectively will require systemic changes in production and consumption patterns, not just optimisation of existing systems. Whilst this technology could enable the same amount of products to be produced and transported with less emissions, IoT-enabled efficiency gains, without a constraint on total impact, risk being part of the dynamics of growth in both outputs and environmental burdens.

The current business system prioritises profit over sustainability. If sustainability is only a co-benefit of a particular technology and it can be leveraged for other purposes, pressure from fiduciary duty to shareholders during any financial squeeze will mean the sustainability benefits are likely to be first to go. Ambient IoT is not inherently a sustainability focused technology, and its versatility means it could be used in other ways, potentially driving emissions higher if it shows, for example, that faster logistics increase profit, or reveals data that shows ways to encourage consumer overconsumption.

No technology is an island – it is developed and deployed within a broader socio-economic context. If the potential sustainability benefits from Ambient IoT devices are to be fully realised, the technology must be deployed alongside systemic social, legislative, and market changes which are required to ensure that actual reductions in carbon emissions occur as a result of the increase in data availability and traceability afforded by these devices. Without these supports, the transformative potential of Ambient IoT risks not achieving its true potential.

6. Ethical considerations

Beyond the environmental considerations, privacy concerns are among the most significant challenges associated with Ambient IoT and the Internet-of-Things more broadly. While a comprehensive analysis of privacy and cybersecurity lies beyond the scope of this report, this section highlights concerns that warrant further investigation and robust safeguards.

Currently, Wiliot Pixels are limited in their data collection capabilities, focusing on location, temperature, and humidity, and requiring dedicated infrastructure for energising. The Bluetooth data can be received by dedicated Wiliot bridges, or by smartphones using the Wiliot app or Software Developer Kit (SDK). However, future advancements could theoretically expand these capabilities. For example, if IoT sensors were energised by/in communication with existing infrastructure like WiFi routers or smartphones, they could enable tracking outside of their intended application e.g. of individuals without their consent, raising potential surveillance and privacy concerns.

The tagging of consumer products with Ambient IoT devices also has the potential to produce a large amount of data about consumers and their habits, which could extend to behaviour after the point of sale if energising by existing infrastructure is developed. Consumers should be made aware of any data collection that could occur, with opt-in requirements as required by GDPR.

It is important to acknowledge that technologies far more invasive than Ambient IoT already exist and are subject to strict regulation. The same principles of safeguarding privacy and preventing misuse – whether through hacking, inappropriate data access, or covert tracking – must be applied to Ambient IoT as they are to existing digital tools. Proactive measures, including robust regulatory frameworks and ethical design practices, need to ensure the technology is used responsibly and solely for its intended purposes.

7. Ambient IoT in practice with Royal Mail

The first full-scale deployment of Ambient IoT in the UK has taken place with Royal Mail[4]. Each of the Royal Mail's 900,000 wheeled cages that hold parcels and letters in its distribution centres and HGV trunking transport network have been tagged with Wiliot IoT Pixels. HGVs and sites have been fitted with units that energise the IoT Pixels and receive their Bluetooth data. This generates a substantial amount of data on the transportation and sorting of mail, allowing the company to optimise operations and address issues faster. Royal Mail hope that the technology will help them progress towards their Net Zero by 2040 target, given that road transport is responsible for 63% of their Scope 1, 2 and 3 emissions (and HGV trunking represents the largest proportion of this)[5].

The data collected allows an improvement in the specificity of mail carbon footprint monitoring compared to conventional methods. Output from the IoT Pixels collates accurate journey distances and vehicle type, loading, routing and speed. The latter has potential to improve the estimates of fuel consumption compared to the usual 'consumption per mile' approach that doesn't consider speed or conditions. A vehicle at 60mph uses more fuel per mile than at 55mph, and a vehicle heavily braking and accelerating uses more fuel than one anticipating the road ahead and braking less. Weather data could be applied to show where headwinds or low temperatures increase fuel consumption, further enhancing the carbon calculation.

Additionally, vehicle loading data allows emissions to be allocated per cage or emissions per piece of mail inferred. This improved carbon footprint estimation could be reported internally for optimisation, and reported externally to show the emissions associated with different options for customers, such as slower postage which may result in less emissions if more efficient modes of transport can be utilised.

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[4] Wiliot, 2024. Royal Mail becomes world's first delivery company to use tech innovator Wiliot's digital tags to boost efficiency and cut carbon: https://www.wiliot.com/royal-mail-becomes-worlds-first-delivery-company-to-use-tech-innovator-wiliots-digital-tags-to-boost-efficiency-and-cut-carbon
[5] Royal Mail, 2024. Powered by Posties – ESG Report: https://www.royalmail.com/sites/royalmail.com/files/2024-06/Royal_Mail_ESG_Report_2023-24.pdf

Overall, the large amount of data produced has the potential to expose areas for efficiency improvements which might not otherwise be visible when working with annual, or even weekly, averages for fleet emissions. Opportunities may exist through changes to routing, vehicle speed, vehicle loading or other logistics optimisation. Many of these opportunities will also come with cost savings.

Royal Mail already uses vehicle telemetry technology on an individual vehicle level, which records data on actual vehicle fuel use and provides feedback to drivers[6]. This data could be used to calculate carbon emissions from exact fuel usage, representing a level of accuracy Wiliot's technology cannot reach alone. However, it does not allow allocation to individual mail or consideration of loading. If the telemetry fuel consumption data were to be combined with the data from the Wiliot devices, this would allow a further improvement in accuracy *and* specificity.

In joining forces, Wiliot is able to assist Royal Mail in improved tracking of its mail and carbon emissions, highlighting gaps for efficiency improvements. Royal Mail could also expand the use of IoT Pixels to other branches of its operations (air freight and last mile deliveries), covering a greater proportion of its emissions. The IoT Pixels coverage could also be expanded to every piece of mail, rather than every cage, allowing even more specific data, but an evaluation of whether the benefits of this additional level of granularity will justify the additional environmental impact of IoT Pixels production and operation is recommended, as discussed in section 5.

8. Potential applications in the food system

Ambient IoT tags provide a clear opportunity for transport emissions quantification and optimisation, and monitoring the conditions (temperature and humidity) surrounding a product. As such, the technology could be of particular interest for the food system – where transport contributes to emissions, and conditions can influence wastage. While the emissions from 'food miles' are often over-estimated[7], they are responsible for around 5-10% of food system emissions, and for some foodstuffs, they are a more significant contributor. Likewise, wastage is responsible for 15%[8] of food system emissions. It is also the case that there can be a trade-off between the two, with higher carbon transport sometimes reducing wastage (refrigerated vehicles, or faster freighting).

To illustrate the application of Ambient IoT in this industry we look to consumption habits of asparagus, a crop with demand all year round in Britain, despite only being seasonal locally between May and June. For the rest of the year the crop is imported, primarily from Peru by air freight. The air freight of an average product is around 10 times higher emissions than moving it by road and 70 times worse than shipping. Average carbon footprint values could already be enough to inform consumers that their asparagus are a high carbon purchase, and that eating seasonal vegetables instead will be a lower carbon option, however demand remains.

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[6] Transport+Energy, 2021. Royal Mail adds emissions-efficiency tech to vans: https://transportandenergy.com/2021/02/18/royal-mail-adds-emissions-efficiency-tech-to-vans/
[7] Ritchie, 2020. "You want to reduce the carbon footprint of your food? Focus on what you eat, not whether your food is local": https://ourworldindata.org/food-choice-vs-eating-local
[8] Poore, J. and Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science, 360(6392), pp.987-992.

However, with the data from Wiliot IoT Pixels, more insight could be achieved. Like the Royal Mail case study, data for shipping and air freight could be collated, albeit with a slight change in technology[*]. The data, combined with aircraft and ship records, would allow the exact plane or ship to be identified, and its efficiency to be considered in the carbon footprint calculation. Data on weather conditions such as wind direction can also be added.

An additional level of data could be added for air freighted goods, to reflect the complicated, but significant issue of non-CO_2 emissions. For jet-powered aircraft, over half of the global warming impact over 20 years comes from non-CO_2 warming from contrails[9], however this effect is highly variable in different atmospheric conditions, geographies and times of day[*]. Combining Wiliot's data with models that quantify contrail formation of specific flights could allow these emissions differences to be quantified and reflected in a product carbon footprint. Making these emissions visible to retailers and consumers could add pressure to the aviation industry to investigate and instigate contrail management.

It is difficult to predict the exact impact that improved carbon footprint calculations might have on retailer and consumer behaviour. However, providing live transparency on the environmental impact of food products, particularly for high carbon items such as meat products and out of season imports, could shift perceptions of global food systems and encourage greater advocacy for sustainable practices. In an increasingly climate-aware society, such transparency could empower both consumers and companies to elevate their climate ambitions and address issues that were previously considered too uncertain or lacking sufficient data to tackle effectively. These granular insights enabled by Ambient IoT could, with the right deployment, play a role in reshaping purchasing norms and driving structural changes across supply chains.

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[*] data reported from the Pixels would need to be stored and uploaded to the Cloud only once back within network coverage

[9] Lee, D.S., Fahey, D.W., Skowron, A., Allen, M.R., Burkhardt, U., Chen, Q., Doherty, S.J., Freeman, S., Forster, P.M., Fuglestvedt, J. and Gettelman, A., 2021. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric environment*, *244*, p.117834.

[*] Contrail induced warming results from the blanketing effect of contrail cirrus clouds in the atmosphere. These are produced by a minority of flights that fly in the particular atmospheric conditions that result in persistent contrail formation. During daytime this warming effect is partly counteracted by the increased reflectivity of contrail cirrus clouds reflecting incoming solar radiation, having a cooling effect. This cooling effect is most notable over dark surfaces such as the ocean. The effect is that a flight that generates contrails at night, or over land/ice, will have a far greater non-CO_2 warming effect than one that doesn't generate contrails or does so in daytime over the ocean. You can learn more about measures to manage contrail induced warming here.

9. What is needed next

As we continue to innovate in our response to the climate crisis, Ambient IoT presents an opportunity to refine how we track and manage carbon emissions. It offers a step-change in the specificity of carbon footprints by following individual products in real time. This real-time, item-specific carbon footprinting can reveal efficiency improvements that are otherwise hidden by averaging, and allow communication of product footprints with improved specificity, with opportunities ranging from influencing consumer purchasing to informing carbon pricing. With careful application, the technology could help drive the systemic changes needed to drastically reduce emissions on a global scale.

However, it is crucial to balance these technological advancements with ethical considerations, ensuring that IoT is deployed responsibly and transparently. Part of this responsibility involves assessing the carbon footprint of the technology itself – can we demonstrate that the emissions generated by deploying Ambient IoT are outweighed by the additional reductions it can unlock?

Another key element is establishing robust industry standards and legislation. The current state of LCAs illustrates the problems that arise when tools are used without universal rules – lack of consistency and transparency leads to inconsistency and undermines the effectiveness of carbon management. As Ambient IoT establishes its role in carbon accounting, there is a unique opportunity to address these gaps and create a framework that improves on the issues present in today's ‘wild west’ of carbon accounting.

To contribute meaningfully to tackling climate change, IoT must be integrated thoughtfully into a systemic approach that includes changes to our institutions, provisioning systems, and social structures. Technology alone, no matter how innovative or well-intentioned its applications, cannot overcome the wider forces of current business models that often push against meaningful climate action. Its deployment must be guided by deliberate policies and practices that prioritise sustainability, ensuring that its benefits align with the urgent need for systemic transformation.

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