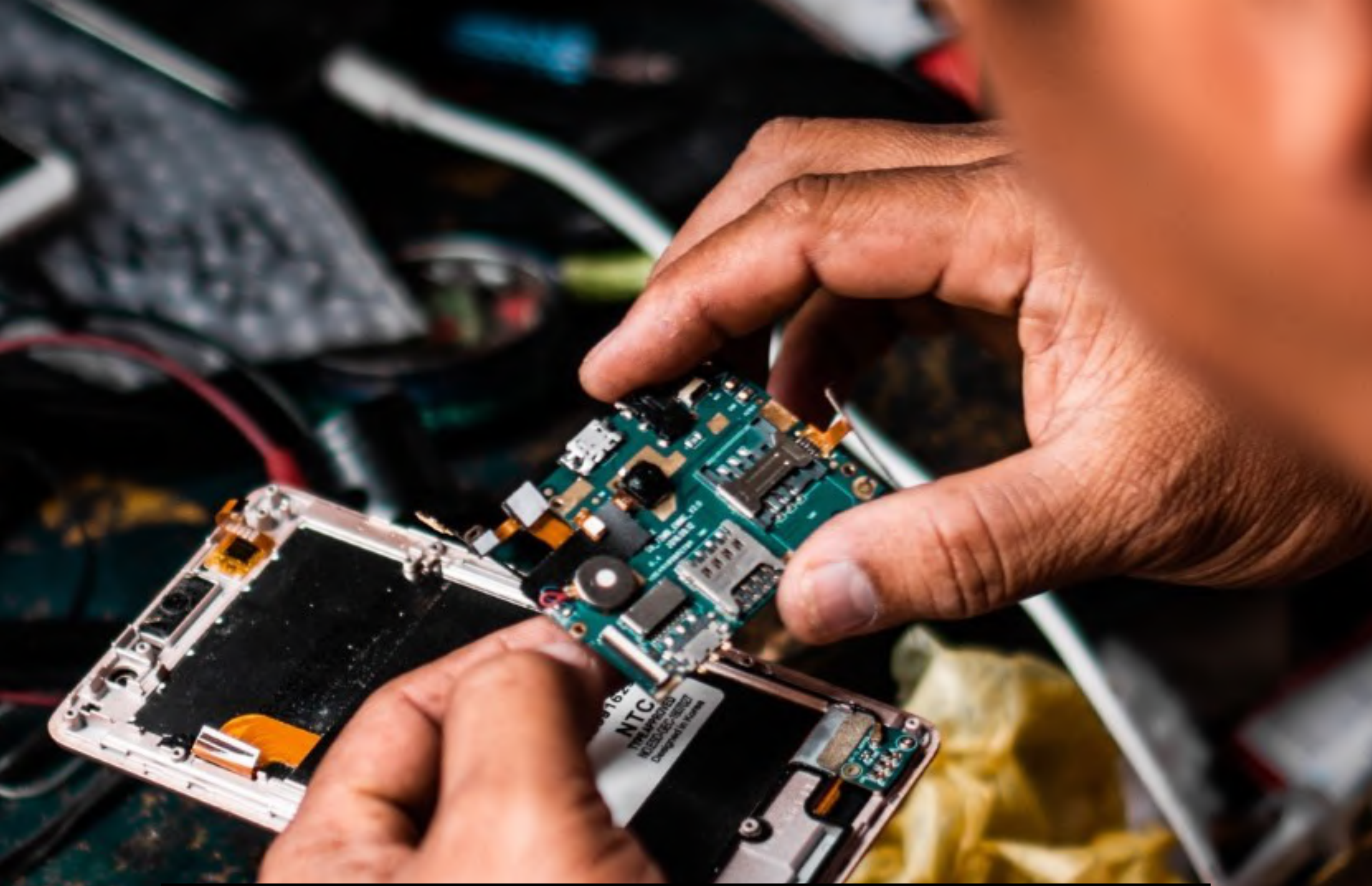

KATINKA BJØRNDAL THOMSEN & ANIKA SCHULTE

CIRCULAR SUPPLY CHAIN TRANSFORMATION:

CHALLENGES, OPPORTUNITIES, AND TRADE-OFFS FOR CIRCULAR SMARTPHONES AND COMPUTERS

REIMAGINING SUPPLY CHAINS INITIATIVE 2023

CBS DEPARTMENT OF OPERATIONS MANAGEMENT
COPENHAGEN BUSINESS SCHOOL

NORDAKADEMIE
HOCHSCHULE DER WIRTSCHAFT

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EXECUTIVE SUMMARY

Electronic devices have revolutionized the way we conduct business, connect with friends, and get around in our daily lives. However, they also contribute to one of the fastest-growing waste streams in the world: e-waste. In 2019, the world produced 53.6 Mt of e-waste out of which only 17.4% was recycled properly.[1] This calls for a reimagination of the business models and supply chains that sustain the consumption and production levels.

This report aims to take stock of the current state and future opportunities for circular smartphones and portable computers and highlight some of the sustainability tensions that may arise when moving toward circularity for these products.

By providing concrete examples but also societal reflections, the report intends to give decision-makers a better understanding of the challenges, opportunities, and risks related to IT procurement and circular supply chains for electronic devices.

In this report, the following findings are developed.

Linear supply chains generate more than 50 Mt of e-waste every year and induce premature replacement cycles of smartphones and portable computers

The rising consumption rates of electronic devices are not only contributing to the fastest-growing waste stream in the world but also accelerating the depletion of natural resources and fueling conflicts in areas with rare materials.

Extending the lifetime of smartphones and portable computers is thus one of the most important measures to reduce the environmental and social impact of the devices.

Yet, smartphones and portable computers are often replaced prematurely due to design strategies, changing consumer preferences, low consumer awareness, affordability, and linear supply chains with little or poor incentives to reuse, repair, and recycle electronic devices.

The relative obsolescence of these electronic devices suggests that everyone in the supply chain has an important role to play – from designers and producers to legislators, procurement departments, and users.

A circular systems approach for electronic devices requires effort and collaboration between all stakeholders in the supply chain

It is the system surrounding the product and not the product itself that determines its level of circularity. Multi-stakeholder collaboration and circular supply chains are thus pivotal for a successful transformation.

This report identifies six enablers along the supply chain that can help accelerate the transition toward a circular system for smartphones and portable computers:

[1] Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows, and Resources," 2020.

1. **Designing for circularity,** meaning that electronic devices should be built with recycled and recyclable materials as well as designed for modularity and longevity both in terms of repair, software updates, and aesthetics.

2. **Changing the narrative surrounding circular devices through consumer education,** meaning that current prejudices surrounding reused, refurbished, and remanufactured devices, as well as recycled materials, should be replaced by a desire to purchase devices from the circular economy.

3. **Steering market demand for circular devices through new purchasing practices**, meaning that private and public organizations should adopt procurement and supply chain policies that include criteria for circularity.

4. **Increasing collection rates and take-back systems,** meaning that used devices to a larger extent are brought back into the system thanks to reverse logistics and formal take-back contracts.

5. **Inducing circularity through regulatory measures**, such as product passports, a right to repair, and VAT reductions on repairs.

6. **Fostering collaboration across the supply chain to accelerate systemic and sustainable change**, meaning that all actors in the supply chain have a role to play when it comes to turning circular supply chains for electronic devices into reality.

The enablers demonstrate that all companies have a role to play in the transformation toward circular electronic devices. Moreover, by thinking in terms of circularity when purchasing, using, and discarding electronic devices, companies can save money while reducing their negative environmental and social impact.

In the report, we highlight different examples and develop how they can be implemented in practice.

No size fits all: If implemented poorly, the circular transformation may be to the detriment of environmental and social sustainability

Circularity and sustainability do not necessarily go hand-in-hand. If designed poorly, circular supply chains may indeed spur consumption levels through rebound effects and destroy millions of informal jobs in the recycling sector.

In addition, companies may face issues when reconciling their circular strategies with their short-term greenhouse gas (GHG) emission reduction targets.

The final section of this report addresses the potential sustainability tensions of a transformation toward circularity and encourages actors from across the supply chain to keep these considerations in mind when developing practices that address current barriers.

The report is structured into four sections, highlighting
1- the potential of circularity for electronic devices,
2- the current state of circular supply chains for smartphones and portable computers,
3- enablers that may accelerate the transformation, and
4- the sustainability tensions that may arise when moving toward circularity.

Photo by David Dvořáček on Unsplash

SCOPE

As the lifespan and life cycle GHG emissions of electronic devices vary greatly, this report focuses on the current state, barriers, and opportunities, as well as the sustainability tensions, related to a circular transformation of two types of electronic devices: smartphones and portable computers.

Smartphones:
Smartphones are devices that combine the functions of cell phones and handheld computers, allowing the user to make calls, connect to the Internet, take photos, and more from a single device.

Portable computers:
In this report, 'portable computers' refers to laptops and notebooks which may share input materials but vary in terms of functionality and size. As a rule of thumb, laptops tend to have bigger screens and be heavier as well as pricier than notebooks, which, on the other hand, tend to accentuate lightweight portability and sleek design.[2]

Following this, 'electronic devices' and 'devices' refer to these two products unless otherwise stated.

The report is based on nine expert interviews with practitioners and researchers from Northern Europe as well as a literature review of academic articles and industry reports.

The authors would thus like to thank Andreas Schjølin, Annika Overröder, Hannah Jung, Lars Steffensen, Leon von Zepelin, Maja Johannessen, Stephen Haskew, Tim McAloone, and Vasileios Rizos for their contribution to this report.

While the report mainly focuses on smartphones and portable computers in the European Union (EU), the findings may apply to similar contexts given the transboundary nature of the supply chains for these electronic devices.

Photo by Jonas Leupe on Unsplash

[2] Finley-Moise, "Laptop vs Notebook: What Is the Difference?," 2019.

INTRODUCTION

Rapid innovation cycles, increasingly complex products, and skyrocketing consumption levels have turned e-waste into one of the fastest-growing waste streams in the world. This calls for drastic change – one of them being a transformation toward circular business models and supply chains in the electronics sector.

The circular economy – an alternative to the take-make-dispose paradigm

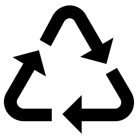
Circularity – or the circular economy – has become a buzzword, but also a core principle of sustainability transformations. For instance, the circular economy is one of the main pillars of the European Green Deal and a prerequisite for reaching the EU's net-zero greenhouse gas (GHG) emission target by 2050.[3]

At its core, the circular economy seeks to design out waste and opposes the linear take-make-dispose paradigm that dominates current modes of production and consumption. The circular economy has been defined in many ways,[4] but it is often associated with work from the Ellen MacArthur Foundation (EMF).

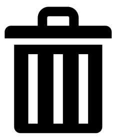
The EMF defines the circular economy as "an industrial economy that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models".[5]

Here, it is worthwhile to notice that the social aspects of the circular transformation are often neglected or only hinted at intrinsically. The final section of this report highlights the dilemmas and potential problems that may arise from this in the context of electronic devices.

The circular economy thus builds on three principles:



Keep products and materials in use at their highest value



Eliminate waste and pollution

Regenerate natural systems

[3] European Commission, "A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe," 2020.

[4] See, for instance, Geissdoerfer et al., "The Circular Economy – A New Sustainability Paradigm?," 2017; Kirchherr et al., "Conceptualizing the Circular Economy: An Analysis of 114 Definitions," 2017.

[5] Ellen MacArthur Foundation, "Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition," 2013, p. 7.

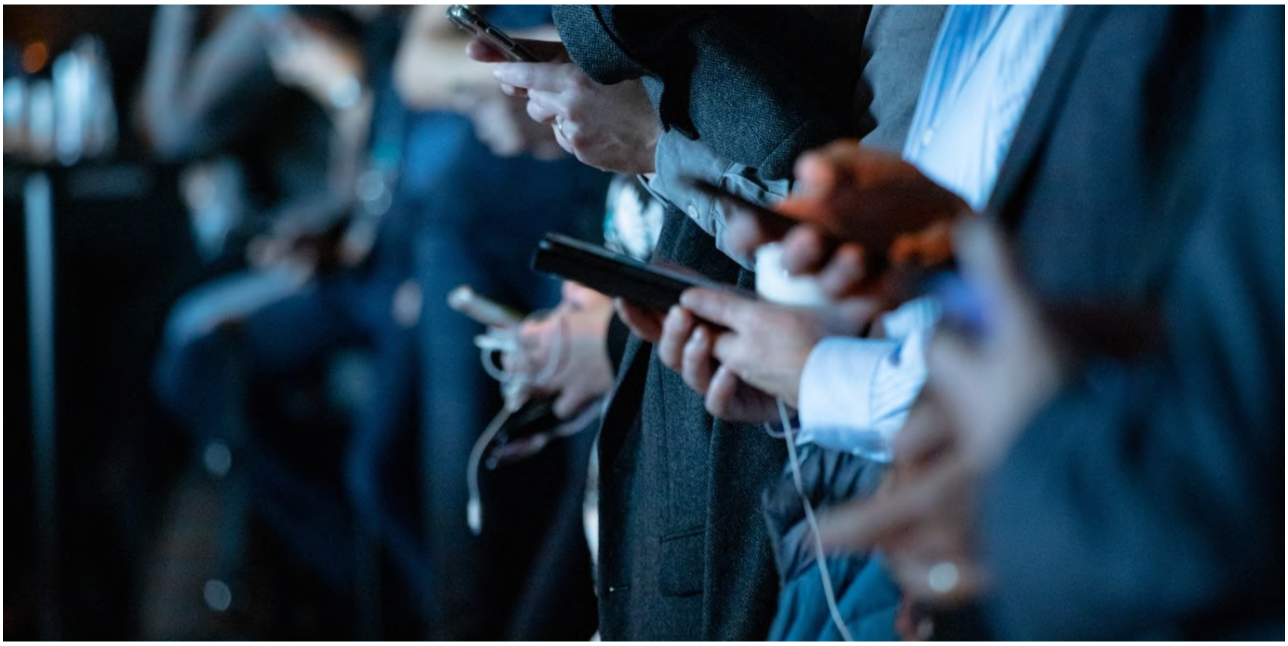


Photo by Camilo Jimenez on Unsplash

Development and Definition: Circular Economy

While the origin of the circular economy cannot be traced to a single author or point in time, it has increasingly received attention since the late 1970s. Since then, the concept has been developed by different schools of thought – including cradle-to-cradle, regenerative design, and performance economy.[6]

Today, the concept is commonly associated with the definition developed by the Ellen MacArthur Foundation: “A circular economy is an industrial economy that is restorative or regenerative by intention and design”.[7]

The aim and structure of the report

This report highlights the opportunities, but also potential problems related to a circular economy for electronic devices in a way that will make it easier for decision-makers – and citizens in a larger sense – to understand and navigate the circular transformation.

The intention of the report is thus to disseminate information about the current state and impact of current consumption and production modes, but also to share examples that can inspire companies to take more action.

Finally, the report seeks to highlight some of the unintended consequences that may arise if the transformation toward circularity is implemented without a holistic approach to sustainability.

The report is structured in the following way.

First, it is highlighted why portable computers and smartphones present a good use case for the circular economy and why the transformation matters.
Second, it is briefly outlined how the circular principles can be turned into practice on a general level. Third, the report takes stock of the current state of circularity in the context of portable computers and smartphones.

Fourth, six enablers that can help facilitate the transformation toward circularity are presented. By highlighting examples, the findings are related to the way companies of all sorts can participate in the circular transformation of electronic devices. Fifth, potential downsides that decision-makers must be aware of when developing circular strategies for electronic devices are discussed.

[6] Ibid.; Kara et al., “Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?,” 2022.

[7] Ellen MacArthur Foundation, “Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition,” 2013, p. 7.

WHY FOCUS ON PORTABLE COMPUTERS AND SMARTPHONES?

Simple changes can make a huge difference when it comes to reducing the environmental impact of electronic devices. For instance, European CO_2 emission equivalents would be reduced by 3.7 million tons per year by 2030 if all smartphones and notebooks in Europe were to have a one-year lifetime extension. These savings would be equivalent to removing 1.87 million cars from the roads for a year.[8] However, as these devices are perceived as 'up-to-date' products by many, they are often replaced prematurely.

Resource-intensive production calls for extended lifetime

It requires large amounts of energy and non-renewable resources – including rare earth and conflict minerals – to manufacture electronic devices.

While estimates vary across studies, the European Environmental Bureau (EEB) finds that 40–64% of the global warming potential (GWP) of a notebook with an estimated lifetime of four to five years comes from its non-use phases. For a smartphone with a lifespan of three years, the estimates range from 51 to 92%.[9] When the lifetime of these products are extended, the relative share of the GWP from the non-use phases is reduced.

Consequently, it is not only important to reimagine how materials and electronic devices are sourced, designed, and produced, but also the amount of time they are kept in use. This means that circular consumer behavior is equally important in the transformation toward circular electronic devices.

Everyone can play an active role in making electronic devices circular

In 2020, the number of smartphone subscriptions reached 6.4 billion globally. This number is estimated to increase to 7.7 billion by 2027.[10]

The growing numbers do not only call for action but also assign an important role to everyone – from individual end-users to manufacturers and procurement managers.

As most people use electronic devices in their daily lives, a successful transformation toward circular devices could induce a positive feedback mechanism, promoting circular behavior in other aspects of their professional and personal lives.[11]

Invisible e-waste: a growing problem

Although portable computers and smartphones do not weigh more than a few kilograms altogether, the waste footprint of these devices is surprisingly high.

For instance, Avfall Sverige, a Swedish waste management association, finds that the waste footprint of the production phase of a laptop and smartphone amounts to respectively 1.2 tonnes and 86 kilograms.[12]

[8] EEB, "Coolproducts Don't Cost The Earth," 2019.
[9] Ibid.
[10] Ericsson, "Number of Smartphone Subscriptions Worldwide from 2016 to 2027 (in Millions)," 2022.
[11] DHL, "Delivering on Circularity: Pathways for Fashion and Consumer Electronics," 2021.
[12] Avfall Sverige, "The Total Waste of Products – a Study on Waste Footprint and Climate Cost," 2015.

In practice, this means that 86 kilograms of waste are generated when producing a 169-gram smartphone.

To our knowledge, there is no current data on the proportion of portable computers and smartphones that enter the global e-waste stream. However, it is certain that vast amounts of invisible – and often toxic – waste and poor recycling rates harm the environment and human health.

Complex supply chains with global reach and low transparency

The supply chains of electronic devices are highly complex, non-transparent, and span several continents. In addition, electronic devices contain several conflict minerals – minerals such as gold, tungsten, and cobalt which are commonly extracted in regions with war. This increases the risk of violating human rights in the mining and production phase of the devices.[13]

Reimagining current supply chains and procurement practices thus lies at the core of a successful transformation toward circular smartphones and portable computers.

Multi-stakeholder collaboration and increased transparency between different actors in the supply chain – from miners and manufacturers to users and recyclers – are pivotal to achieving this transformation.

Background: E-waste

Electrical and electronic equipment (EEE) covers six different product categories:

- Temperature exchange equipment
- Screens and monitors
- Lamps
- Large equipment
- Small equipment
- Small IT and telecommunication

Waste from these categories is called waste electrical and electronics equipment (WEEE), commonly referred to as e-waste. As each product has a unique lifetime profile, the waste quantities, economic value, and environmental impact of e-waste vary considerably across the different categories. The same goes for consumer attitudes and recycling opportunities.[14] Consequently, this report focuses on the circular barriers and strategies that apply to portable computers and smartphones.

[13] TCO Certified, "Conflict Minerals Used in IT Products Fund Wars and Drive Human Rights Abuses," 2022.

[14] Baldé et al., "The Global E-Waste Monitor 2017: Quantities, Flows, and Resources," 2017.

TURNING CIRCULAR PRINCIPLES INTO PRACTICE

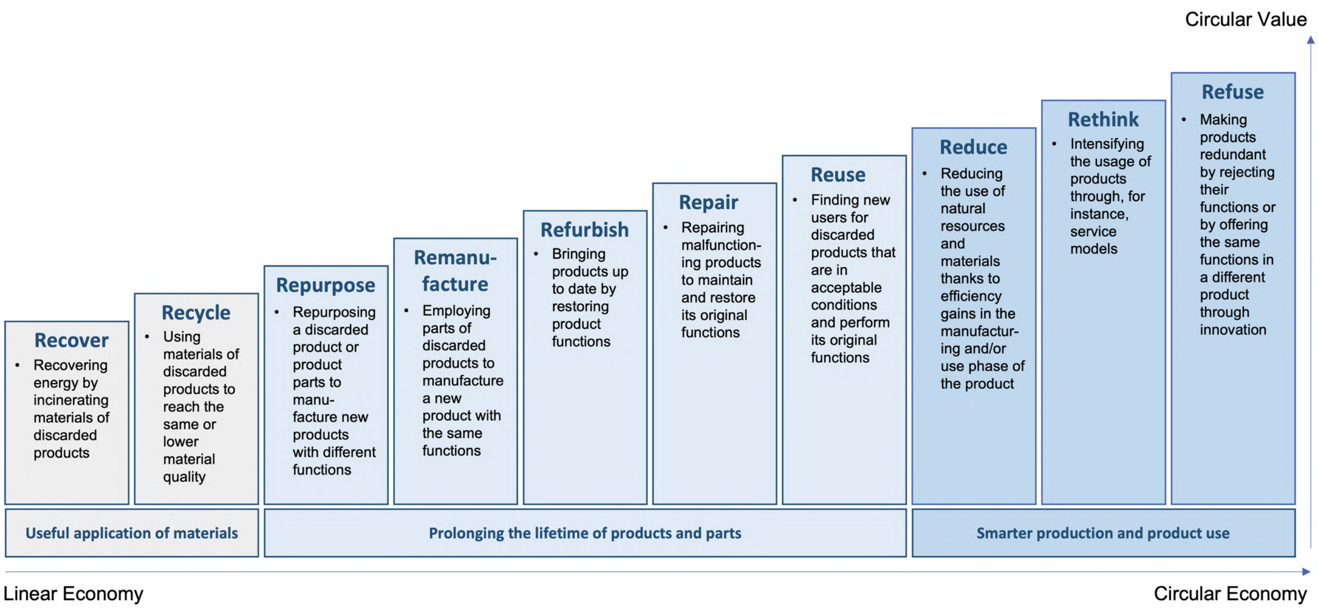
The principles of the circular economy have been developed and depicted visually in various forms throughout the years. The 9R framework can be used by practitioners and academics alike as a tool to turn circular principles into practice.

The 9R framework: establishing the principles of the circular economy

The 9R framework establishes the underlying principles of the circular economy as well as the hierarchy between different circular strategies.

While the 3R framework – reduce, reuse, or recycle – was developed in the early 1980s, new 're-strategies' have increasingly been developed since the 2000s.[15] Kirchherr and colleagues suggest that the 9R framework (figure 1) provides the most nuanced depiction of the principles of the circular economy.[16]

Figure 1: The 9R framework



Adapted from Kirchherr et al. (2017)[17]

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[15] Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?," 2022.

[16] Kirchherr et al., "Conceptualizing the Circular Economy: An Analysis of 114 Definitions," 2017.

[17] The article by Kirchherr et al. (2017) is licensed under a Creative Commons Attribution 4.0 (CC BY 4.0).

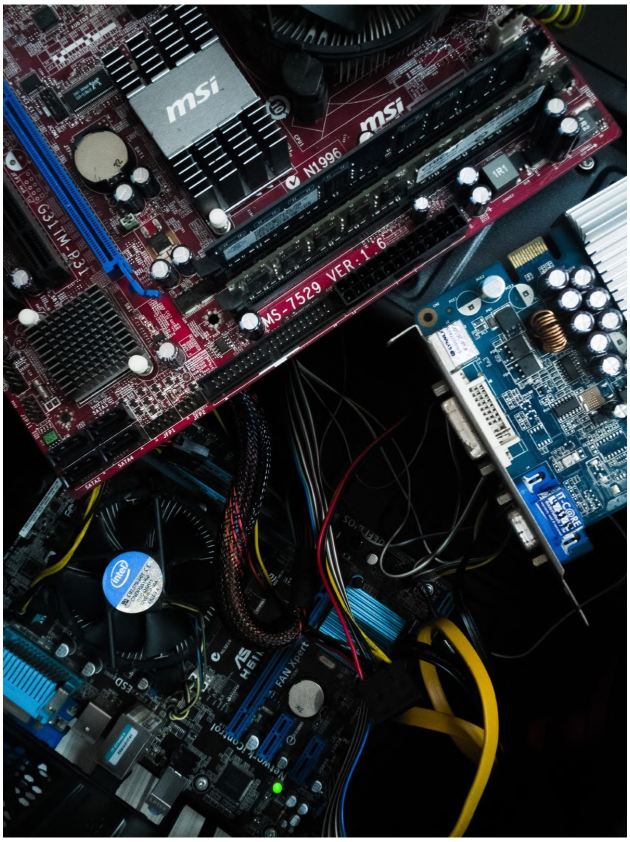


Photo by set.sj on Unsplash

Smarter production and product use

The 9R framework highlights that refusing, rethinking, and reducing are the most effective strategies when it comes to turning circular principles into practice.

In the case of portable computers and smartphones, this means that the highest potential of the circular economy is achieved when business models are reimagined – for example, by employing product-as-service models, by using less or better materials in the design and manufacturing phases, or through radical innovation.

Prolonging the lifetime of products and parts

The following five strategies – reusing, repairing, refurbishing, remanufacturing, and repurposing – are intended to prolong the lifetime of products once they have been produced.

As the non-use phases account for a large share of the GWP of smartphones and portable computers, these strategies do not only yield a high potential but also imply that users play a pivotal role in the transformation toward circularity. From a user perspective, these principles are not only turned into practice when devices are kept in use longer and repaired when broken, but also when purchasing decisions are made. Choosing to buy refurbished or remanufactured products when possible is thus an important, but often neglected, part of making procurement practices for electronic devices circular.

Useful application of materials

The final two strategies – recycling and recovering – are viable ways of handling parts and materials of the product once the product has reached its end-of-use phase. While these strategies are inferior to the abovementioned strategies, they are crucial when it comes to reintegrating materials into the loop and avoiding poor waste management.

For instance, urban mining (i.e., extracting materials from e-waste in this case) does not only reduce the health and environmental risks associated with hazardous e-waste in the informal recycling sector but also lowers the need to extract conflict minerals.[18]

[18] World Economic Forum, "A New Circular Vision for Electronics: Time for a Global Reboot," 2019.

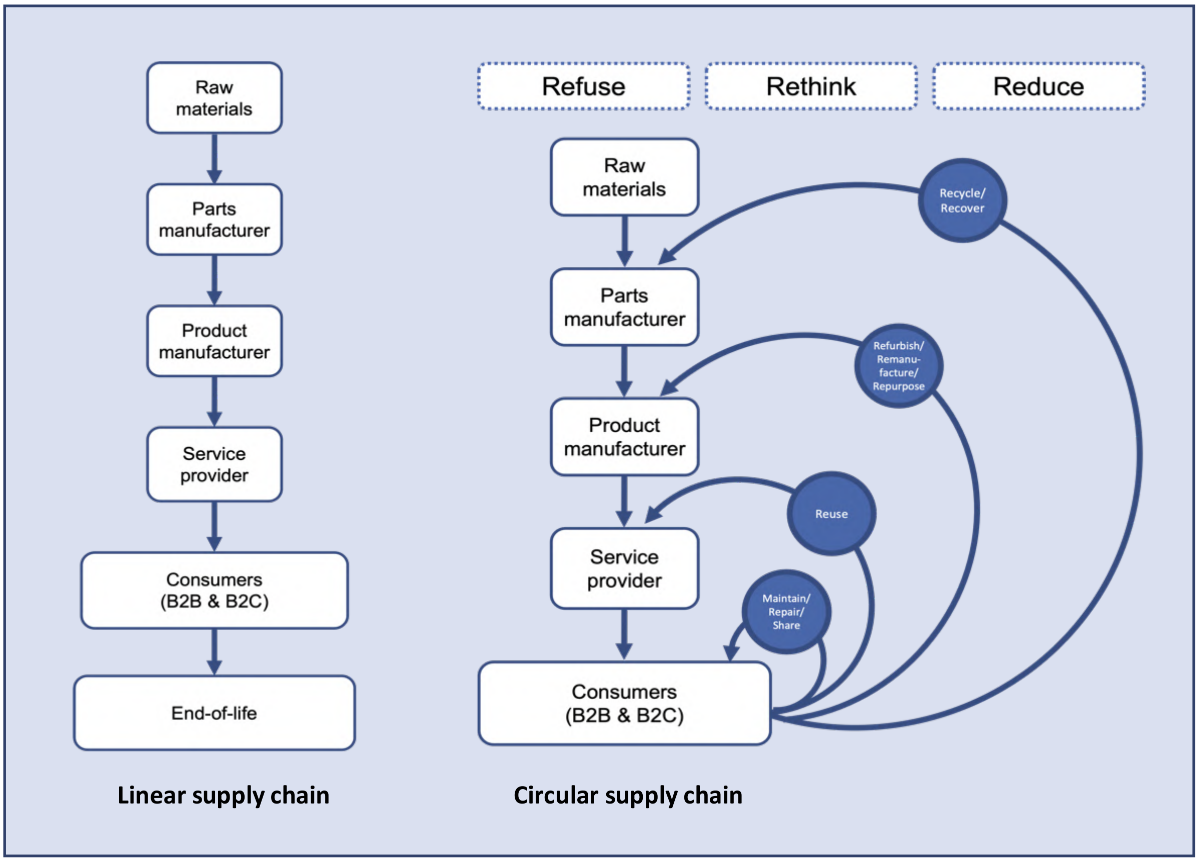
Closing the loop requires collaboration across the supply chain

The 9R framework establishes the hierarchy of different circular strategies and highlights the importance of multi-stakeholder collaboration.

Everyone has a role to play – from designers and manufacturers to users, purchasers, refurbishers, and recyclers. Crucially, the impact and implementation of the circular principles requires reverse supply chain models that ensure that the electronic devices and their subcomponents are collected and reintegrated into the loop in a highly efficient and safe manner.

While the shift from linear to circular supply chains is not explicitly highlighted in the 9R framework, most of the strategies hinge upon this transformation. In this regard, the EMF stresses the 'power of the inner circle' when establishing the hierarchy between the circular strategies (figure 2).[19]

Figure 2: From linear to circular supply chains



Inspired by the Ellen MacArthur Foundation (2018) and similar visualizations.

[19] Ellen MacArthur Foundation, "Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition," 2013.

TAKING STOCK OF THE CIRCULAR TRANSFORMATION OF ELECTRONIC DEVICES

Despite the vast potential of the circular economy in the electronics sector, the production and usage of portable computers and smartphones continue to be linear. While manufacturing companies seldom design for circularity, private and professional users are to a large extent unaware of the social and environmental impact of their current consumption levels as well as the economic value of their used devices.

Linearity continues to be the norm

Historically, the production and usage of electronic devices have been linear – from the design of the hardware and software to the manufacturing and disposal of used devices.

While the reasons are many, the interviewed experts for this report noticed that rapid innovation cycles, increasingly complex products, current business models, consumer perception, and lack of awareness are among the main barriers that currently make linearity the norm.

Rapid innovation makes it tricky to design for circularity

Companies can find it difficult to design for circularity when products are still growing on the S-curve because they keep getting cheaper, better, and faster.

As the market penetration of smartphones and portable computers has grown steadily over the years, the S-curve for these products has arguably flattened over time. However, high innovation rates and rapid software developments have – among other things – kept manufacturers from employing circular design strategies, according to Tim McAloone, Professor at the Technical University of Denmark (DTU).

> **Imagine if the first iPhone were designed solely for longevity… We wouldn't have this conversation today (…). The designers of the iPhone would not have been able to foresee, let alone physically encapsulate, the technology that should be there. So, designing for circularity from a longevity perspective for products which are still on a steep S-curve is really tricky. That's where competency in other circularity strategies becomes important, depending on how mature the technology of one's product is – but these strategies are commonly not known for companies.** – Tim McAloone

Similarly, Stephen Haskew, Group Sustainability Director at Circular Computing, highlights that while rapid software developments in the early and mid-2000s turned most hardware obsolete within a few years, cloud services have made it increasingly possible to extend the lifetime of hardware today.

However, as many brand manufacturers do not support their software beyond a few years, many electronic devices are replaced before the hardware breaks down. This is known as absolute or planned obsolescence (for more details, see p. 16).

The narrative surrounding circular devices impedes proper take-off

According to several of the interviewed experts, consumer perceptions and a lack of awareness put a spoke in the wheel for circular smartphones and portable computers. While there may be a certain willingness and desire to become more circular, several of the experts suggested that used, refurbished, and remanufactured electronic devices continue to be perceived as inferior to new products.

In addition, a lack of awareness and trust in circular processes reduces users' willingness to buy reused devices. In this regard, Andreas Schjølin, Sustainability Manager at ATEA, concludes that the narrative surrounding circular devices makes it difficult to implement circularity in practice:

Background: The S-curve

The S-curve has often been used to describe the evolution and diffusion of new technologies and products. Put simply, the S-curve suggests that most successful products and technologies develop through three phases which altogether form the shape of an S.[20]

In the first phase, only a few people (early adopters) are willing to buy and test the new product. In the second phase, the adoption rate increases rapidly and new firms with similar technology enter the market. In the third phase, when the product has reached market saturation, the adoption rate declines, and the total number of users stagnates.

Eventually, a new technology or product may replace the former, thereby paving the way for a new S-curve.[21]

> **If [your company] says you will have a reused computer next time, the image you get in your head will be; okay, it is going to be an old, slow, and noisy brick that will not work. Nobody wants that, but the thing is... We have options nowadays where 'used' is good.**
> **–** Andreas Schjølin

Photo by Christina @ wocintechchat.com on Unsplash

[20] Fisher et al., "S-Curve Analysis," in *Strategy in 3D : Essential Tools to Diagnose, Decide, and Deliver*, 2020, pp. 109–17.

[21] Ibid.

The lack of transparency in supply chains increases environmental and social risks

The supply chains of electronic devices span multiple countries and usually involve almost all continents. Following this, it is more accurate to depict current supply chains for electronic devices as webs (as opposed to linear chains). The high level of complexity and lack of transparency increase social and environmental risks.

Forced labor, as well as child labor, corruption, and environmental degradation are likely to occur when mining for conflict minerals (e.g., minerals such as tin, tantalum, tungsten, and gold that are extracted in conflict zones and sold to finance conflicts).[22]

Different organizations have, for instance, reported on the use of child labor in gold and cobalt mines in Ghana and the Democratic Republic of Congo as well as poor workers' rights, including deficient safety measures, in countries like Bolivia, the Philippines, and Bulgaria.[23, 24]

The high complexity and lack of transparency have detrimental social and environmental effects and hamper the circular transformation due to the limited information-sharing amongst supply chain actors.

In practice, this means that brand owners and recyclers do not know the exact origin or composition of their supplies. This impedes efficient and safe refurbishment, recycling processes, and waste treatment.

The Fair Mouse: Creating Fair Conditions for People Involved in the Production of IT Products

The Fair Mouse was created to foster fair working conditions for everyone involved in the global production of IT products. However, the illustration of its supply chain has often been used to demonstrate the complexity and risks in the supply chains of IT products.

As the red boxes indicate, the suppliers of raw materials are often unknown and there are typically no checks or knowledge about the product or working conditions in this part of the supply chain. If this is the example of one of the fairest, most transparent supply chains in the industry, then imagine what the supply chain of a traditional portable computer or smartphone looks like.

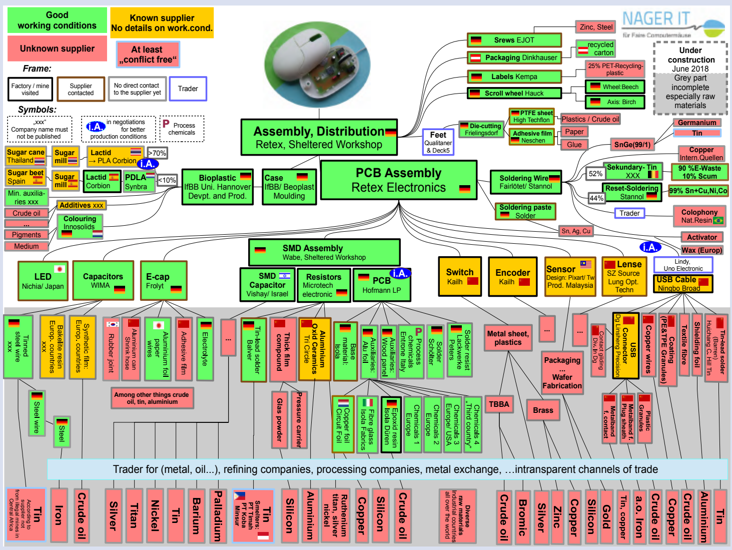


Illustration: Nager IT

[22] TCO Certified, "Conflict Minerals Used in IT Products Fund Wars and Drive Human Rights Abuses," 2022.

[23] GSMA, "Strategy Paper for Circular Economy: Mobile Devices," 2022.

[24] Merk, "Human Rights Risks in ICT the Supply Chain: A Collection of Articles by Make ICT Fair," 2021.

TCO Development: A Sustainability Certification for IT Products

Product certifications have become a viable tool for purchasers and manufacturers to showcase their commitment to minimizing sustainability-related supply chain risks.

TCO Certified is a world-leading certification program for electronic devices developed by TCO Development. The certification is based on a vast number of sustainability criteria – including hazardous substances, socially-responsible manufacturing, and circularity in terms of materials reuse and recovery.[25] Independent accredited experts verify that certified products meet all criteria. Throughout the validity period of the certificate, verification is mandatory and is carried out continuously – before and after certification.

The Product Finder on the certification body's website allows private users and corporate purchasers to assess whether their desired IT product adheres to the sustainability and circularity criteria in the certification documents.[26] The certification is associated with a given product – as opposed to the brand owner – and provides information on sustainability and circularity measures. It can thus be a helpful tool in turning circular procurement principles into practice.

Smartphones and portable computers are replaced prematurely

Smartphones and portable computers are up-to-date products – or so-called 'fashion electronics' – and therefore often replaced before they break. On average, smartphones and portable computers are replaced every two and four years, respectively.[27]

However, from a global warming perspective (GWP), these devices should be used for as long as possible as new devices do not only require additional resources in their production phase but also tend to consume more energy than previous generations.[28]

While the reasons are many, the EEB highlights that the short replacement cycles may not only be driven by a desire to keep up with the latest technology trends but also by business models that encourage device replacements (e.g., through phone and internet subscriptions), declining prices, and poor upgradability.[29]

Importantly, relative obsolescence appears to be one of the driving forces behind the short replacement cycles of electronic devices. For instance, based on interviews with businesses in the electronics industry in four Nordic countries, Watson and colleagues find that consumers replace their smartphones because they want the latest model (47%), because their existing phone is not functioning (40%), or because they want the latest software (13%).[30]

This suggests that sociocultural change is as important as technical change for a successful transformation toward circular devices.

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[25] TCO Certified, "Environmental and Social Criteria with Direct Impact," 2022.
[26] TCO Certified, "Product Finder," 2022.
[27] Bachér et al., "Electronic Products and Obsolescence in a Circular Economy," 2020.
[28] EEB, "Coolproducts Don't Cost The Earth," 2019.
[29] Ibid.
[30] Watson et al., "Circular Business Models in the Mobile Phone Industry," 2017.

Background: Obsolescence

While there is no fixed definition of the different types of obsolescence, the European Environment Agency (EEA) defines absolute, relative, premature, and planned obsolescence as follows.[31]

Absolute obsolescence occurs when products become dysfunctional because of mechanical failures or software incompatibility. Here, the actual and designed lifetime will be the same.

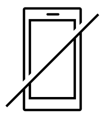
Relative obsolescence denotes products that are still functioning but perceived as obsolete by the user. Consequently, the EEA distinguishes between **psychological, style, cosmetic, or aesthetic obsolescence** (e.g., when the product is discarded because the user wants a new product), **economic obsolescence** (e.g., when the product is replaced because the cost of repair is perceived to be too high), and **technological obsolescence** (e.g., when the product is replaced to improve functionality, quality, or effectiveness).

Premature obsolescence happens when products break before their designed or desired lifetime. If premature obsolescence has been designed to occur, it is called **planned or programmed obsolescence**.

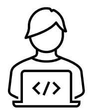
Reasons (according to business) for smartphone replacement

Watson et al. (2017)

47% want the latest model



40% existing phone not functioning



13% want the latest software

Electronic devices do not stay in the loop

The supply chains for smartphones and portable computers continue to be linear. Estimates suggest that only 12–15% of European mobile phones are being recycled and that millions of devices are left unused in European homes.[32]

For instance, various studies suggest that 124 million mobile phones are hibernating in German homes. In France, the numbers are estimated to be around 100 million.[33]

While most manufacturers and retailers of smartphones and portable computers have formal buy-back systems,[34] the expert interviews that were conducted for this report highlight that the low collection and recycling rates tend

[31] Bachér et al., “Electronic Products and Obsolescence in a Circular Economy,” 2020.
[32] Rizos et al., “Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods Industry: Opportunities and Challenges for Businesses, Workers and Consumers – Mobile Phones as an Example,” 2019.
[33] Ibid.
[34] Atea Sustainability Focus, “Report to Responsible Business Alliance: Closing the Loop on Materials,” 2020.

to be rooted in consumers' emotional attachment, lack of awareness, lack of collection points, and concerns about data security. In addition, the high costs of professional repair, lack of spare parts, and availability of good repair services reduce the consumers' willingness to repair their devices once they break.

Accordingly, 40% of the respondents in a survey conducted by Cerulli-Harms and colleagues noted that it would have been too expensive to repair their broken phone.[35] 33% of the respondents said that they preferred to buy a new phone, while another 28% responded that they preferred to replace their broken phone because it was out of fashion or obsolete. These findings highlight the issues related to relative obsolescence.

Global e-waste: an untapped gold mine

E-waste is an untapped mine of precious metals and minerals. Take an old phone, for instance. According to the WEEE Forum, a tonne of smartphones contains 100 times more gold than a tonne of gold ore.[36]

Rizos and colleagues estimate that by collecting and recycling 35% of the mobile phones sold in Europe in 2017, it would be possible to recover around 1,360 tonnes of valuable metals with a worth of roughly €105 million.[37]

Still, recycling remains costly as products are not designed for disassembly and recycling[38] – let alone refurbishing and remanufacturing – and formal recycling centers are not necessarily capable of identifying the elements of the different components. As the price of virgin materials does not reflect the environmental and social impact of mining and refining, it is often cheaper to use virgin rather than recycled materials.[39]

Closing the Loop (CTL) – Waste Compensation: A Pragmatic Solution to Reduce E-Waste while Addressing the Demand for Sustainable Devices

Only 17.4% of all global e-waste was documented as collected and recycled properly in 2019.[40] This means that considerable amounts of e-waste were exported (sometimes illegally) to low- and middle-income countries with informal recycling sectors – often to the detriment of the environment and the health of workers as well as local communities.

Closing the Loop (CTL) is a Dutch company that offers E-Waste Compensation. Through waste compensation, companies pay a fee to CTL for every new IT product they buy or discard.[41] In return, CTL uses this money to collect and recycle the equivalent amount of e-waste in African countries.

CTL ensures that the waste is documented and recycled properly in formal recycling facilities and that reusable materials are reintegrated back into the loop.[42] In addition, the company promotes methods and provides incentives that make the informal sector more environmentally responsible and safe. This reduces the environmental impact of e-waste, but also the severe health risks associated with being exposed to hazardous waste in the informal recycling sector.

The current business model is a pragmatic – but not perfect – solution that allows companies to make their IT use more sustainable at a low cost.

According to a representative from the company, most of the waste is brought back to European recycling facilities due to the lack of certified infrastructure in the countries where CTL collects e-waste. In the long run, the company hopes that it will be possible to develop formal recycling facilities in the countries where they collect the e-waste and thus create even more decent and safe jobs for the local communities.

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[35] Cerulli-Harms et al., "Behavioural Study on Consumers' Engagement in the Circular Economy," 2018.
[36] WEEE Forum, "Too Much E-Waste Ends up in the Bin : International E-Waste Day to Focus on the Role of Consumers in Improving Rates of Reuse, Refurbishment and Recycling," 2021.
[37] Rizos et al., "Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods Industry: Opportunities and Challenges for Businesses, Workers and Consumers – Mobile Phones as an Example," 2019.
[38] Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows, and Resources," 2020.
[39] TCO Certified, "Circular IT Management in Practise - Impacts and Insights," 2020.
[40] Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows, and Resources," 2020.
[41] Closing the Loop, "Client Cases," 2022.
[42] Closing the Loop, "Greener Procurement: Safe, Solid and Engaging," 2022.

Photo by Malachi Brooks on Unsplash

Steps taken by the public sector toward circularity

Although the circular economy remains underdeveloped when it comes to smartphones and portable computers, the public sector is increasingly taking steps toward making these products more circular.

For instance, in France, a minimum of 20% of public procurement must be spent on a list of products – including portable computers and smartphones – that are reused or incorporate recycled materials.[43]

In Denmark, the national procurement service (SKI) is currently developing a new framework that aims to enable public institutions to buy circular devices.[44,45] According to Lars Steffensen, Business Unit Manager of Circular Computing at Elitecom Aps, this is an important step in the right direction, as large-scale public procurement so far has been bound to framework agreements that made it difficult for public institutions to engage in circular IT procurement.

As part of a pilot project that was initiated during the Covid-19 pandemic, Danish municipalities such as Gladsaxe, Copenhagen, and Albertslund have likewise started to use remanufactured computers.

In an interview with a Danish magazine, a spokesperson from the municipality of Gladsaxe emphasized that the pilot project allowed the municipality to reduce the environmental and economic costs associated with their electronic devices. However, effective communication was pivotal to ease employee concerns about the performance and functionalities of the remanufactured computers.[46]

Circular Computing:
“Because IT Shouldn’t Cost the World”

Circular Computing is a remanufacturer of used laptops. In 2021, the company’s remanufacturing process was certified with the world’s first BSI Kitemark for remanufactured computers.

The ISO9001-accredited remanufacturing process takes more than five hours and involves a 360-point quality check to ensure consistent quality and “equal to or better than new” performance requirements.[47]

Circular Computing is currently remanufacturing used laptops from HP, Dell, and Lenovo. Compared to a brand-new computer, a remanufactured computer provides up to 40% cost savings, according to the company.[48]

The remanufactured computers enable procurement managers to save money and reduce the environmental impact of their IT procurement practices.

[43] Ministère de la Transition Écologique, “Décret No 2021-254 Du 9 Mars 2021 relatif à l’obligation d’acquisition par la commande publique de biens issus du réemploi ou de la réutilisation ou intégrant des matières recyclées,” 2021.
[44] SKI, “02.01 Genbrugte Computere (2023),” 2022.
[45] SKI, “SKI Vil Udbyde Genbrugte Computere På Ny Aftale,” 2022.
[46] Den Ansvarlige Indkøber, “Gladsaxe Kommune Indkøber Genproducerede Laptops,” 2022.
[47] Circular Computing, “The Circular Remanufacturing Process,” 2022.
[48] Ibid.

Legislative measures are put into place to promote circularity in the EU

The circular economy has been a strategic priority in the EU since the adoption of the first Circular Economy Action Plan (CEAP) in 2015.

The CEAP from March 2020 introduces several sector-specific initiatives such as the Circular Electronics Initiative. The aim of this initiative is to increase the product lifetime of electronics by – among others – introducing the following action:

1. **Regulatory measures under the Ecodesign Directive,** ensuring that electronic devices are designed for "energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling";[49]
2. **Right to repair**, including the right to update obsolete software in the electronics and ICT sector; and
3. **Improvements to the collection and treatment of e-waste** through, for instance, an EU-wide take back scheme for electronic devices.[50]

As part of the CEAP, the European Parliament and Council negotiators have decided that the USB Type-C will become the standard charging port for small and medium-sized portable electronic devices by 2024.

According to the European Parliament, these new obligations will not only save consumers up to €250 million yearly but also reduce the number of disposed and unused chargers. Currently, chargers are estimated to generate 11,000 tonnes of e-waste annually.[51] Other proposals – including EU regulation that aims to make it easier to remove and replace batteries – are underway.[52]

While this is good news, Rizos and Bryhn stress that bureaucracy, regulatory complexity, and uncertainty due to overlapping legislation in the EU can impede a proper take-off of the circular economy for electronics.[53] Similar concerns were raised by one of the interviewed experts who highlighted that international regulation can make it difficult for companies to build circular cross-border business models in the recycling sector.

Background: EU Circular Economy Action Plan

The objective of the new EU Circular Economy Action Plan (CEAP) from March 2020 is to lead global efforts on the circular economy by – among others – making sustainable products the norm and empowering consumers as well as public powers in a way that fosters circularity.

The action plan includes general initiatives, such as a sustainable product policy framework, which will extend the scope of the Ecodesign Directive and propose minimum mandatory green public procurement criteria as well as sector-specific initiatives such as the Circular Electronics Initiative.[54]

Overcoming the current barriers requires collective efforts

The potential for circularity continues to be high in the production and design phases of smartphones and portable computers. However, consumers, legislators, and procurement departments also play a crucial role in the transformation toward circular devices.

Overcoming current barriers will thus not only require fundamental changes in the way that companies extract materials, produce products, and conduct business, but also in the way consumers and other stakeholders perceive and use electronic devices.

[49] European Commission, "A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe," 2020, p. 7.
[50] Ibid.
[51] European Parliament, "Deal on Common Charger: Reducing Hassle for Consumers and Curbing e-Waste," 2022.
[52] European Parliament, "Batteries: Deal on New EU Rules for Design Production and Waste Treatment," 2022.
[53] Rizos and Bryhn, "Implementation of Circular Economy Approaches in the Electrical and Electronic Equipment (EEE) Sector: Barriers, Enablers and Policy Insights," 2022.
[54] European Commission, "A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe," 2020.

SIX ENABLERS THAT WILL HELP OVERCOME THE CURRENT BARRIERS TO CIRCULAR DEVICES

This report identifies six enablers that will help overcome current barriers and support the transformation toward circular devices. Importantly, as the list of circular enablers is constantly evolving, the actions below should not be understood as an exhaustive blueprint of the circular transformation. Instead, the enablers are actions that can be undertaken by decision-makers and society at large.

Six Enablers That Will Help Overcome the Current Barriers to Circular Devices

- Design for circularity
- Foster circularity through legislation
- Change narrative through consumer education
- Implement circular purchasing practices
- Increase take-back programs
- Engage in supply chain collaboration

Designing for circularity

Circular design strategies vary from product to product. However, designing for circularity – such as longevity, repairability, modularity, recyclability, and with recycled materials – is pivotal for making portable computers and smartphones more circular.[55]

For smartphones, Bachér and colleagues highlight that water and dust protection as well as improved battery and software upgradability can help improve the durability, and thus the designed lifetime, of smartphones.[56]

In a similar vein, Bakker and Schuit highlight that postponing, resisting, and reversing obsolescence are important design strategies that could extend the product lifetime of electronic devices (figure 4).[57]

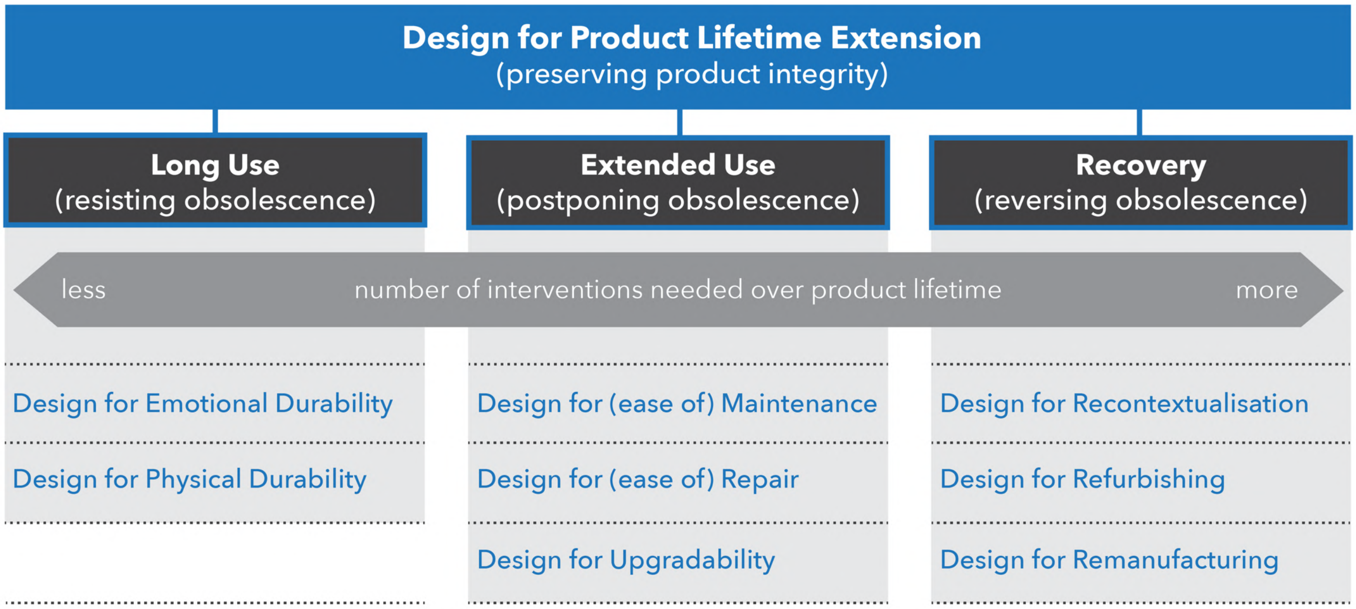
In addition, brand manufacturers need to choose materials and components that are easy to repair, disassemble, and reintroduce into the circular economy once the devices have reached their end-of-use or end-of-life. In other words, they need to focus on conserving the value of their electronic devices in both the inner and outer loops of the circular cycles (figure 2).

[55] Examples include the Nokia G22, and devices produced by Fairphone and Shift. For more information about the recently launched Nokia G22, please see, Gibbs, "Nokia Launches DIY Repairable Budget Android Phone," 2023.

[56] Bachér et al., "Electronic Products and Obsolescence in a Circular Economy," 2020.

[57] Bakker and Schuit, "The Long View: Exploring Product Lifetime Extension," 2017.

Figure 4: Designing circular electronic devices with extended product lifetime



Typology of design approaches for Product Lifetime Extension, Den Hollander (2018)

SHIFT: Designing for Circularity

SHIFT is a social enterprise, located in central Germany, which translates circular principles into electronic devices by designing and producing modular, upgradeable, and easily repairable phones and tablets.

To encourage customers to repair their SHIFT devices, the Shiftphone is delivered with a screwdriver and a repair guide. Spare parts are also easily accessible. At the end of the first use cycle of the product, users are offered a refund if they send back their device. As such, users are incentivized to reintegrate materials and components into the loop.

SHIFT was founded in 2014 by two brothers, Carsten and Samuel Waldeck, to make the big players in the smartphone industry move toward circularity. Leon von Zepelin, who is part of the Research and Communication department at SHIFT, emphasizes: “We want to be a lighthouse and demonstrate that it’s possible to change a battery within a second or two. Our devices are designed according to our repair statistics, and we want to share that good design also depends on how quickly and easily you can repair your own phone.”

Legislation needs to induce circular products and user behavior

To facilitate the circular transformation of electronic devices, it is paramount that regulatory measures induce manufacturers and consumers to adopt circular practices. While it is beyond the scope of this report to provide a detailed and exhaustive list of potential measures, previous studies and our expert interviews suggest that a revision of the Ecodesign Directive, the implementation of a digital product passport, extended producer responsibility, a right to repair, and a value added tax (VAT) reduction have the potential to push brand owners to design and manufacture electronic devices that are more durable and repairable.

These measures could also make it easier and cheaper for users – individuals as well as companies – to adopt circular behavior. Addressing the uncertainty and complexity of the requirements for reused and refurbished devices as well as e-waste in the EU is another key lever that could support the growth of circular business models and supply chains.[58]

The Right to Repair

The right to repair gives professional, third-party repairers the right to access technical information and spare parts.[59,60] Extending the right to repair, including the right to update obsolete software, electronics, and ICT is a key focus of the EU Circular Economy Action Plan.

The right to repair could empower consumers to extend the lifetime of electronic devices, thus reducing the environmental and economic costs associated with the use phase of the products.

VAT Reduction on Repair

Repair costs remain a barrier to the circular transformation. For instance, replacing the smartphone screen can cost more than 40% of the original price of the device.[61]

A VAT reduction or tax break on the repair, refurbishment, and resale of electronic devices could reduce financial imbalances and incentivize consumers to extend the actual lifetime of their devices.

Digital Product Passport

The purpose of the Digital Product Passport is to gather and share information about a product and its supply chain to promote sustainable production and recycling, steer circular business models, enable verification of compliance with legal obligations, and make consumers more informed about their purchases.

Although information-sharing is a delicate topic, transparency and collaboration throughout the supply chain are vital for the transition toward circular IT devices.[62]

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[58] Rizos et al., "Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods Industry: Opportunities and Challenges for Businesses, Workers and Consumers – Mobile Phones as an Example," 2019.

[59] Šajn, "Right to Repair," 2022.

[60] The right to repair may refer to different things, notably the "right to repair during legal guarantee", "the right to repair after the legal guarantee has expired", and "the right for consumers to repair products themselves". For more information, please see Šajn, "Right to Repair," 2022.

[61] Bachér et al., "Electronic Products and Obsolescence in a Circular Economy," 2020.

[62] Ellen MacArthur Foundation, "Circular Consumer Electronics: An Initial Exploration," 2018.

Background: Key Enablers According to the Industry

In a study based on interviews with 31 companies that engage in circular processes, Rizos and colleagues report that **consumer and societal awareness (81%)** and **policy and regulation (61%)** were the most frequently mentioned enablers of the circular economy in the electronics sector. However, company organization, financial and economic factors, and supply chains were also highlighted by the stakeholders from the industry.[63]

Consumer and societal awareness	Policy and regulation	Company organization	Financial and economic factors	Supply chains
81%	61%	58%	42%	32%

Changing the narrative through consumer education

Used, refurbished, and remanufactured devices are often considered inferior to new devices. The transformation toward circular smartphones and portable computers is therefore not only technical and political but also sociocultural. This means that the narrative surrounding circular devices and user behavior needs to change.

In this regard, consumer education is key and can, for example, be promoted through campaigns, collaborative workshops, use and repair guides, as well as product labels. Crucially, consumer education and societal awareness should aim at reducing the number of products that get replaced prematurely and make it desirable as well as accessible to repair and upgrade devices before they are reintegrated into the loop for recycling.

Organizations that purchase electronic devices also have a role to play in this regard. Specifically, several of the interviewed industry experts noticed that it is important that employees are informed about why their employer has chosen to opt for refurbished or remanufactured devices. Creating bottom-up support does not only reduce employee dissatisfaction; it also has the potential to foster new user behavior in their private lives, thus furthering the transformation toward the circular economy.

New purchasing practices to steer market demand for circular devices

While the actions undertaken by brand owners are crucial for the circular transformation, systemic change toward circularity also depends on what procurement departments in the public and private sector choose to buy.[64]

Public and corporate procurement policies and practices are thus crucial enablers for the circular transformation of electronic devices. To increase market demand for circular devices, public and private entities can adopt KPIs that foster circular purchasing practices and – for instance – commit a certain percentage of their spending on circular devices and services.[65]

[63] Rizos et al., "Barriers and Enablers for Implementing Circular Economy Business Models: Evidence from the Electrical and Electronic Equipment and Agri-Food Value Chains," 2021.
[64] Atea Sustainability Focus, "Report to Responsible Business Alliance: Closing the Loop on Materials," 2020.
[65] PACE, "Circular Economy Action Agenda: Electronics," 2021.

Tenders also need to be adapted so that providers of remanufactured and refurbished devices can enter the market. The interviewed industry experts noticed that public institutions are good starting points because they often have a strong sustainability focus as well as performance requirements that do not exceed the functionalities of circular devices. However, that should not keep managers in the private sector from purchasing circular products.


Photo by Elly Filho on Unsplash

Increase collection and take-back programs

The formal collection and recycling rates of electronic devices are currently not keeping up with the growth rates of global e-waste.[66] Take-back programs and improved recycling infrastructure are thus pivotal in the transformation toward circularity.

Most brand owners and retailers offer formal take-back programs that extend the lifetime of products and materials. However, to increase the use of take-back programs, several of the interviewed experts stressed the need for increased trust in data security (e.g., through General Data Protection Regulation certification, GDPR) as well as economic and administrative incentives to reintroduce devices into the loop.

The increased collection and recycling rates will not only have an important environmental and social impact but also ensure a sufficient supply of used parts and materials for manufacturers who increasingly need to incorporate recycled materials in their devices. These circular supply chains can reduce costs for buyers and manufacturers and reduce their reliance on scarce and conflict materials from different corners of the world.

That said, take-back programs need to be designed carefully. Portable computers and smartphones should neither be brought back too early, and thus artificially reduce the lifetime of the products, nor too late, and thus make repairs, remanufacturing, and upgrades impossible. In addition, specific performance requirements and user behavior should be considered when establishing replacement cycles.

Atea: Prolonging the Life of Electronic Devices Thanks to the Atea Return Program

Atea is one of the market leaders in providing IT infrastructure to companies and public institutions in Northern Europe. Atea has committed itself to take back and reuse or recycle all the IT products that the company sells by 2030. To reach the 1:1 ratio between sold and recovered devices, Atea has launched the Atea Return program.

As part of the Atea Return program, customers receive a carrier in which they can place the IT equipment they would like to return. From there, Atea brings the electronic devices to a large logistics center where data sanitization, deidentification, and diagnostics are executed to establish how the equipment should circulate in the loop (reuse, recycle, etc.).

In 2021, more than 435,000 devices were taken back thanks to the Atea Return, saving the equivalent of 49,492 tons of CO_2 emissions.[67] According to Atea, companies can reduce 43% of the CO_2 -equivalent emissions of their IT products if they are returned and reused or recycled properly.[68]

[66] Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows, and Resources," 2020.

[67] Atea, "Corporate Responsibility & Sustainability Report," 2021.

[68] Atea, "Atea Return: genvendelse og genbrug af jeres IT-udstyr," 2022.

The role of supply chain collaboration to enable systemic change

The previous enablers require that collaboration and partnerships across the supply chain become the norm and that long-term systems thinking replaces the current take-make-dispose paradigm of electronic devices.

This means that supply chains need to be redesigned and developed to facilitate new movements of goods and materials.[69] In addition, multi-stakeholder initiatives are needed to overcome current barriers relating to the design, use, disassembly, and recycling of electronic devices. Partnerships – such as the Circular Electronics Initiative – can help facilitate effective action and dialogue between the industry, government, civil society, and international organizations and further the understanding of different issues in the transformation toward circularity.

Here, it is worthwhile to highlight that all actors in the supply chain need to develop ideas and behavior that do not only reduce the impact, but also the consumption and production of new smartphones and portable computers.

While sociocultural changes are often harder to implement than technical solutions,[70] they are necessary for a successful transformation toward circularity and highlight the importance of not only multi-stakeholder partnerships but also consumer education and increased societal awareness.

Photo by ThisisEngineering RAEng on Unsplash

[69] Bachér et al., "Electronic Products and Obsolescence in a Circular Economy," 2020.

[70] Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?" 2022.

POTENTIAL TRADE-OFFS AND UNINTENDED CONSEQUENCES OF A CIRCULAR TRANSFORMATION OF ELECTRONIC DEVICES

While circularity and sustainability are often understood as two sides of the same coin, circularity does not by default lead to a more sustainable future.

The final section of this report seeks to cast light on the trade-offs and potential (unintended) consequences of a circular transformation of electronic devices. This is not to discourage decision-makers from adopting circular practices, but instead to broaden the scope and highlight additional performance measures that could be considered when transforming current business models.

Three sustainability issues are thus discussed in relation to the transformation toward circular electronics. These discussions do not by any chance cover the full range of sustainability issues that the world is currently facing. However, they are part of a bigger picture which is crucial, but often neglected, when encouraging a circular transformation.

Adding considerations about social sustainability to the circular transformation

Social sustainability is one of the most underresearched and underdeveloped elements of the circular economy, according to our expert interviews. Consequently, the social dimension is often forgotten or only implicit in the development and implementation of circular action plans.

Different from a holistic sustainability perspective, the circular economy accentuates the possibility of improving economic and environmental performance concurrently through redesign, waste reduction, and closed loops.[71] While the environmental promises and protection of the biosphere will most likely benefit humanity at large, it is unlikely that the benefits of the circular economy will be equally shared and promote justice unless proactive measures are put into place. [72]

For instance, it remains largely unexplored to which extent the circular economy creates consumption hierarchies between the Global North and the Global South.

Similarly, we only know little about how circular supply chains and design strategies will affect mining communities and workers in the production and recycling sector.

The circular transformation could potentially remove or relocate hundreds of thousands of jobs and thus have a negative impact on local communities in the areas where these sectors currently exist. Alternatively, one could fear that a circular economy for electronic devices would create more jobs with little to no social protection in the informal sectors in the Global South.

[71] Geissdoerfer et al., "The Circular Economy – A New Sustainability Paradigm?," 2017.

[72] Ibid.; Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?" 2022; Murray et al., "The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context," 2017; Kirchherr et al., "Conceptualizing the Circular Economy: An Analysis of 114 Definitions," 2017.

Altogether, this could lead to social insecurity, unrest, and unequal wealth distribution. It is thus worthwhile to keep in mind that jobs that are 'good for the environment' (e.g., in the waste collection and recycling sector) are not necessarily 'good for workers'. [73]

That said, the circular economy has the potential to advance the decent work agenda and improve the livelihood of workers across global supply chains. Circular design strategies and proper handling of e-waste could, for instance, reduce exposure to hazardous substances, which, among others, increases the risk of cancer and premature birth among people working in the informal recycling sector.[74]

It is, however, pivotal that public and professional decision-makers employ proactive measures that go beyond the core principles of the circular economy to ensure that formal jobs and safe working conditions are created throughout the supply chain.

Reconciling short-term GHG emission reduction targets with circularity

As a circular transformation has the potential to cut GHG emissions, GHG emission reduction targets and circularity strategies should ideally be developed conjointly. However, as designing for durability sometimes requires more energy and resources than linear design strategies in the short term, the circular transformation may work against short-term GHG emission reduction targets.

In this regard, Tim McAloone, professor at DTU, adds that it is often difficult to implement circularity at the core of products and that circular measures do not necessarily reduce GHG emissions just because they are circular or as rapidly as one may wish for.

Consequently, decision-makers may be inclined to turn circularity into side campaigns with smaller initiatives that do not jeopardize the short-term GHG reduction targets of the company.

> **Really getting into the circularity of the product itself, that's quite scary. So we need to understand what design for circularity versus design for sustainability means. We also need to understand that design for circularity is only good if it is also sustainable and that the trade-offs between eco-efficiency and eco-effectiveness can be very complex to reconcile. Design for circularity has a huge potential to contribute to reduced GHG emissions, but it's not a given – and if it is, the benefits might first be manifest in one or two product life cycle's time.** – Tim McAloone

While designing for eco-efficiency is all about reducing the negative consequences and thus the environmental and social damage associated with a given product, designing for eco-effectiveness moves beyond GHG emission targets by "focusing on the development of products and industrial systems that maintain or enhance the quality and productivity of materials through subsequent life cycles".[75]

In the case of electronic devices, eco-efficient smartphones and computers would, for instance, be manufactured with more energy-efficient components. In turn, eco-effective smartphones and computers would be designed according to circular principles (figure 4) and be manufactured with more sustainable materials. As such, the overall environmental impact is at the heart of eco-effective design strategies. While these principles improve the circularity of the product, they may not be cost-effective nor reduce short-term GHG emissions.

These trade-offs do not imply that decision-makers should discard circular design strategies. Instead, they demonstrate that companies that seek to become more sustainable and circular face inherent dilemmas. Understanding these trade-offs and avoiding tunnel vision is thus pivotal for a successful and systemic transformation toward circular devices.

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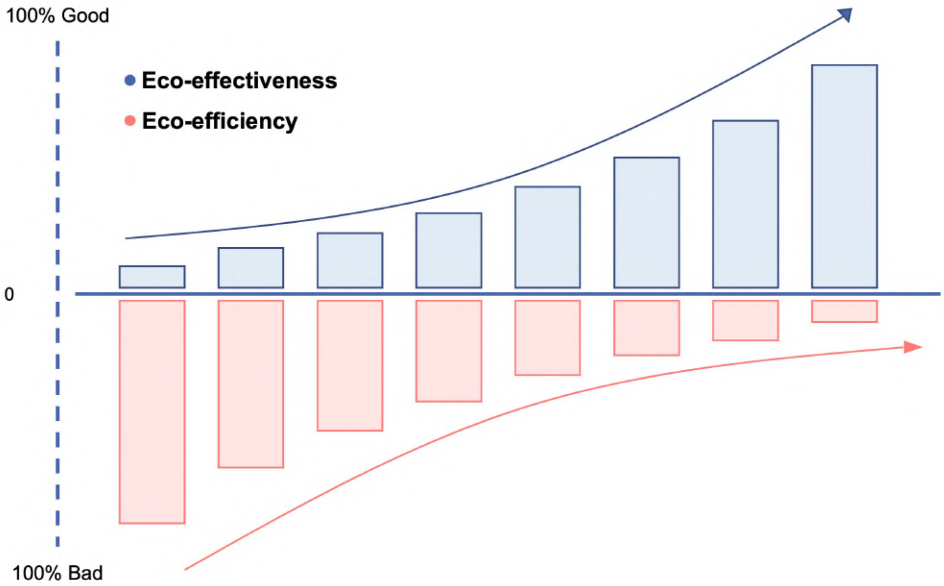
[73] Nair and Datta, "The Circular Economy: Could It Provide Opportunities for Greener and Better Jobs?," 2021.

[74] Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows, and Resources," 2020.

[75] Braungart et al., "Cradle-to-Cradle Design: Creating Healthy Emissions - A Strategy for Eco-Effective Product and System Design," 2007, p. 1337.

Figure 5: Eco-effectiveness vs. eco-efficiency



Adapted from The Upcycle Chart ©2016 MBDC, LLC.

Background: The Risk of Carbon Tunnel Vision

The carbon tunnel vision is a well-established risk associated with the transition toward sustainability. Put simply, the concept seeks to capture the danger of focusing solely on carbon reductions and thus disregarding other dimensions of sustainability. However, the idea is easily relatable to other issues, including starring blindly at circularity.

If the transformation toward circular devices is to be successful and sustainable, it is pivotal that decision-makers embrace a more holistic perspective and incorporate different dimensions of sustainability into their practices. A life cycle assessment and/or a social life cycle assessment can be used to cast light on issues such as biodiversity loss, air pollutants, poverty, inequality etc.[76]

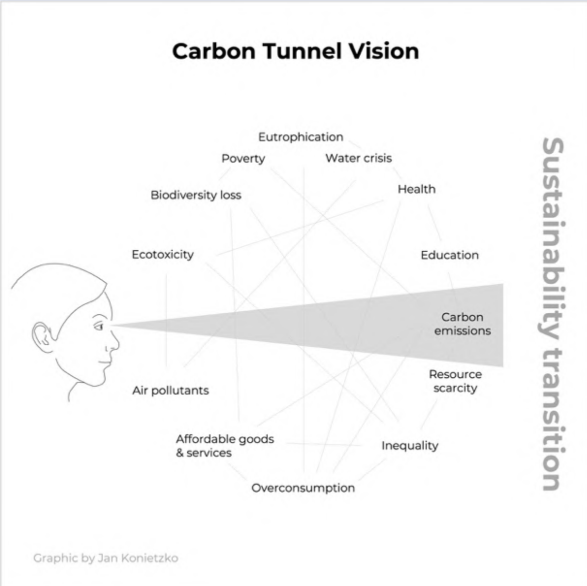


Illustration: Jan Konietzko

[76] Konietzko, "Moving beyond Carbon Tunnel Vision with a Sustainability Data Strategy," 2022.

The rebound effect: When good intentions have adverse environmental effects

The circular economy for smartphones and portable computers is supposed to improve the environmental sustainability of the devices. However, under certain conditions, the transformation toward circularity may indeed have the opposite effect and increase production as well as consumption levels.[77] This is known as the rebound effect or the Jevons Paradox.

Put shortly, the rebound effect is associated with the unintended outcomes of behavioral or systemic reactions to technological change, including improved environmental efficiency.[78] Rebound effects occur when circular strategies create price reductions that ultimately increase production and consumption levels or when the circular products do not replace the demand for new products perfectly. In both cases, the environmental benefits of the circular transformation are reduced.

In a study conducted in the U.S., Makov and Vivanco demonstrate that the rebound effect could offset 27-46% of the life cycle GHG emissions savings associated with reusing smartphones.[79] For other regions, the authors suggest that the emission savings could be offset completely by the rebound effect and thus have a 'backfire effect'. While it is possible to mitigate this effect and promote behavioral change through taxes, consumer education, and reduced aggregate demand,[80] the study demonstrates that circular activities must be chosen wisely and designed in a way that truly fosters a more sustainable future.

Background: The Rebound Effect in a Nutshell

According to Zink and Geyer,[81] the rebound effect occurs "when circular economy activities, which have lower per-unit-production impacts, also cause increased levels of production, reducing their benefit". It is common to distinguish between direct and indirect rebound effects.

Direct rebound effect

Direct rebound effects occur when a low-impact, secondary product or part does not fully replace the primary production of the given product or part (imperfect substitution). Consequently, the production of a circular product and/or service (e.g., refurbished smartphones) may happen in addition to the primary production, thus reducing the positive impact of the circular strategy.[82]

Indirect rebound effects

Indirect rebound effects refer to price changes that occur because of increased demand for circular goods.[83] For instance, when products such as recycled plastic or refurbished phones are sold at a discount due to their (sometimes perceived) inferior quality, buyers have more money to spend on the same product or other goods and services.[84] This gives the buyer additional spending power (income effect) and may reduce the positive impact of a circular transformation. Additionally, as the price of primary and secondary goods compete with one another, the prices of both goods will decrease over time due to supply and demand dynamics. As such, the indirect rebound effects may increase overall production and consumption levels, which, in turn, may harm the environment.[85]

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[77] Rizos et al., "Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods Industry: Opportunities and Challenges for Businesses, Workers and Consumers – Mobile Phones as an Example," 2019.

[78] Makov and Vivanco, "Does the Circular Economy Grow the Pie? The Case of Rebound Effects from Smartphone Reuse," 2018; Castro et al., "The Rebound Effect of Circular Economy: Definitions, Mechanisms and a Research Agenda," 2022.

[79] Makov and Vivanco, "Does the Circular Economy Grow the Pie? The Case of Rebound Effects from Smartphone Reuse," 2018.

[80] Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?" 2022; Makov and Vivanco, "Does the Circular Economy Grow the Pie? The Case of Rebound Effects from Smartphone Reuse," 2018.

[81] Zink and Geyer, "Circular Economy Rebound," 2017, p. 1.

[82] Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?" 2022.

[83] Zink and Geyer, "Circular Economy Rebound," 2017.

[84] Kara et al., "Closed-Loop Systems to Circular Economy: A Pathway to Environmental Sustainability?" 2022.

[85] Ibid.

Similarly, Kara and colleagues point to multiple studies that argue that the direct rebound effect may decrease the positive impact of replacing new smartphones with refurbished ones.[86] Specifically, the authors highlight that the positive impact of refurbished smartphones is likely to be lower than estimated because they tend to be sold in the Global South where the alternative to a refurbished phone would be no phone (as opposed to a new one). While affordable devices can improve social sustainability through increased connectivity, information-sharing, access to micro-financing etc., refurbished phones create a new market potential which may increase the overall production, consumption, and thus environmental impact of the industry.[87]

This is not to say that people in the Global South should be denied access to affordable electronic devices. On the contrary, the examples highlight the inherent trade-offs that exist between social and environmental sustainability and that the environmental impact of circular strategies may indeed be lower than first expected due to the rebound effects. This is why circularity must be envisioned and implemented holistically.

The absolute impact is what matters: is circularity even sufficient?

The described trade-offs and unintended consequences make it worthwhile to question whether the current narrative and promises of untapped growth potential through circular business models can ensure sustainable development. While circular strategies can reduce resource requirements and thus get business models closer to meeting environmental targets, several studies suggest the circular economy will not be sufficient to stay within the safe operating space of our planetary boundaries.[88]

This inevitably casts a shadow over the promises of the circular economy. However, that should not keep decision-makers from pursuing circular strategies. While the initiatives may not be enough, perfection is often said to be the enemy of progression. We thus encourage practitioners, private consumers, and researchers alike to explore the opportunities and potential trade-offs of the circular economy with an open mind and a critical eye.

Photo by AJ Garcia on Unsplash

[86] Ibid. 2022.

[87] Ibid.

[88] Ibid.

CONCLUDING REMARKS

Electronic devices have significantly transformed the way we conduct our daily lives. However, it is now time to address how these devices can be transformed and become part of a more sustainable future. This report took stock of the current state and identified future opportunities as well as underlying sustainability tensions related to circular electronics. Hopefully, these findings will help decision-makers understand the opportunities, challenges, and risks related to IT procurement and circular supply chains.

Current state: the take-make-dispose paradigm still dominates

Linearity continues to be the norm in the electronics sector. High innovation rates, lack of financial incentives, and fashion narratives foster short life cycles that sustain the linear system. Consequently, relative obsolescence and premature replacement cycles remain common, resulting in millions of hibernating devices and a rapidly growing e-waste stream.

A lack of transparency along the supply chain makes the circular transformation of electronic devices even more challenging. Fortunately, these problems are increasingly considered in the political sphere as well as in public and private procurement departments.

Six enablers that can help accelerate the circular transformation of electronic devices

The report identifies six enables that can help promote the circular transformation of electronic devices:

1. Internalize circularity in the design phase of electronic devices,
2. Educate consumers to increase the desire for circular devices,
3. Include circular criteria in procurement practices,
4. Foster higher collection rates and take-back systems,
5. Induce circularity through regulatory measures,
6. Engage in supply chain and stakeholder collaboration.

Underlying sustainability tensions: a note of caution

Despite the high potential of a circular transformation of electronic devices, this report ends with a note of caution. If implemented poorly, the circular transformation may be to the detriment of environmental and social sustainability as it can spur consumption levels and distribute the financial and social gains of a circular transformation unevenly.

We thus encourage decision-makers and actors from across the supply chain to keep these considerations in mind when developing practices that address the current barriers of the circular economy.

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