Green and Smart?

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While green and smart technologies are essential for reducing emissions, their sustainability depends on optimizing their life cycle, particularly in material sourcing, recycling, and waste management. The blog examines their life-cycle impact and highlights the urgent need for sustainable practices at every stage—from extraction to disposal—to ensure they truly contribute to a low-carbon sustainable development.

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Renewable energy sources such as solar, wind, and hydropower are essential for reducing global carbon emissions by replacing fossil fuel-based energy generation. According to the International Renewable Energy Agency ((IRENA), 2020), the large-scale deployment of renewable energy, combined with energy efficiency improvements, has the potential to reduce energy-related CO2 emissions by 70% by 2050. This would take us a long way toward fulfilling the Paris Agreement, though further efforts across other sectors will still be necessary to fully achieve the agreement's goals. The widespread adoption of electric vehicles and the electrification of public transport and heavy-duty vehicles are also critical components of the energy transition, as they significantly reduce emissions from one of the largest sources of global carbon pollution transportation. Additionally, IT technologies — especially smart grids and digitalization — are crucial for optimizing energy systems. These technologies enhance the integration of renewable energy sources and the efficient use of energy storage, which are essential for overcoming the intermittent nature of solar and wind power. Moreover, smart technologies improve energy efficiency in buildings and industries, help manage resources like water and energy more efficiently by reducing waste and overuse, and enable smarter, low-emission transportation solutions. Together, these advancements play a significant role in reducing overall emissions across various sectors. While green and smart technologies hold great promise for mitigating climate change, a critical aspect often overlooked is their environmental impact throughout their entire life cycle—from raw material extraction to disposal. This raises an important question: Are *"green"* and *"smart"* truly as green as they seem?

The Life-Cycle Dilemma of Green and Smart Technologies

While there is not a single definition of green technologies, many definitions from organizations like the OECD, IPCC, and UNFCCC emphasize their role in climate change adaptation and mitigation. However, the life-cycle approach is becoming increasingly important in defining what it means to be green. Under this approach, a product must minimize its environmental impact at every stage — from raw material extraction to production, use, and disposal or recycling — ensuring that its overall environmental footprint remains as small as possible. Indeed, many technologies may seem green based on their use (e.g., solar panels or electric cars). Still, the environmental cost of raw material extraction, manufacturing, and end-of-life disposal can offset some of their benefits. For example, while solar panels produce clean energy, the extraction of silicon and rare earth metals, along with the challenges of recycling them, creates a significant environmental burden. Similarly, battery production for electric vehicles requires mining lithium and cobalt, which can deplete water resources, damage ecosystems, and expose local communities to environmental contamination (Sovacool et al., 2020).

Smart technologies designed to improve efficiency also contribute to the growing problem of e-waste due to their short lifespans. For example, smartphones typically last 2 to 3 years, while laptops, tablets, and smart home devices generally last around 3 to 5 years. These devices are often replaced due to battery degradation, lack of software updates, or the release of newer models (Aboughaly & Gabbar, 2020).

According to the Global E-waste Monitor (Baldé et al., 2024), the world generated 62 million metric tons of e-waste in 2022, but only 22.3% of it was collected and recycled through official, regulated processes. This leaves a substantial environmental and health burden, as much of the remaining e-waste is handled in unregulated, informal sectors or sent to landfills.

The issue of e-waste is not only an environmental crisis but also a matter of environmental justice since a significant portion of the e-waste generated in developed countries is exported to developing nations, where regulations and infrastructure for safe disposal are often lacking. Approximately 5.1 million metric tons of e-waste are shipped annually to developing countries, with 3.3 million metric tons of it transported in an uncontrolled manner, often without proper oversight or compliance with environmental regulations (Baldé et al., 2022). However, since much of the global e-waste trade goes untracked or moves through illegal channels, these figures represent only the tip of the iceberg. This uncontrolled e-waste frequently ends up in informal recycling sectors, where unsafe methods such as burning or basic dismantling are used to recover valuable materials. These practices release harmful substances like lead and mercury into the environment, posing severe health risks to local communities. Children, in particular, are vulnerable to these toxins, which can lead to cognitive impairments, reduced IQ, and diminished educational and economic potential (WHO, 2021).

A major driver of this transboundary movement of e-waste is the high cost of metal treatment and extraction in developed countries, where strict environmental regulations make disposal expensive. Developing countries, with cheaper labor and weaker regulations, become economically attractive destinations for both legal and illegal e-waste exports, often lacking the infrastructure to safely manage hazardous waste (Ilankoon et al., 2018).

Beyond Quick Fixes: Rethinking Environmental Externalities for True Sustainability

One of the fundamental concepts in economics is ‘external effects’, or externalities, which occur when the production or consumption activities of one party affect the welfare of others. While externalities are often seen as exceptions or market failures, environmental externalities — due to the laws of mass and entropy — are the rule.

The Law of Conservation of Mass states that matter cannot be created or destroyed, only transformed, meaning every production process leaves behind waste or emissions in the form of byproducts or pollutants. The second law of thermodynamics explains that energy use inevitably leads to lost energy quality or entropy, often in the form of waste heat or pollution. Pollution is thus an unavoidable consequence of energy use and production (Huesemann, 2001).

As Sterner (1990) points out, environmental policies have historically been designed not to fully solve environmental problems but to transfer or delay them. These policies often result in shifting pollutants to other areas — either geographically or temporally — without addressing the root causes of pollution.

For example, in its 1974 Guidelines, the OECD recommended the use of tall chimneys to disperse sulfur dioxide emissions higher into the atmosphere, reducing local pollution. However, this approach merely transferred the problem to other regions, as pollutants traveled long distances and eventually returned as acid rain, damaging ecosystems hundreds of miles away (Sterner, 1990).

Similarly, several nations dumped radioactive and hazardous waste into the sea between the 1940s and 1970s, assuming deep ocean waters would act as a containment zone. Over time, however, corroding containers leaked, causing marine pollution. Although the full impact remains difficult to quantify, the persistence of these hazardous materials continues to raise concerns (Häder, 2021).

Another example is the pollution in the Arctic, where industrial activity has never occurred. Persistent organic pollutants, banned in developed countries, are still produced and exported to nations with weaker regulations. These pollutants return to the Arctic via air and ocean currents, accumulating in ecosystems and entering the food chain (Varotsos & Krapivin, 2018). Indigenous communities, reliant on marine diets, suffer from high levels of toxic substances, leading to health issues such as cancers, hormonal disruptions, and birth defects (Dudarev, 2012).

All these examples illustrate how environmental solutions often lead to unintended consequences. If we fail to address the root causes of pollution and resource depletion, we risk solving old problems while creating new environmental crises. Achieving true sustainability requires a holistic approach that tackles environmental externalities throughout the entire life cycle of goods—from production to disposal. Only by doing so can we develop policies and practices that fully mitigate the environmental consequences of consumption and production.

Can Green and Smart Technologies Truly Be Green?

For green and smart technologies to be genuinely sustainable, we must prioritize sustainable design, power them with renewable energy, source minerals responsibly through recycling or sustainable mining practices, and ensure effective recycling and waste management. If we fail to consider their entire life cycle, we risk shifting the environmental burden elsewhere rather than addressing it comprehensively.

While many circular economy policies emphasize sustainable design, material recovery, and recycling, their implementation remains incomplete. Several key areas require attention to close the loop entirely. First, investment in recycling infrastructure is critical for efficiently recovering materials like rare-earth elements (REEs) and electronic components. Globally, recycling rates for REEs remain below 1%, even though these materials are essential for high-tech products like electric vehicle batteries, wind turbines, and electronics (Jowitt et al., 2018). This is particularly concerning, given that recycled materials could account for more than half of the raw material demand for lithium-ion batteries by 2040 if proper systems are in place ((IEA), 2021).

Countries such as the EU and China have taken steps to hold manufacturers accountable for battery recycling through regulations like recycled content standards and extended producer responsibility. However, much of the world, including the United States, lags behind in such initiatives, leaving significant gaps in recycling infrastructure and enforcement (Dunn et al., 2022). Under the new EU Batteries Regulation, which will become enforceable starting in 2030, manufacturers must include a minimum percentage of recycled materials in new batteries. This regulation is designed to increase demand for recycled content, potentially creating stronger economic incentives for developing recycling technologies more rapidly.

Large tech and automotive companies have a significant role in driving sustainable mining practices. Some companies, like Tesla and Apple, have already established firm commitments through transparency initiatives or direct promises to improve their supply chains and reduce reliance on conflict minerals. For instance, Apple has pledged to use 100% recycled materials in its products, and Tesla has joined the Fair Cobalt Alliance to promote ethical sourcing. However, despite these positive steps, much must be done. Many industries still heavily rely on unsustainable mining practices, and efforts to improve transparency and enforce ethical standards must be scaled globally.

It is worth noticing that much like how certain raw materials (e.g., wood, coffee, or diamonds) require certification to prove they come from sustainable sources, there could be a system where recycled materials are verified through sustainable practices. This would require companies to trace the life cycle of recycled products and show proof of ethical, environmentally sound recycling processes. Consumers and manufacturers could opt for products that use materials recycled in sustainable facilities, incentivizing companies to improve their recycling methods.

By expanding recycling capacity and enforcing sustainable practices, we can significantly reduce the export of e-waste to developing countries, where it is often handled unsafely. In many of these countries, the informal sector plays a critical role in e-waste collection due to its well-established networks, making it more efficient than formal systems in gathering discarded electronics. However, the informal sector typically lacks proper safety protocols and environmental controls, leading to dangerous working conditions and environmental contamination. To address these challenges, formalizing the informal e-waste sector could create safer, more productive jobs while ensuring toxic substances are appropriately managed.

Countries like India and Ghana have already begun implementing programs supported by international organizations to improve the skills and practices of informal e-waste workers. In India, the government has introduced the *E-Waste Management Rules* to encourage safer recycling practices and formalize informal workers. Ghana has seen similar efforts through projects like Agbogbloshie, which trains informal recyclers in safer methods. These programs provide a foundation that could be expanded and scaled to other countries facing similar e-waste challenges.

Consumer behavior also plays a critical role in enhancing the sustainability of green and smart technologies. The frequent turnover of products like smartphones and smart devices accelerates the e-waste problem, contributing to unnecessary resource depletion and environmental harm. To mitigate this, consumers must be encouraged to make more sustainable choices by opting for longer-lasting, repairable products rather than frequently upgrading to newer models. This shift would not only reduce waste but also decrease the environmental impact associated with the production and disposal of these technologies.

Finally, a crucial area for improvement lies in creating incentives for manufacturers to design products that are easier to repair and recycle, ultimately extending their lifespan. Despite the high value of materials like rare-earth elements, recycling costs remain prohibitively high, even though economies of scale in recycling should reduce costs over time. This issue persists largely because products are designed for performance and cost efficiency rather than end-of-life recyclability. Many devices have tightly integrated components, making disassembly difficult, while small amounts of rare-earth elements are dispersed throughout, making them costly to recover.

Energy-intensive and complex recovery processes, often involving harsh chemicals, further drive-up recycling costs, making it more expensive than mining new materials. This creates a vicious cycle: recycling technologies remain underdeveloped because high costs deter investment, perpetuating the reliance on virgin materials and resulting in low production costs—at the expense of greater environmental damage. The practice of planned obsolescence exacerbates the problem, with manufacturers deliberately designing products with short lifespans to encourage frequent consumer upgrades, increasing both resource demand and e-waste generation.

To achieve sustainability, we must fundamentally rethink product design. Manufacturers should focus on modular designs that simplify disassembly and recycling, using standardized components that facilitate material recovery. Extended Producer Responsibility (EPR) programs must be redesigned to hold manufacturers accountable not only for the take-back and disposal of products but also for ensuring that their products are designed to be recyclable. This can be done through stricter mandates requiring the use of recyclable materials, setting minimum repairability and recyclability standards, and incentivizing manufacturers with tax breaks or penalties based on the recyclability of their products. Without these comprehensive changes, the sustainability promises of green and smart technologies will remain unfulfilled.

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