Future Proofing the Electronics Industry:
The case for circular business models

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pwc

Acknowledgements

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Key Contributors

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In support for this report

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List of abbreviations

B2B	Business to Business
B2C	Business to Consumer
BAU	Business As Usual
CAGR	Compound Annual Growth Rate
CDP	Carbon Disclosure Project
CO_2e	Carbon Dioxide Equivalents
EEE	Electronic and Electrical Equipment
EPR	Extended Producer Responsibility
EU	European Union
E-waste	Electronic Waste
GHG	Greenhouse Gas
ICT	Information and Communication Technology
LCA	Life Cycle Analysis
PaaS	Product-as-a-Service

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Executive summary

Case for rethinking

Electronics have become an integral part of our daily lives. Driven by a myriad of factors such as digitalisation, a burgeoning global middle class, and exponential innovation, demand across various segments such as consumer electronics, ICT, industrial and medical electronics, and automotive electronics are higher than ever before. This increase in demand coupled with the current predominance of linear business models within the electronics industry give rise to a potentially significant increase in negative environmental impacts.

Electronics are associated with a high demand for raw materials and substantial energy use during the manufacturing process. Electronics consumption follows a pattern of short usage periods and premature end-of-life. Furthermore, improper control over material flows has led to the growing environmental issue of electronic waste. We believe there is a clear business case for circularity within the electronics industry, with clear indications that circular electronics can help ameliorate these problems while generating value both from a climate and cost effictiveness perspective. Based on this we have made an attempt to quantify this value, and help provide further evidence for the merit of adopting circularity within electronics.

A linear model, rather than a circular one, is dominating today's electronics industry which is associated with a wide range of environmental, social and economic problems along the value chain. Transitioning to a circular economy presents a solution to many of the challenges facing the industry without diminishing the positive impacts of electronics on business and consumers. In this context, it is relevant to point out that the electronics sector is highly responsible for emitted greenhouse gases in all stages of the electronics's life cycle. Currently, the electronics industry is responsible for a significant share of global greenhouse gas emissions, roughly equivalent to the global footprint of the fashion industry.

Circular economy

Today's linear economy follows the take-make-waste principle, which is characterised by sequential stages of resource extraction, production, consumption, and disposal. It is a concept that describes the linear progression of materials and products through these stages, ultimately leading to their end as waste. It is a principle that shows systematic flaws of the linear economy: it is wasteful, harmful and costly. It involves energy, labour, embodied carbon emissions and other resources to create the final goods that will be in use for only a relatively short time.

Linearity, in many cases results in inefficient disposal methods that are environmentally harmful, leading to pollution, resource depletion, and negative impacts on ecosystems and human health.

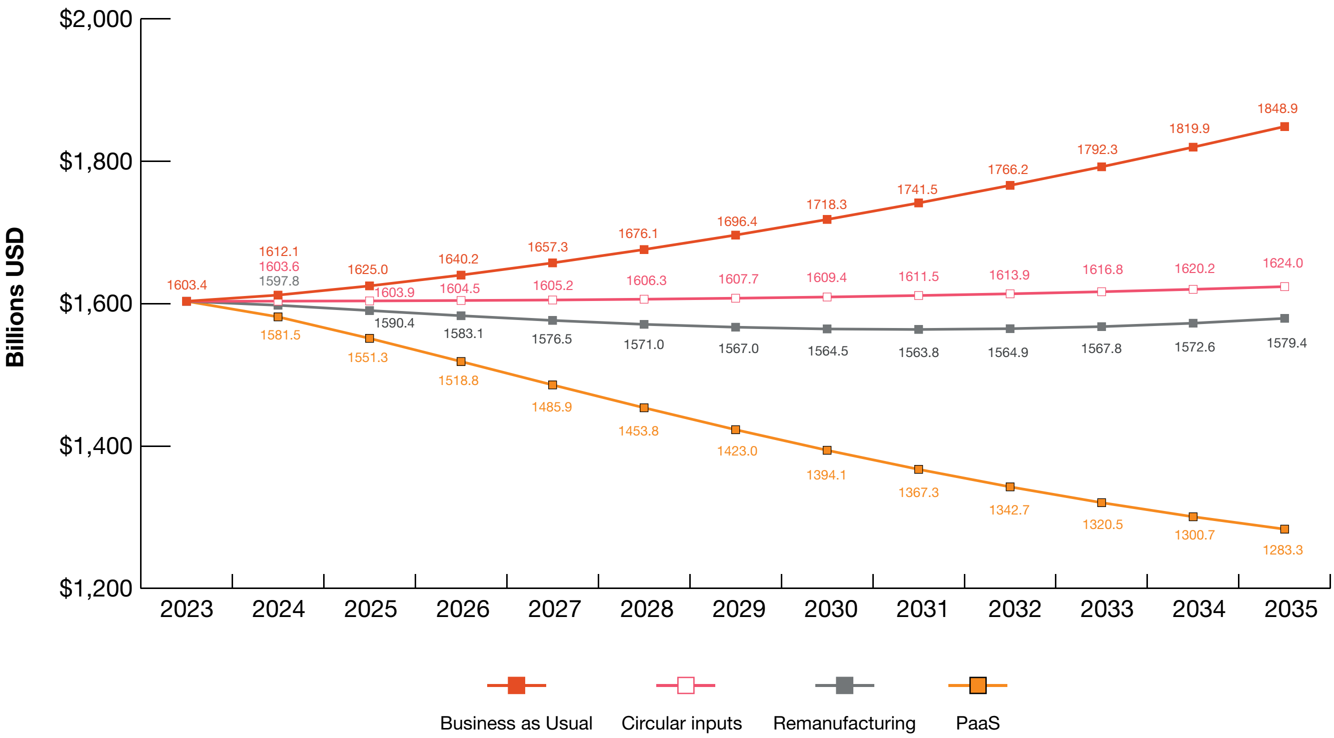
To address the challenges associated with the linear economy, a transition to a circular economy is imperative. The circular economy aims to maximise resource efficiency, design out waste, and promote the reuse, recycling, and refurbishment of products. Circularity follows principles that want to restore natural capital and is inspired by systems thinking with the act of designing products, business models and systems in such a way that economic activity is decoupled from the consumption and destruction of finite resources and nature.

The circular economy is not just about resource efficiency and decoupling, but also about mitigating climate change by an absolute reduction of carbon emissions in the atmosphere. The circular economy is expected to have many co-benefits that enable sustainable development in the fields of climate change, natural capital and biodiversity.

A series of transitions are needed to realise benefits

We present, in this report, the results of our analysis, produced after nearly a year of research & collaboration both across the firm and with external parties, where we have attempted to quantify the climate and financial benefits of moving towards a more circular business model. We have done so using the electronics industry as a case study, but we believe that nearly all industries have some potential for realising the value of transitioning to more circular business models. Our model has evaluated three different circular business models across four different segments in the electronics industry, and found that different strategies excel across different segments, depending on if the business in question is seeking to optimise for cost reduction or environmental impact, **but our key finding is that all circular business models (circular inputs, remanufacturing and PaaS) analysed in this report prove more cost effective and significantly reduce CO_2e compared to using linear model (business as usual) approach** over the next 12 years.

Figure 1: Cost over time for the electronics sector



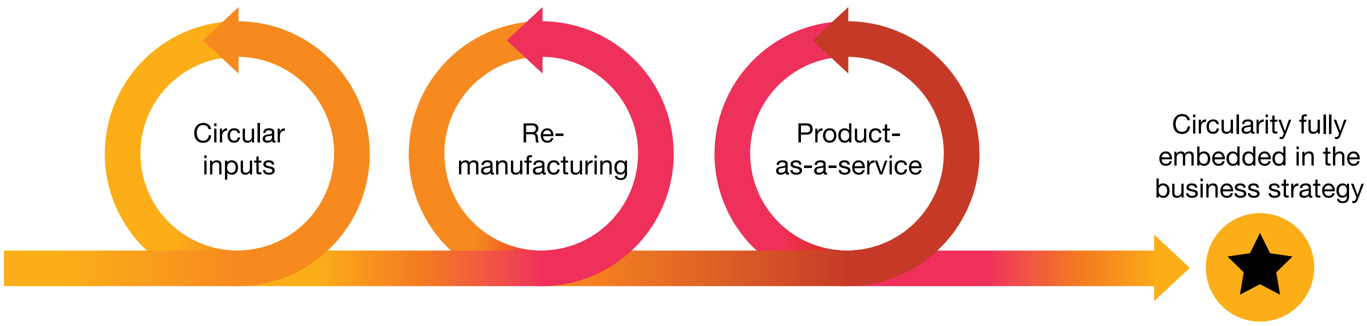
Overall, we found that implementing a circular strategy can lead to an estimated average of 12% in cost savings and 10% CO_2e emissions reduction. Within each segment, we found that product-as-a-service and remanufacturing stood out as the best strategies across consumer electronics, industrial electronics, and ICT, depending on whether one aims to optimise for cost or CO_2e reduction. Within automotive electronics, we found remanufacturing to be the best, as using PaaS at an electronic component level was deemed unfeasible for most actors in the segment at the time of this study.

Nevertheless, it's important to acknowledge that each of these three circular business models requires an initial investment and business transformation. Even apparently straightforward actions, like gradually implementing an enhanced circular input strategy, can yield valuable results and does not require a huge operational or strategic change. Then, as a company matures in its work with circularity, they can gradually move towards more sophisticated business models until circularity is fully embedded in the business strategy, including those not covered by this report.

Moreover, the strategies in practice are often not viewed and implemented in silos but can be implemented in combination to one another. For example, higher cost and CO_2e savings can be achieved through having circular inputs of products in the manufacturing phase and having a PaaS model during the use phase.

There are several factors that encourage companies within the electronics space to pursue circularity aside from those the model has considered, including digitalisation as a driver of business model implementation and increasing resource efficiency, potential partnerships which might provide valuable synergy, as well as a burgeoning regulatory push for circularity. But there are also challenges, such as the aforementioned initial investment and/or business transformation required. However, while we acknowledge the challenges associated with transitioning to a more circular business model, we believe that there is a clear business case to be made for taking the leap, and plenty of value to be captured.

And should you need guidance along the way, you are welcome to reach out to any of our circularity or sustainability experts across the PwC network, and we will be ready to help you capture the opportunity presented by the circular economy and help drive long-term and sustainable value creation for your specific organisation.



Introduction & Background

Digitalisation, a burgeoning global middle class, and exponential innovation are driving a higher demand for electronics across segments than ever before. In the 21st century, technology and innovation play a crucial role in economic development by improving communications, enabling efficiency gains via automation, optimising resource allocation, and more.

Driven by the expanding global connectivity and rapid economic growth in various economies, the demand for electronic and electrical equipment (EEE) continues to escalate. The proliferation of smartphones, tablets, and laptops is allowing an increasing number of people to access the internet, while a rising middle class contributes to the production and purchase of household appliances like refrigerators, washing machines, heating units, and flat panel televisions. Anticipated advancements in connectivity indicate a shift towards decentralised cloud data centres, reducing the reliance on local data centres and corporate IT equipment. Simultaneously, the consumer market for interconnected devices is expected to flourish, with the projected number of connected devices surpassing three times the global population by 2023.

Transitioning to a circular economy presents a solution to many of the challenges facing the industry without diminishing the positive impacts of electronics on business and consumers.

The global electronics market is valued at $1275 billion in 2023 at a CAGR of 7.5% with the Asia-Pacific and North America regions driving demand.[1] However, an estimated 77 million tonnes of electronics were introduced to the global market as a result of this growth, with Asia consuming more than 50%, followed by the Americas (over 20%) and Europe (~18%).[2]

Increased linear EEE consumption has brought into focus the negative environmental and social externalities generated by the take-make-waste status quo. Negative externalities of particular concern to regulators and consumers include the contribution of CO_2e emissions to anthropogenic climate change, short- and long-term health effects resulting from workplace incidents, and environmental and noise pollution for communities near extraction and production facilities.[3] In 2019, only 17% of e-waste was documented to be collected and properly recycled globally, meaning that 44.3 million tonnes of raw materials conservatively valued at USD 57 billion were discarded in one year.[4] In a linear scenario, recoverable high-value materials such as gold, silver, copper, and platinum are being dumped or incinerated instead of treated and reintroduced to the market. In addition to material loss, the improper management of electronic waste has led to the growth of a large informal recycling sector where hazardous practices like burning or dismantling electronics without proper safety measures are prevalent, resulting in disproportionate impacts on the people and environment in developing countries that take on the world's waste.[5]

Transitioning to a circular economy presents a solution to many of the challenges the electronic industry faces without diminishing the positive impacts of electronics on business and consumers. Circular business models aim to create a product system that keeps resources at maximum use for as long as possible and that closes material loops so value is preserved in subsequent use cycles. Keeping materials in a closed loop minimises the negative externalities associated with resource extraction and end-of-life disposal, phases in a product's life with some of the highest reported environmental and social impacts.[6] Circularity is also an opportunity for the electronics industry to increase customer loyalty, net promoter scores, and to create a competitive advantage. Although there are many different circular business strategies, this report focuses on three key strategies hypothesised to have the highest savings potential in CO_2e and cost within the industry: circular material inputs, remanufacturing, and products-as-a-service (PaaS).

Prioritising circularity strategies

As a way to prioritise between circular strategies, companies can refer to the commonly adopted view of the 9 circular strategies ranking where companies should strive to first utilise the strategies at the top of the list, and then make their way down.[7]

- **Refuse** - Is the product designed to fulfil multiple functions so customers are not required to buy different products?
- **Rethink** - Can the company rethink the product to intensify its use? (ex: through sharing)
- **Reduce** - Can the products be made more efficiently and/or can raw material inputs be reduced?
- **Reuse** - Can the products and material be used again in or outside the company or by other users? How easy is it to recover value from my product?
- **Repair** - Can the product be easily repaired to extend its functional life?
- **Refurbish** - Can the product be restored and old parts updated?
- **Remanufacture** - Can the parts of an old product be reused in a new product with the same function? How easy is it to get my product back?
- **Repurpose** - At the end of its life, can the parts of an old product be used in a new product with a new function?
- **Recycling** - Can the materials of the product be recycled to make new products?

Circular business model definitions

Circular material inputs

Circular inputs or material substitution refers to the input of recycled and/or regenerative feedstocks into a product and it also includes the phasing out of toxic and/or hazardous materials. Circular inputs can include a wide range of materials, such as recycled plastics, metals, and glass, as well as renewable resources like bio-based materials and agricultural waste. Recycled materials are materials that have been processed or converted from waste or used products into new products with similar or different properties. This view on circular inputs also aligns with the Ellen McArthur Foundation's view on regenerating loops which include eliminating the use of toxic substances, increasing the utilisation of renewable materials and energy and implementing net positive strategies that leaves the environment in a better state than before.

Using more circular materials is a crucial step to reducing a product's emissions. While the actual design phase of a product is often not the most carbon intensive, the decisions being made on the product components, how it will be used and manufactured can have a big impact on the other life cycle stages. Design is said to be at the heart of the circular economy since the decisions made at the design phase influences how long a product will last, what it is made of, if it can be repaired and what happens at the end-of-life. It is said that approximately 80% of a product's environmental impact is influenced by decisions made at the design stage.[8] Moreover, when looking at companies emissions, 40% of global greenhouse gas emissions are driven or influenced by companies through their purchases and the products they sell.[9] Substituting to less emissions-intensive material can reduce the following Scope 3 emission categories such as 'Purchased goods and services' and 'capital goods'.

Remanufacturing

Remanufacturing is an industrial process that restores used products or components to a like-new condition by disassembling, cleaning, repairing, and reassembling them. In remanufacturing, the original product is returned to its original specifications from the original equipment manufacturer, with any worn or defective parts replaced. Remanufacturing is becoming a critical component to the circular economy as a way to prevent waste generation and reduce the extraction of raw materials. Remanufacturing enables end-of-life products to be sold and used again, reducing waste and extending the product's lifespan.

There are many advantages to remanufacturing products. Remanufacturing decreases economic and environmental costs since less energy is used to remanufacture certain products compared to making new products and thus CO_2e emissions are reduced and the amount of waste sent to landfills is limited. Remanufacturing avoids the cost of procuring and processing virgin materials as the products have already been manufactured and can be reused. It also has the potential to reduce Scope 3 emissions in a company's purchased goods and services, processing of sold products by reducing customer waste through take back programs, and in end-of-life of sold products by reducing customer waste and increasing product lifespan, as less instances of the product would be needed to meet the demand.

Moreover, remanufactured products can be targeted to more price sensitive consumers since remanufactured products can typically cost 30 to 40% less than a new product[10] and enable differentiation against competitors by emphasising their commitment to sustainability (Alatefi et al.m 2023).[11] Many critical raw materials are found in electronics and therefore remanufacturing increases a company's resilience against component shortages and is perceived as a risk-mitigation measure. Some of the most important drivers for remanufacturing are volatile supply and associated costs of raw materials due to increased natural disasters and geopolitical conflicts.

To have an effective remanufacturing strategy, modular design has to be implemented when the products are being designed as if the remanufacturing process is not considered when the product is being designed, it will be difficult to remanufacture the product at its end-of-life.[12] By considering the remanufacturing characteristics of the product at the design stage, it will facilitate product reuse, upgrade and maintenance and make it easier to disassemble and recover. Clear advantages of modular design include improved design efficiency, shortened supply chain, improved product quality and reliability, and good maintainability.[13] These qualities can very much benefit industries as modular design and manufacturing can help make upgrades to key components and keep products relevant and is also a constructive solution to performance-based obsolescence. While the design stage in our model is not the most CO_2e intensive part, research has shown that approximately 80% of the sustainability performance of a product is determined in design and development processes.[14] Using a modular approach does not reduce capital expenses but allows to extend them over the entire life cycle of a data centre which is around 10 years.[15] Operating expenses are reduced and the object's payback period is much shorter. Due to the flexibility of a modular design, it is possible to increase its capacity as the demand for it grows.[16]

Products-as-a-Service

PaaS is a business model in which a company provides a product to customers in the form of a service, rather than selling the physical product itself. Instead of purchasing a product outright, customers pay for the use of the product without any transfer of ownership, usually through a subscription model. In B2B transactions, PaaS transfers the cost of acquiring an asset from a large capital expenditure to more flexible operating expenditure. Adopting such a model can increase the utilisation of a product and extend its useful life with regular scheduled maintenance that reduces unplanned downtime. The provider retains control over the use phase of the product and responsibility for any repairs needed. Therefore, this is a useful strategy when lifecycle emissions are the highest in the use phase of the product.

While PaaS may seem innovative, paying for the use of a product is already commonplace in many industries such as hotels, taxis, railways, airlines and library books. Typically in a purchase-based economy, buyers and providers interact once at the point of sale. In a subscription-based system, buyers and providers maintain ongoing contact throughout the use cycle which builds loyalty and trust. For example, the provider can offer maintenance services during the subscription time and retrieve the product at the end of the subscription for cleaning, repurposing or recycling. An important aspect of PaaS is that for it to make most environmental and financial sense, some repair services have to take place when a returned product needs fixing. To facilitate repair services, these considerations have to occur during product design, so that the product can easily be disassembled and put back together again at a later stage.

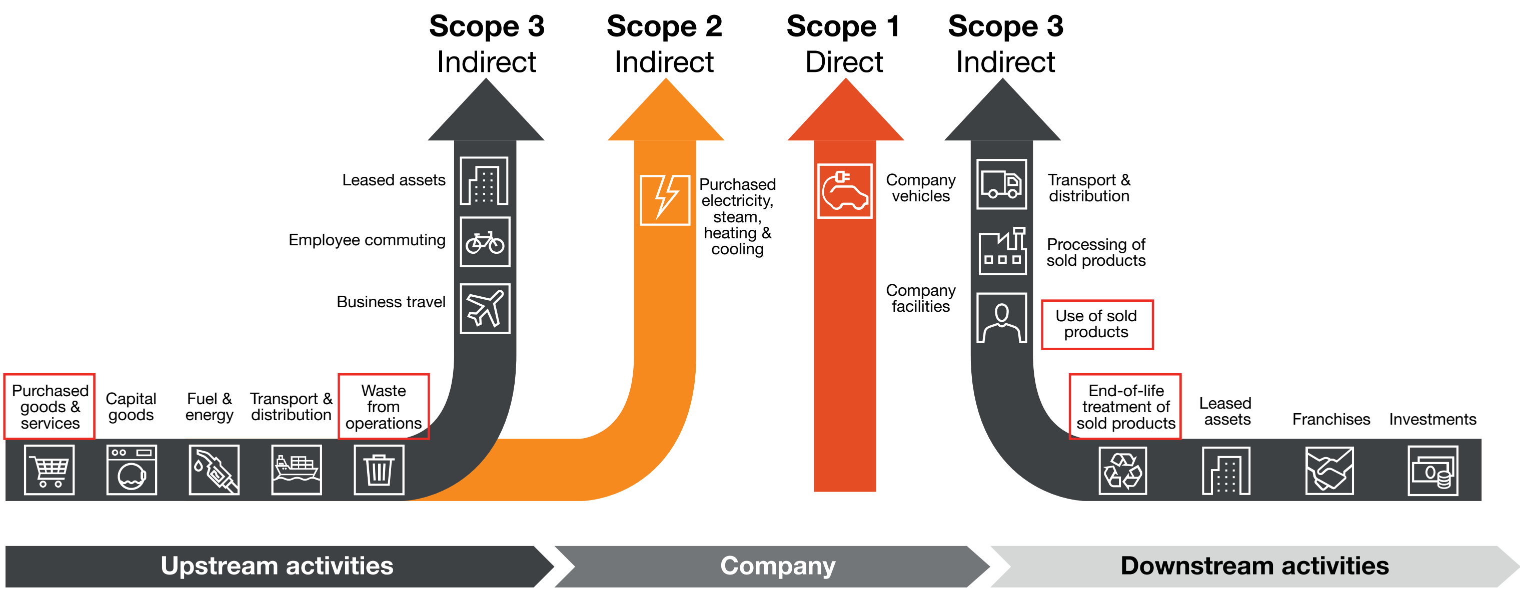
Implementing a PaaS model can reduce emissions in Scope 3 categories especially in the 'use of sold products and services' by providing access to multiple users to share the product, selling products as a service, and increasing product's life span through resell and reuse. It is worth noting that from a greenhouse gas (GHG) accounting perspective, the emissions from the product in question might increase as the use phase of the products is extended.

> "Companies can create programs to take back used products, refurbish or remanufacture them, and sell them again. This not only reduces waste but also opens up new market segments for more affordable, pre-owned devices."
>
> Andreas Nobell, TCO Development

Emission reporting with Greenhouse Gas Protocol

Carbon accounting is a way of measuring how much greenhouse gases an organisation is emitting. The GHG Protocol is the world's most widely adopted GHG accounting standards for measuring GHG emissions outputs. The GHG Protocol establishes comprehensive global standardised frameworks to measure and manage greenhouse gas emissions from private and public sector operations, value chains and mitigation actions.

Emissions are separated into 3 different scopes: Scope 1 and 2 relate to direct emissions from the company operations that are under their control such as company cars, generators, electricity consumed, while Scope 3 emissions relate to all the other indirect emissions both upstream and downstream from the company which are separated into 15 categories. Scope 1 and 2 emissions are often the easiest to calculate compared to Scope 3 but the bulk of emissions are often attributed to Scope 3. In fact, the Carbon Disclosure Project (CDP) estimates that Scope 3 emissions account for 75% of total company emissions.[17] The illustration below emphasizes Scope 3 emissions categories where the circular economy plays a vital role in driving reductions.



There are three different types of PaaS offerings:

- **Subscription-based services:** Customers pay a monthly or annual fee to access the product or service, with the option to cancel or upgrade at any time.
- **Pay-per-use:** Customers pay for the actual usage of the product or service, or for specific outcomes achieved through its use. This approach is commonly used in industries such as transportation, energy, and healthcare.
- **Leasing:** Customers pay to use the product for a specific period of time, with the option to return or renew the lease at the end of the term.

PaaS models create value for both the provider of the service by enhancing customer relationships, creating new revenues and making them more competitive and for the customers by minimising the total cost of ownership and only using the product when they need it. PaaS models are a big opportunity for the electronics industry to capitalise on as it incentivizes companies to create new revenue streams.

PaaS has proven to be a good business opportunity as long-term contracts secure future revenue streams, it establishes strategic product differentiation, a more integrated and long term relationship is established with the customer and use of raw materials is optimised.[18]

> PaaS models encourage the creation of durable, easily repairable products because the companies still own them and are responsible for their upkeep. This approach not only generates a consistent income but also helps in building stronger relationships with customers.
>
> Andreas Nobell, TCO Development

The potential for circularity in the electronics industry

There is a reluctance in the electronics industry to invest in circular business transformations due to limited specific demand from customers in B2B segments and the fallacious assumption of a tradeoff between climate progress and financial performance. However, shifting to circular business models could lead to operational cost savings due to its contributions to developing supply chain resilience and decreased need for material extraction and disposal at the end of a product's useful life.

Factors that make the electronics industry uniquely well positioned to implement circular business models include:

- **Global supply chain:** The electronics industry has a highly globalised supply chain, capturing efficiencies from regional differences in cost of labour, raw material availability, skill sets, and proximity to markets. However, the disruption of this global supply chain has led to major losses across industry segments, such as in the case of the recent worldwide chip shortage.[19]

- **High product value and durability:** Many segments of the electronics industry manufacture products that perform high-value functions and can be built for durability. As such, they satisfy conditions for successful implementation of transformative circular business models such as PaaS and remanufacturing.

- **Dependence on scarce, non-renewable materials:** The production of electronic products require large volumes of scarce raw materials such as rare earth elements, cobalt, lithium, and indium. And the mining of certain minerals, such as tin, tantalum, tungsten, and gold (3TG) in particular has contributed to human rights abuses and armed conflict in the global south and as such, are subject to strict import regulations.[20] Responsibly recovering these minerals from products that have reached the end of their useful lives would almost guarantee conflict-free sourcing of critical inputs with reduced need for supply chain due diligence.

- **Price elasticity and market segmentation:** The electronics industry is growing across markets and B2C and B2B customer segments driven by the industrialisation of developing nations and the rise of Industry 4.0. This means that there will be a wide range of customer types with differing performance requirements and price sensitivity. Circular business models would enable producers to target a broader spectrum of customers in markets and industries deemed commercially unviable in a linear scenario.

- **Environmental and social responsibility:** The electronics manufacturing industry faces increasing scrutiny regarding environmental sustainability and social responsibility. Businesses in the electronics sector need to adhere to stringent regulations and demonstrate transparency in their supply chain to meet consumer and regulators' expectations.

Putting circularity to action requires a fundamental paradigm shift toward business strategies that decouple economic growth from endless resource extraction. This report aims to make the case for applying circularity principles for the electronics industry to unlock the full potential of future-resilient business models.

Methodology & Scope

Sustainable development, which circularity can be a driver of, is commonly defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Historically, sustainability initiatives have been seen as a cost, one not gladly borne unless there has been a clear tradeoff, such as a marketing advantage or need for regulatory or legislative compliance. However, there is a clear need for the electronics industry of today to operate in a manner that is sustainable for the industry as a whole, and an overall global need across all industries to minimise negative climate impact for the sake of the planet.

We have tried to prove two hypotheses, that circular business models, specifically within the electronics industry, are, when compared to a linear business as usual (BAU) scenario, (1): more climate friendly, as measured from a CO_2e perspective, and (2): lead to greater operational cost savings. We did this by modelling the BAU scenario over time as compared to three circular business model scenarios, and seeing how this would affect the costs and CO_2e emissions of a hypothetical average company by 2035. 2035 is the year we've set as to when the company would hypothetically achieve business model maturity in their new circular business model. The model tracks CO_2e and cost development starting from 2023, assuming an initial investment phase followed by gradual changes in the company's operations until full maturity is reached. Our primary focus has been CO_2e data, capturing Scope 1, 2 and 3 emissions both upstream and downstream, as well as operational costs from a product perspective.

In a linear business model, material value erodes throughout the use phase until it is negative at the end of life, whereas circular business models strive to maintain the value of those materials at the end of life. We chose to focus on a material flows perspective as we deemed it comparable both across the diversity of products and geographical differences within the global electronics industry.

In a linear business model, material value erodes throughout the use phase until it is negative at the end of life, whereas circular business models strive to maintain the value of those materials at the end of life.

The input data, from which we constructed our model and future scenarios which are presented herein as our research results, was constructed predominantly by life cycle analyses (LCAs) and life cycle costing analyses (LCCs), and market and segment size estimates and projections, gathered from public and private databases, research articles, external partners, as well as internal firm benchmarking data. Furthermore, industry experts were consulted for critical insights. We chose this methodology due to the lack of large scale case studies, and the inherent comparability, quantity of, and level of detail within LCAs.

Our model has been designed to operate within specific parameters, primarily comparing linear and circular business models It covers four segments; consumer electronics, automotive, industrial electronics and ICT/telecom. For the consumer electronics sector, the model includes PCs, smartphones, TVs, and similar products, while excluding products such as white goods. In the ICT sector, the model covers products like photovoltaic panels, antennas, and servers. The industrial sector includes products like CT scanners, pacemakers, and assembly-line robots. The automotive sector's focus is predominantly on components for combustion engine vehicles, electric vehicles, A/C, and more. When we in regard to results refer to the whole electronics industry, we are referring to the sum of these four segments. A guiding principle for building the model was the 80/20 rule, emphasising the 20% of products and components that account for roughly 80% of the market volume. This principle was followed as a way to capture a fair representation of the market segments without data collection and synthesis turning into a never-ending endeavour.

Furthermore, our model encompasses four distinct scenarios: Business as Usual, Circular Inputs, Remanufacturing, and product-as-a-service. The model in question operates using variable financial and CO_2e coefficients, which aim to capture the variations that occur across the life cycles of products over time. From a financial standpoint, the coefficients mirror the costs that are associated with both primary and secondary activities, all based on the Porter Value Chain framework. These costs are viewed from the lens of a manufacturer, with the prediction that future carbon pricing will act as a catalyst for more sustainable practices. The model's premise is most valid for industry-average global companies spanning the four aforementioned sectors. However, it is worth noting that the model does not account for any potential unforeseen disruptions such as major geopolitical or catastrophic events that may significantly affect the global economy or electronics value chain. Further limitations are discussed at a later part of this report.

Findings across the electronics industry

The business environment is constantly changing and what is considered to be business-as-usual today will look very different in 2035 due to increasingly stringent regulations and growing market expectations which will lead to more expensive end-of-life costs, raw material extraction, logistics and CO_2e pricing.

Our model projects that the electronics industry as a whole will see a **~15% increase in its operational costs in 2035 compared to a 2023 baseline.** Some of the main factors driving this are: rising landfill prices from higher tipping fees for landfills as they are running out of space; longer distances driven to get to landfills and more expensive gas prices; price volatility of raw material extraction and reserve depletion of critical raw materials used in electronics such as copper, cobalt, lithium and gold; and more CO_2e pricing of carbon intensive industries. In order for companies to prepare and mitigate this rise in costs, companies can explore proactively adopting circular business models as they lead to lower costs due to CO_2e savings and operational synergies and efficiency gains. This is in comparison to passively pursuing minimal compliance with regulations, when sticking to a linear business model.

As seen in table 1, **our model shows that all three circular business model scenarios lead to a cost savings of at least ~12% and a CO_2e reduction of at least ~10% compared to a business as usual model by 2035.** Therefore, it clearly shows that adopting a circular strategy to your business is visibly better regardless of the strategy employed. However, the best circular business model across all industries in relation to the linear model is pointing towards Product-as-a-Service (PaaS). Adopting PaaS has an operational cost savings potential of ~31%, meaning **$566 billion USD for the global electronics industry and a CO_2e savings of ~15%, with an estimated value of over $22 billion USD based on the current price of carbon.**[21]

Table 1:
Cost and CO_2e savings in relation to BAU in 2035

Savings relative to linear 2035			
Cost Reduction	**Circular Inputs**	**Remanufacturing**	**PaaS**
Automotive	10%	12%	N/A
Consumer	12%	13%	27%
Industrial	12%	16%	36%
ICT	13%	17%	34%
All segments	12%	15%	31%

CO_2e Reduction	**Circular Inputs**	**Remanufacturing**	**PaaS**
Automotive	3%	5%	N/A
Consumer	2%	31%	36%
Industrial	6%	9%	8%
ICT	22%	32%	33%
All segments	10%	15%	15%

Figure 1:
Cost over time for the electronics sector

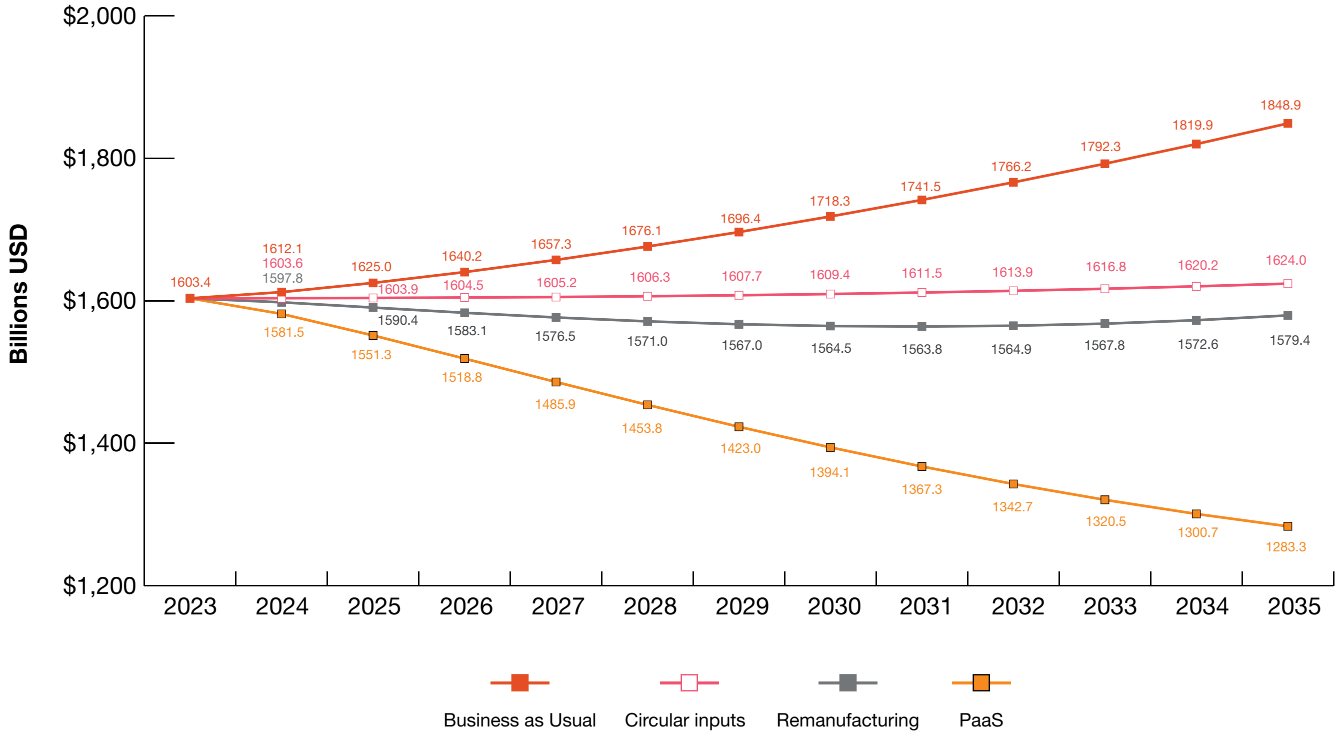
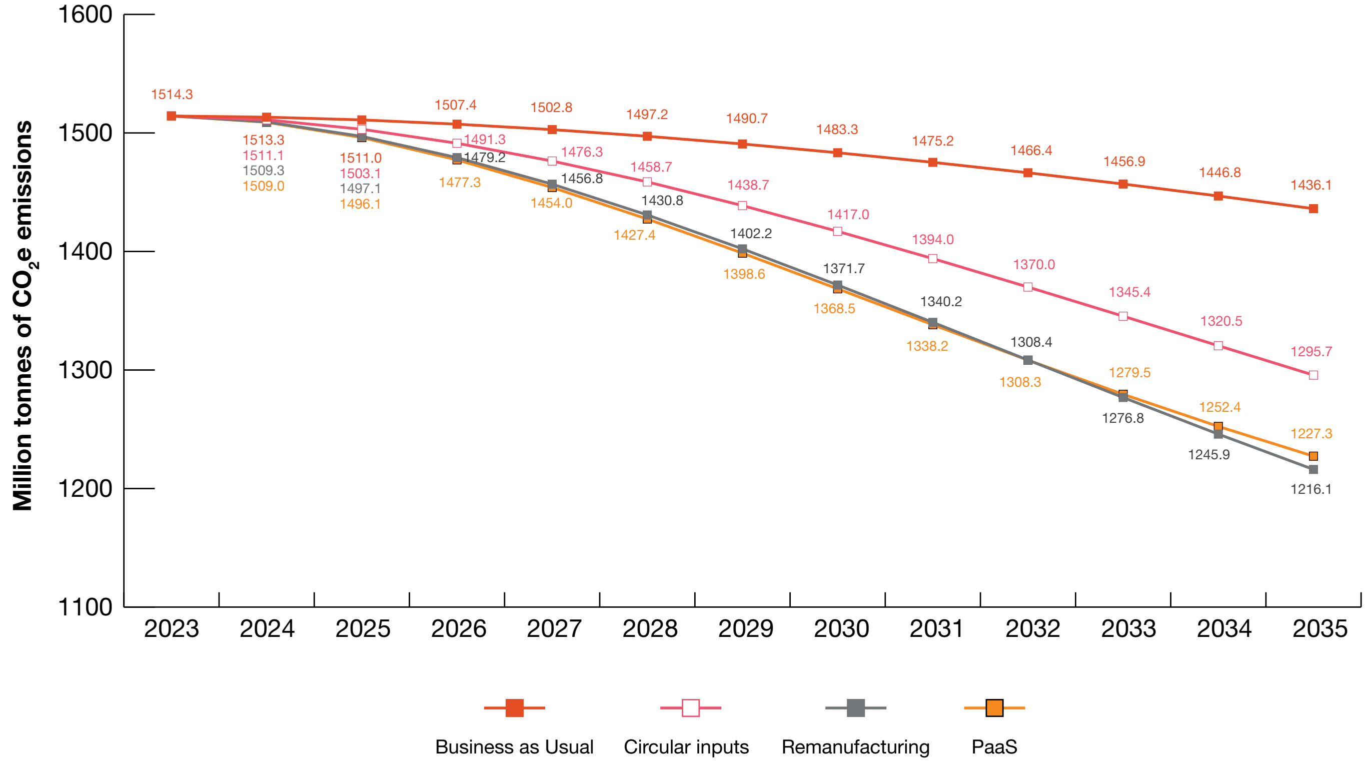


Figure 2:
CO_2e over time for the electronics sector



PaaS

PaaS is gaining in popularity as they allow customers to access products according to their fluctuating needs. Due to a rising uncertainty in revenue streams, competition from low cost countries and price volatility, companies are looking to operate their businesses in a more cost effective way while differentiating their offerings and being more competitive. The advantages of PaaS types of model has already been growing in the past as the proportion of worldwide manufacturers using performance-based service contracts increased to 65% in 2015 and more than 70% of manufacturers are set to use services as a key product differentiators.[22]

By being an early adopter of servitisation models, companies can experience an annual business growth of 5 to 10% of revenues.[23] PaaS models are becoming more popular due to their broad range of applications. They are also transforming consumers into users which allows companies to retain product ownership for easier repair, reuse and remanufacture. This links to a main benefit with PaaS from a circular economy point of view is that this business model incentivises the producer to design for durability and repairability since they only get paid when the products are in use and not when they are broken.

When adopting a PaaS scenario, operational costs such as cost of raw material extraction, production and end-of-life significantly decrease. On the one hand, costs of raw material extraction are substantially reduced over the course of the product's useful life as the production of one product delivers more use cycles compared to the linear business model. End of life costs decrease due to a lower need for product disposal services compared to minimum compliance with extended producer responsibility obligations under the linear business model. On the other hand, CO_2e emissions are also reduced by adopting a PaaS strategy since it extends the useful life of a product, which leads to lower average emissions from raw material extraction and production per use cycle.

Remanufacturing

Remanufacturing shares many of the benefits of PaaS such as extending the useful life of materials, thereby reducing raw materials required to manufacture the same product, drastically reducing the end-of-life disposal costs, etc. However, the biggest distinction between remanufacturing and PaaS is that the latter offers multiple use cycles from one production process when a product is returned to the manufacturer. Since a remanufactured product has to offer a product "as new", it requires each use cycle to undergo production again (hence, re-manufacturing) which is more cost and carbon intensive than PaaS. Moreover, other circular business models such as reuse and refurbishment allow the manufacturer to retain a higher value than refurbishment since less production needs to occur. This should be kept in mind when deciding on the most appropriate circular business model for your company.

When adopting a remanufacturing strategy, operations costs of raw material extraction and end-of-life significantly decrease while design, production and logistics costs increase. Costs related to raw material extraction and end-of-life would decrease due to less materials needed and waste at the end of life since materials are reused for another lifecycle. However, design production, logistics costs would increase due to companies having to adapt their business model, review how they design their products to ease remanufacturing at a later stage, and take back of their products from customers to prepare for remanufacturing which can be quite costly for bulky products like industrial electronics and ICT. The CO_2e emissions would be found in raw material extraction, production and end-of-life, following the same reasoning as in costs.

Circular inputs

According to our model, circular inputs business model is not the most impactful standalone business model in any of the industry segments evaluated since cost and CO_2e savings from remanufacturing and PaaS scenarios are significantly higher. Incorporating circular inputs in electronic products would not require a business model change and has low barriers to entry since it is about using different materials but does not influence the use, logistics or end-of-life of products. Using recycled materials as input for products lowers the emissions from raw material extraction and rather leaves the rest of the products' life cycle fairly similar to the linear business model. Nevertheless, using circular inputs also means substituting harmful and hazardous materials with renewable, recycled and biobased materials in the production process. This is a very important aspect of this strategy since electronics contain many hazardous chemicals such as lead, cadmium, and mercury that are harmful to the environment and human health. Proper recycling of electronic waste is a key part to avoiding these harms taking place.

In the following sections, we will go into detail for each electronic segment projections for 2035 and which circular business model is the best from a cost and CO_2e perspective.

Automotive electronics

The global automotive electronics industry is a vital and integral part of the automotive sector, as it controls vehicle functions and enhances safety and performance since the commercialisation of motorised vehicles. The automotive electronics sector is expected to continue growing in the coming years mainly being driven by the increased automation and digitalisation driven design technologies to enhance better driving assistance, advance vehicle safety and improve in-vehicle user experience. The rising popularity of electric vehicles and automated vehicles combined with government initiatives to promote the use of zero-emissions vehicles is also driving this market development, which leads to a higher demand for automotive electronics. In this report, automotive electronics refers to the electronic components and systems used in vehicles to enhance their performance, functionality, safety, and comfort. These electronics include various components such as engine management systems, infotainment systems, navigation systems, driver-assistance systems, sensors, control modules, and communication systems. They play a critical role in modern vehicles, enabling features such as engine control, entertainment, connectivity, advanced driver assistance, and overall vehicle management.

While the model yields that PaaS has the potential for even greater reductions, we have chosen to exclude it from the analysis owing to the high degree of difficulty of implementation within the automotive electronics segment, at the moment this report was written. While PaaS is not feasible specifically for automotive electronics, the automotive industry as a whole has seen one of the biggest shifts to the sharing economy with the huge growth in sharing-based and access-driven solutions in the mobility industry. Driven by a change in the attitude of younger generations around mobility, new services are popping up in every city for car sharing services like Zipcar, DriveNow by BMW, Car2Go, GoMore and Volvo on demand and ride sharing services like BlaBlaCar.[24] However, this growth of car sharing solutions are at an OEM level and does not necessarily mean that PaaS is applicable at Tier 1-2-3 suppliers.

Remanufacturing

With PaaS being excluded, our analysis indicates that remanufacturing is the best circular business model due to the projected cost and CO_2e savings potential in addition to feasibility of implementation for actors within the segment. The core findings of our analysis suggest that the remanufacturing scenario presents a ~12% reduction in costs, confirming its financial attractiveness to manufacturers, while also offering a 5% reduction in CO_2e. The biggest cost (~61%) and CO_2e savings (~59%) are in the raw materials extraction since often the remanufactured part of the product is the “core” which is the most expensive part. Naturally, there is also an increase in logistics costs (of approx. 23%) and CO_2e emissions (of approx. 9%). Major savings also occur in the end-of-life stage in both cost (~30%) and CO_2e (~83%). These figures are all in relation to a 2035 linear scenario.

The rationale behind remanufacturing being the best strategy can be attributed to the fact that remanufacturing involves the refurbishment and restoration of used electronic components which replaces full-scale production with cleaning, testing, and minor repairs. Currently, electronic components are often intricately designed to suit specific models, making hardware upgrades challenging due to compatibility issues and high resource consumption. However, by integrating circular and modular design principles, the potential arises to create standardised components that can be easily replaced or upgraded, reducing the environmental impact associated with manufacturing new components for each model. This shift towards more modular and interchangeable designs presents a significant opportunity for remanufacturing, as it becomes feasible to refurbish and reintegrate upgraded components, contributing to both sustainability and cost-effectiveness. Indeed, by reusing and repairing existing parts, remanufacturing reduces the demand for new raw materials and energy-intensive manufacturing processes, thus conserving valuable resources. Currently, the biggest users of remanufacturing services are original equipment manufacturers (OEMs) like GM, Chrysler, Toyota and Honda who use these services to handle recalls that require replacements and for tier 1 suppliers to OEMs like Bose, Clarion and Aptiv who use remanufacturing services when there are problems with entertainment services and radios.[25]

As the automotive industry experiences rapid shifts, the traditionally prominent remanufacturing practices in mechanical components are now expanding. The industry has demonstrated leadership in this area, with remanufacturing practices deeply embedded, albeit more commonly in mechanical components than electronics. However, the potential for remanufacturing electronics is becoming increasingly salient. The transformative dynamics sweeping through the automotive industry are rapidly gaining substantial momentum driven by consumer preferences and regulatory changes. This demand-driven shift is pushing the industry to adopt circular strategies like remanufacturing, particularly in the realm of electronics, to meet the evolving expectations of environmentally aware consumers and new regulatory frameworks. As a result, a noteworthy number of new competitors have entered the electric vehicle domain. Followed by that, automotive enterprises and their collaborative partners committed substantial resources to software innovation and advancing electrification initiatives. While remanufacturing has been less prevalent for electronics within vehicles owing to their relative complexity, this is expected to change as cars increasingly integrate electronic components to support critical functions such as EV batteries, safety systems, etc. Moreover, existing secondary markets and dismantling services can be leveraged to expand the scope of remanufacturing to include auto electronics, bolstering the industry's commitment to circular practices.

In summary, the automotive industry's most elegant solution lies in prioritising remanufacturing over other stand-alone circular business models, although it should be noted that, in a real business case, incorporating several circular practices is what could be the most impactful strategy. This choice, driven by historical success and industry expertise, aligns with practicality and sustainability. Collaborative efforts and partnerships will be pivotal in driving the transition, capitalising on the industry's existing leadership in remanufacturing. The promising landscape of electronic integration foretells an evolution towards remanufacturing automotive electronics, supported by an increasingly sustainability-driven automotive industry. Through these steps, the automotive industry can chart a course towards reduced climate impact and enhanced financial viability.

Consumer electronics

Consumer electronics have become an integral part of modern life, impacting communication, entertainment, productivity, and daily living. The market relevance of consumer electronics is immense, with billions of devices being sold and used worldwide. The industry is driven by rapid technological advancements, increasing demand for connectivity, digitalisation, and changing consumer preferences. Consumers seek devices that offer convenience, functionality, connectivity, and improved user experiences. Since consumer electronics covers a wide range of products with different purposes and emissions, the focus of this report is only on so-called "black goods" which includes devices and appliances intended for personal and household use, such as smartphones, televisions, computers, audio systems, gaming consoles, and cameras. For this report, personal IT equipment is also included that is directed to private or professional end-consumers, e.g. computers, laptops, and peripherals like keyboards, mice, and printers. To clarify, so-called 'white goods' such as fridges, laundry machines and freezers have been scoped out. This is due to large variations in emissions hotspots, differing lifespans and intended purposes.

PaaS

According to our model (see table 2), PaaS seems to be the best strategy from both a cost and emissions perspective for consumer electronics leading to cost savings of ~27% and CO_2e savings of ~36%, the highest CO_2e savings across all industries and segments compared to a linear 2035 scenario. This makes sense since the biggest source of emissions for devices such as smartphones and laptops, is the raw material extraction and production (76%) since energy usage is quite low during use.[26] Therefore, solutions like PaaS that prolong the life of products and remanufacturing models to reduce raw material extraction and avoid the need to produce more consumer electronics such as phones can be a very beneficial way of saving costs and reducing emissions per product. This was reflected in our model where raw material extractions savings were ~67% for costs and ~70% for CO_2e, relative to a linear 2035 scenario. This is especially valuable since devices such as smartphones and televisions which are currently being used for shorter amounts of time than both their designed and desired lifetime.[27] Since smartphones are the primary consumer electronic device by revenues and units and contributes to a major part of the wider communications market,[28] the report uses it as a case example.

From a Global Warming Potential (GWP) perspective, our phones should last at least 20 years longer than they currently do and therefore it requires a significant change in how smartphones are being designed and marketed.[29] The bulk of emissions from making a new smartphone originates from the raw material extraction, processing and production phases. Indeed, the production of phone components, which contain rare and critical raw materials, is material and energy intensive. To show, it is said that 1 million smartphones contain 15 kg of palladium, 34 kg of gold, 350 kg of silver, and 16,000 kg of copper.[30] 75 kgs of resources are used to produce a new phone that is used for only 2.7 years with 1.2 billion being sold each year (2022).[31] Nevertheless, prolonging life may not be enough because people do not buy a new smartphone because it breaks but for other reasons such as to keep up with latest technology, because they are offered upgrades with their contracts or because they feel locked into frequent hardware upgrades.[32] Manufacturers therefore have to focus on the improvement options in the design phase to promote longer use. This could be through interchangeable casings and chargers, upgradability options for both software and hardware and replaceable batteries and screens.[33] A frontrunner in this industry is Fairphone who celebrates its 10 years on the market this year who has the goal to craft the world's most ethical phone. In an effort to incentivize people to use their phones for longer, they have a PaaS offering called "Fairphone Easy" which was launched as a pilot as a smartphone subscription service in the Netherlands. Indeed, since smartphones contain most of our private consumer information and store a lot of users' life memories, companies that are going to move to PaaS models need to have strict and transparent consumer data protection policies as consumers could easily be reluctant to hand back a phone for fear of data leakage. Consumers also have a preference for ownership of smartphones and they tend to perceive cost of usage as higher than cost of ownership and therefore the business case for consumers to switch to an access-based rather than ownership-base should be made clear.

> Data Security Concerns: For devices that hold data, such as computers and smartphones, data security can be a significant concern. Consumers and businesses may be reluctant to return devices for reuse or recycling out of fear that their data might be accessed by unauthorised parties.
>
> Andreas Nobell, TCO Development

PaaS strategy within B2B consumer electronics have manifested through the use of Device-as-a-Service which is a model where customers can get their hands on computers, smartphones and other computing devices as a paid service. The advantages would include simplifying customers needs by not having to worry about device management aspects such as device backups, asset tracking, and end-of-life disposal.[34] Many companies like Lenovo, HP and Foxway are offering these services to companies to use in their IT equipment. This type of product offering is quite beneficial on a company scale and thus this strategy has mostly been implemented in a B2B setting. This type of model helps to increase the lifetime of devices through usage of devices in multiple lifecycles. Some companies like Foxway also refurbish or repair the majority of the devices they get back so they can be used for another lifecycle. Companies who opt for Device-as-a-Service models have greater flexibility as they have the ability to scale up or down depending on business needs or temporary project needs and devices can be recirculated to a new employee. As with other types of PaaS models, it has a predictable cost structure with a monthly subscription fee and an off-balance sheet solution.

The pace of innovation in the consumer electronics industry is fast, with manufacturers constantly striving to introduce new features, improved performance, and sleek designs. Companies invest heavily in research and development to stay competitive and meet the evolving needs of consumers. Product innovation focuses on areas such as display technology, battery life, processing power, camera capabilities, software features, and user interfaces. As consumer electronics continue to evolve, sustainability and environmental considerations are gaining prominence. Manufacturers are increasingly emphasising energy efficiency, recyclability, and responsible sourcing of materials. The industry is also witnessing a growing trend of refurbished devices and extended product life cycles as part of efforts to reduce electronic waste.

Moreover, consumer electronics is expected to continue in a current upward trajectory caused by the rising disposable income of consumers, market witnessing a rapid change in technologies and the introduction of latest technology like IoT, AI, cloud computing which are significantly influencing consumer electronics market. As the market for new smartphones is growing, so is the market for used smartphones: conservative estimates range from 100 to 140 million used smartphones which were sold and traded in by consumers, representing a USD ~18 billion market. The used smartphone market is a fast growing market, outperforming the overall smartphone market

four to five times.[35] To showcase, in the United States, the Environmental Protection Agency reported that more than 416,000 cell phones are disposed of everyday (151 million phones a year) and that the average American is expected to buy a new cell phone every 24 months.[36] On top of that, Americans are said to have spent over $3 billion USD in 2017 fixing smartphone screens.[37]

Circular business models such as PaaS are thus a good way for companies to take advantage of these existing markets by developing business models such as affordable leasing or PaaS to reduce the number of products by increasing utilisation rates and thus reduce environmental impact. According to a study from the European Environmental Bureau in 2019, extending the lifetime of all smartphones, laptops, washing machines and vacuum cleaners in the EU by one year would lead to annual savings of around 4 million tonnes of carbon dioxide by 2030, which is equivalent to taking over 2 million cars off the roads for a year.[38]

A PaaS strategy could also be extended to incorporating a remanufacturing component when the product is returned because it is no longer functioning. Indeed, the remanufacturing of valuable electronic components like the semiconductor and integrated circuits would make business sense since they are often the most expensive part of electronic products.[39] However, it is rarely applied today even though it would make sense from both an environmental and cost perspective. This is due to the fact that the semiconductor technology has a very fast innovation cycle which leads to a high variation in the semiconductors available on the market and thus the difficulty is to find appropriate phones to remanufacture.[40]

It would also make a lot of business sense to offer repair services as it is cheaper to repair a broken part of a product for companies than to make a whole new product. On top of that, current regulations such as the EU Right to Repair and Ecodesign Directive, the self-declared repairability index in France's recent Zero Waste law, and Sweden and Austria have also adopted financial incentives are all pushing for easier access to repair services for consumer electronics.

Industrial electronics

Industrial electronics is a broad field where the industry manufactures electronic equipment for industrial purposes. It caters to specialised electronic equipment used in industrial processes, manufacturing, automation, medical devices, scientific instruments, control systems, and other professional applications. In terms of this report, it includes B2B heavy machinery like industrial robots, temperature sensors, pacemakers, ultrasound devices, CT scanners, MRI scanners, human-machine interfaces (HMI), and other industrial equipment like induction motor, synchronous reluctance motor and emotional quotient metres.

The results from our model for the industrial electronics sector are not as clear cut as the automotive and consumer electronics parts as the CO_2e and cost data point to two different circular business models. From a cost reduction perspective, the best scenario is a PaaS model for industrial electronics and it also has the highest percentage of cost savings potential across all four industry segments compared to the linear model, standing at ~36%. However, the CO_2e savings are only ~8% with remanufacturing leading to slightly higher CO_2e savings (~9%). Therefore, in the following paragraphs, both circular business models will be expanded on as potential avenues for companies to change their business towards.

PaaS

Having a PaaS model is ideally suited for industrial electronic products since they are designed to be durable products and are considered high value capital investments. A PaaS business model aligns with the interest of both parties since customers pay for performance and not ownership of machinery and they can thus focus on their core operations. Their machinery would then shift from CapEx to OpEx on their balance sheets. This shift could be an attractive option for start-up companies that do not have access to enough capital or for companies wanting to test the waters in a new market. Moreover, the PaaS business model enables producers of industrial electronics to offer more flexible terms and open to new customer types that have steady revenues, but have insufficient capital to make large asset investments. For example, it allows customers to be more experimental with international expansion or branching out to new business types without committing to a long payback period.

This is also advantageous for producers as they have an incentive in prolonging the useful life of their units and perform regular preventative maintenance to reduce unplanned downtime. For example, Rolls Royce offers "Power by the hour" which is their performance-based circular business model to help reduce waste and optimise resource efficiency.[41] This benefits customers since engines are valuable assets that require high upfront R&D investments and it extends service intervals. This servitisation model helps them reduce waste production and optimise resource efficiency since having engines fly for longer means there is less demand to manufacture new products.

Within the medical device industry more specifically, leasing medical equipment has also a high potential. Indeed, there are many advantages to leasing medical equipment since purchasing it can be costly for many organisations to acquire. Its main benefits include: low initial costs, the possibility to upgrade, quality and affordable services to customers, in certain countries tax on leasing medical equipment is considered a deductible expense, and reduced maintenance and repair costs.[42] For example, Philips offers its healthcare customers a PaaS model of Medical Equipment-as-a-Service where they provide healthcare organisations access to the latest medical technology without having to purchase the equipment upfront.

Remanufacturing

Remanufacturing is the best circular business strategy from a CO_2e perspective with ~9% savings and ~16% in cost savings. Remanufacturing practices are not new in this segment and they have been explored since the 1970s in order to preserve high value products and it is the main circular business strategy used in the sector. For example, manufacturers such as Caterpillar, a manufacturer of construction and mining equipment, have been remanufacturing the core of their industrial machines since 1973 as it makes business sense. It is an affordable alternative for customers since the remanufactured products are offered at 45 to 85% lower costs compared to new products and 80 to 90% less raw materials are used.[43]

Having this offering allows them to tap into a new customer segment that does not have the capital to purchase new products since they require large capital investments. For example, to capture demand amidst rapid development in Egypt, which aims to meet housing needs by expanding its capital city of Cairo to an area nearly as large as Singapore.[44] To build these cities a lot of industrial manufacturing equipment will be required and thus remanufacturing business models could fit those growing needs.

Remanufacturing of industrial electronic equipment has high potential in the medical device industry since oftentimes medical equipment like MRI and CT scanners are disposed of when they have only been used for a few years in exchange for newer models and still have many years of service left. Thus, similar to some consumer electronics, these products are being replaced due to other reasons than the product breaking. These regular product upgrades occur because hospitals upgrade their equipment to stay on top of the latest technology and thus rapid technological innovation is the main reason why many high-end medical devices are frequently replaced since better equipment leads to better diagnosis and treatment of patients.[45]

However, there are large gaps in standards of medical care globally which are continually growing due to the different speeds of development and access to capital. This leads to still functioning products being disposed of when many countries are lacking access to these machines. There is a potential for legacy devices from Global North countries to live subsequent lives improving the standards of care in regions that would otherwise lack these capabilities altogether. In general the medical industry is quite highly regulated and has high standards for reprocessing and remanufacturing of medical devices. Remanufacturing of medical electronic equipment could present a great opportunity for actors that can overcome regulatory barriers.

For example, Philips has their Circular Systems offerings for products like mobile C-arm system, ultrasound, magnetic resonance and computed tomography where companies can save on average 25% compared to the same new Philips systems for same-as-new products where they can reuse 80% of average weight of pre-owned systems.[46] Major cost savings for the OEM is due to the savings in raw materials in the model (~59% savings for costs and ~61% for CO_2e in raw material extraction phase). Manufacturers having a take-back system for their products and then remanufacturing them to sell back to new clients could, in some cases, help them reduce their Scope 3 emissions in the emission category ‘Purchased goods and services’. This is because they would have less need for new raw materials than previously, as long as the emissions from the logistics of take-back systems and the repair/remanufacturing process is lower than the emissions from new products.

Industrial electronics play an important role in improving the efficiency and productivity of various other industries like energy, transportation, semiconductors, agriculture, etc.

Industrial electronics play an important role in improving the efficiency and productivity of various other industries like energy, transportation, semiconductors, agriculture, etc. One key area is the automation of processes where automation is used to control and monitor industrial processes and reduce the need for human intervention. The recent advances in technology have made industrial electronics more sophisticated and more cost-effective, meaning it is used more in mainstream applications from material handling, food and beverage processing to industrial robotics. Due to its growing use, the demand for industrial electronics is expected to follow a similar curve in the years to come and therefore there is a need to also make them grow in a more sustainable manner. While industrial electronics is an extremely broad and wide area with various applications, our model has shown that PaaS and remanufacturing are two good alternatives to consider to make the growth of this sector less carbon intensive as previously explained.

Information and communication technology (ICT)

Telecommunications operators are at the centre of the digitalisation movement due to the growing need of infrastructure to meet the new technologies of Internet of things, automation, and artificial intelligence. ICT encompasses devices and systems that are used in communication and in the creation, storage and transmission of information. In terms of this report, this segment focuses on the production and installation of information systems infrastructure, e.g. servers, networking equipment, communication devices, telecommunication networks, satellite systems, routers, modems, and other networking devices. It does not include consumer electronics. Therefore, for this report, the focus is mostly oriented towards B2B type of transactions.

For the ICT industry, our model projects that PaaS is the best circular business model from a cost and CO_2e perspective, resulting in savings of ~34% and ~33% respectively compared to a linear 2035 model. From a cost and CO_2e perspective, the phases that benefit the most from the implementation of the business model are at raw material extraction and end-of-life phases compared to a linear model.

A PaaS scenario within the ICT electronics industry makes sense and it is already become mainstream practice as ICT customers are increasingly moving away from owning traditional IT hardware toward cloud-based PaaS services since cloud computing offers more benefits since it has on-demand self-service, broad network access, resource pooling, and rapid elasticity and less costs.[47] Having a PaaS model shifts the infrastructure expenses from CapEx to OpEx on balance sheets which is an interesting option in the ICT industry due to the high upfront costs of big infrastructure needs like data centres. This market growth is also rising in parallel with strong market growth and the growing use of data and ICT services worldwide. According to Ericsson, the number of people using the network is expected to grow at a linear rate while the Internet of Things will grow exponentially.[48] While ICT equipment is growing globally, ICT sales in Global South countries has exceeded rates in Global North countries as more people are getting access to internet and broadband.[49]

There are three typical PaaS models used in the ICT industry which are major cloud service models that involve cloud providers to deliver their own data centre resources to customers by means of the internet. These include: Software-as-a-Service, Platform-as-a-Service and Infrastructure-as-a-Service (see table 2 for definitions).

The current ICT market is growing, largely driven by the increased use of cloud computing, big data analytics and AI. The fastest growing application segment, the cloud service market, is starting to apply PaaS strategies. Operators like Amazon Web Services, Google, and Microsoft are already now capitalising on identifying niche business opportunities in specific markets and local geographic areas by using such service options.

As such, ICT providers are not only competing between each other but with new players called over-the-top (OTT) services, trying to capitalise on this growth movement. OTT are services that are provided over the internet but do not require infrastructure nor are they subject to the regulatory framework of telecommunications operators. Players such as Skype, WhatsApp and Facebook have redefined the communication standard among people with their free applications and have eroded the sector's main source of income. Additionally, companies such as YouTube, Netflix and Spotify have digitised the consumption of audio and video, and at the business level, providers like Amazon, Microsoft, Google and IBM have made use of the cloud infrastructure globally widespread. These new entrants have a major impact on the operators' business models and companies have to change their business models as their main sources of revenue are changing.

Overall, change in the ICT industry is being driven by an increased demand for finite resources which leads to increasing urban mining and recycling efforts. Due to an increasing digitalisation movement and connectivity, new business models are arising such as PaaS and remanufacturing.

Table 2:
Comparison of the three main PaaS models used in the ICT sector

	Software-as-a-Service[50]	Platform-as-a-Service[51]	Infrastructure-as-a-Service[52]
Definition	Software distribution model where the software and data it processes is stored in the servers of an ICT company and accessed via the internet by the client. Compared to platform-as-a-service it offers a finished workload. The market for Software-as-a-Service is currently worth $3 trillion and market projections estimate it to grow to $10 trillion by 2030.[53]	Category of cloud computing services that provides customers with a platform to develop, execute and administrate applications without having to build the infrastructure. It offers tools needed to help a business create and manage its workload. Platform-as-a-Service was valued at $44 billion in 2020 and is projected to reach $319 billion by 2030.[54]	Outsourcing of computers used to support operations like storage, hardware, servers and network components.[55] IaaS had a market size of $53.7 billion in 2021 and is expected to hit $485.1 billion by 2030.[56]
Examples of companies currently having this PaaS offering	Salesforce, Google apps, Trello, Netflix, Zoom, Spotify, Slack, etc.	Google Cloud, Microsoft Azure, Oracle Cloud Platform, etc.	Simple Storage Service by Amazon, Google Cloud Platform, Microsoft Azure Virtual Machines and Rackspace Managed Cloud.
Advantages	• Flexible payments • Scalable usage to access more or less services on demand • Automated updates • Customizable and easy integration with other business applications	• Simplicity and convenience • Eliminates capital expenses • Compute and storage infrastructure • Enables teams to collaborate and work together remotely	• Often faster, easier and more cost-efficient to operate a workload without having to buy it • Effective for temporary, experimental workloads
Challenges and risks	• Issues out of customer control • Customers do not have control over new versions of the application • Hard to switch vendors • Cloud security	• Service availability or resilience can be a concern • Vendor lock-in • Internal changes	• Extremely granular • Not transparent infrastructure configuration • Concerns on service resilience since dependent on provider

Limitations & Discussion

In this section, we will touch upon the limitations of the model we have built and the current challenges companies could face when adopting circular business models.

Limitations of our prediction model

The nature of this report is exploratory, as it tries to predict a circular business transition that has little historical precedence. In order to inform the reader on the generalizability of our findings, we have chosen to be transparent in regard to the limitations of the model. We argue that the circular economy is a complex topic, and as with any modelling there are a multitude of facets that need to be considered that have fallen out of scope of our analysis. This does not mean that our findings aren't robust, rather, we wish to be transparent with any potential flaws or shortcomings, while acknowledging that all modelling that has assumptions built in and tries to model the future will in one way or another be imperfect.

The insights derived from the model are context-specific, which means their generalisability is somewhat limited. The model acknowledges the intricate relationship between causality and correlation and does not provide a comprehensive assessment of rebound effects or potential external disruptions that might arise. To maintain transparency and a balanced view, the research team has openly acknowledged these limitations. Furthermore, the model's timeline spans from 2023 to 2035, aiming to explore the impacts within this 12-year period. It operates under the assumption of an initial investment phase dedicated to transitioning to circular models, which is then followed by gradual changes over time.

The nature of this report is exploratory, as it tries to predict a circular business transition that has little historical precedence.

Regarding data availability and quality, as mentioned previously, the data utilised in this report is sourced from a variety of avenues. Environmental input data is primarily derived from Life Cycle Assessment (LCA) data, which encompasses a wide range of products. On the financial front, the data combines information from market research, estimated market volumes, and company annual reports. It is noteworthy to mention that the consumer electronics sector displayed a higher degree of data availability, largely attributed to public disclosure. The primary focus of the data is on Carbon dioxide equivalent (CO_2e) data, which captures emissions from Scope 1, 2, and 3, both upstream and downstream. The LCAs were generously provided either by the manufacturers themselves or by academic institutions. To ensure the accuracy and relevance of the data, industry experts were also consulted to provide critical insights. However, it's essential to note that there might be potential biases that could influence the findings. While the report endeavours to offer a balanced perspective, the availability of data does vary across sectors. Notably, consumer electronics had a plethora of public and private data sources we could leverage, whereas our results within automotive are built on a smaller overall dataset and somewhat less robust.

One downside of our model being reliant on LCAs as input data is the non-standardization across them. Different sources have different scopes and limitations for each step within the LCA, and their boundaries and inclusion/exclusion criteria may differ. Due to the sheer size of input data, normalising these boundaries across all our sources has not been feasible and thus the quality of input data will have an effect on the margin of error of our results, which should be taken into account.

Furthermore, there are several factors that, due to the already very complex nature of our model, had to be excluded, such as reputation (first mover advantage vs just needing to meet the bare minimum as a hygiene factor) or labour costs in different countries, etc. Keeping these factors in mind, our results serve as a simplified estimate rather than an absolute truth, and an indicator of potential value that might be captured from both a planetary and financial perspective.

A common depiction of the circular economy is that circular business activities interact in a stronger ecosystem setting than the linear economy. In order to conserve embodied carbon emissions in the waste hierarchy, businesses have to increase collaboration efforts and build on ecosystem synergies. Even though we support this logic of industrial symbiosis, the model scenarios cannot reflect this complexity. The assumption making is considered to take place in independent and isolated environments, and thus the interaction of various circular business models, and scenarios is not part of the modelling. Similarly, the model environment is excepting disruptive elements, e.g. geopolitical events, rebound effects or extraordinary events, due to the difficulty in predicting.

Due to the complexity of human behaviour and even greater uncertainty on the future prediction, the analysis excludes intricate factors of consumer behaviour and infers a general willingness to accept new circular business models and subsequent consumption behaviour.

Barriers to implementation

The benefits of circular business models are not always reflected in current GHG accounting methods

A barrier to transition into circular business models regards the topic of greenhouse gas emissions accounting. With current regulations such as the Corporate Sustainability Reporting Directive (CSRD) in the EU pushing for more transparency in companies' emissions reporting, the importance of properly reporting these in a transparent way is gaining significance. GHG accounting standards are more adapted to a linear economy and as such it is challenging to account for certain types of emission reductions or emissions being avoided. For example, when a product's life is being extended through repair services or being made more durable to last multiple use cycles (e.g. PaaS), emissions on an individual product level increases even if we know that prolonging the life of products is an important measure to reduce our emissions from consumption on a global level.

Therefore, accounting standards like the Greenhouse Gas Protocol, which is the most widely used standard for GHG reporting, do not always reflect the benefits in terms of emission reductions caused by circular business models. As a way to circumvent the limitations of the Protocol, organisations such as the World Business Council for Sustainable Development (WBCSD) have been developing guidance documents for quantifying 'avoided emissions'. The Net Zero Initiative has defined avoided emissions as a way to quantify the benefits that a company provides through its products and services compared to a reference scenario.[57] In the context of this paper, companies adopting circular business models such as circular inputs, PaaS and remanufacturing could use avoided emissions to communicate the CO_2e savings by comparing it to making a new product.

Initial investment costs for companies to embark on their circular economy journey

Implementing circular business model strategy can sometimes lead to higher upfront costs for companies which can disincentivise them from starting the journey. To implement some circular business models, as we have seen in our model, some areas will lead to higher costs in the design, production, and logistics phase in addition to their traditional business costs. Nevertheless, the potential of the circular economy in offering long-term sustainable financial return has already being recognized in many forms of capital investments, e.g. early stage, venture capital and private equity, but also bank lending, project financing and circular insurances.[58] The Ellen MacArthur Foundation estimates that the number of private market funds with a circular economy focus has increased tenfold from 2016 to 2020. While no funds of this kind existed prior to 2017, by 2020 already 10 public equity funds focusing either in part or fully on the circular economy have been launched by leading providers such as BlackRock, Credit Suisse and Goldman Sachs.[59] This increase in money being allocated and invested is a crucial part of the transition since a common barrier in kick starting circular business models is that they require upfront investment costs and high resource availability.

Thus, the landscape of circularity holds promising opportunities and enabling financial services for businesses. However, it is essential to recognize that the strategic landscape within which companies operate can pose limitations. Those who venture into this arena early on often find themselves fully committed, bearing the high costs of both learning and implementation. Meanwhile, competitors who enter later might secure cost advantages. While the Platform-as-a-Service scenarios demonstrate substantial potential in terms of carbon emission performance and possible cost reductions, it's crucial to acknowledge that this path represents a lengthy journey, demanding significant resources and time. PaaS type of strategy can be a complex implementation journey due to the fact that it disrupts a company's go-to-market strategy since it changes how a business earns money. Managers seeking to harness the rewards of circularity must consider the distinct circumstances, capabilities, and resources of their company and formulate a tailored circular economy action plan. Even with ambitious visions, taking incremental steps can eventually culminate in a profound shift towards circularity.[60]

Therefore, a practical starting point involves evaluating the potential of a circular inputs scenario, which serves as a foundation for this transformative journey. Changing the input materials can be a relatively low hanging fruit since a company does not have to change its business model. Assessing new procurement opportunities and integrating circular principles, can be seen as a more approachable action track for most businesses, without diminishing competitive advantages. We see great potential for a learning process that prepares you for further steps on a fully circular vision, that already allows you insights into potential optimizations of operational processes, circular product design changes, and circular metrics for successful reporting.

Once a company manages to successfully implement a circular inputs strategy, it can move on to its next loop or phase and assess if remanufacturing is a viable option. A remanufacturing would require more effort compared to circular inputs in terms of e.g. securing reverse logistics solutions, potentially having to have additional production lines to handle “used” products/material since it will be difficult to merge with the ordinary production line with new products/material. It might also lead to IT systems changes, e.g. requirements of upgrading ERP system to handle returns, pricing and production of used products/materials.

Finally, remanufacturing would require a new go-to-market model offering customers an additional way of purchasing the company’s products. However, as we have seen in the model, a remanufacturing strategy almost always leads to higher cost and CO_2e compared to circular inputs. At this point the company can reassess if a PaaS model makes more sense for them since the company might be better off exploring the more disruptive PaaS business model that all in all is harder and more risky to implement, but offers greater returns in terms of carbon reduction and cost savings.

Pathways to Circularity

Our results underscore the necessity of transitioning away from a linear business model, which can lead to reduced profitability over time. Embracing circular business models not only aids in cutting CO_2e emissions but also substantially lowers costs. We recommend for companies to begin immediate exploration of a circular business model that aligns with their strategic vision. The findings presented in this report can serve as a foundational guide for companies in the electronics sector venturing into circular models.

Transitioning to circular business models offers not only sustainability benefits but also significant growth prospects. Companies across industries are adopting circular principles because they make business sense. These principles help in cost reduction, revenue growth, and risk management.

Figure 3:
A potential circularity journey

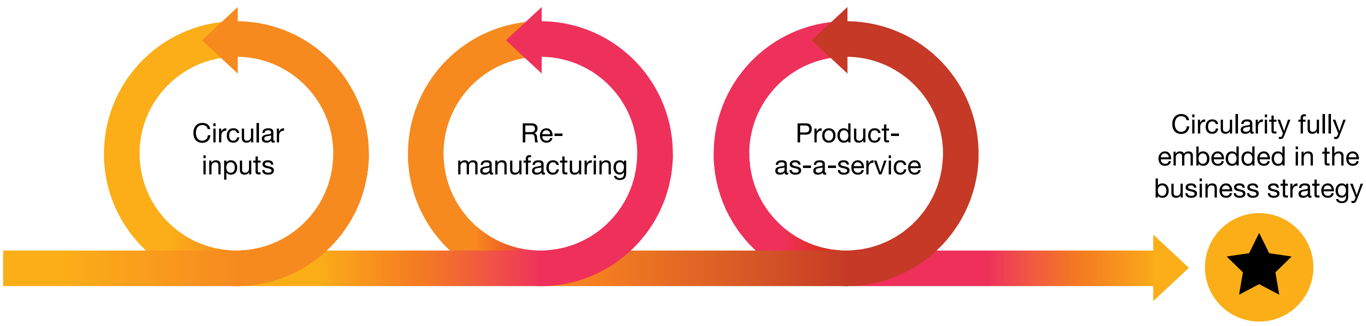


Table 4: Heatmap of circular economy drivers in the electronics industry segments[61]

	Drivers of circular economy growth potential in the electronics industry		
	Innovation and corporate action	**Regulation**	**Consumer preferences (B2C & B2B)**

Consumer electronics	• Increased demand for finite resources leads to an increase in urban mining and recycling efforts as demand for rare earth materials rises in electronic industry (only 1% of rare earth elements are being recycled)[62]
	• Technologies and digitalisation are enabling new business models and more reverse logistics options are available
		• Growing number of regulations on electronics across the globe:
		  ◦ EU (EU right to repair, France: Zero Waste Law, EU Circular Economy Action Plan)
		  ◦ Africa: Nigeria implementing EPR legislation for electronics, South Africa's Waste Act, Ghana's Hazardous and Electronic Waste Control and Management Act and Regulations)
		  ◦ Americas: Chile's national roadmap on CE, 25 American states have e-waste recycling legislations
		  ◦ Asia: China has high targets for circular economy in electronics, South Korea's EPR scheme for e-waste covers 27+ products nationally
		• Increased political interest in accessing rare earth materials (ex: EU Critical Raw Materials Act)
			• An increasing number of customers are opting for refurbished products and product-as-a-service models in order to keep up with the fast pace electronics industry through companies like Fairphone, Samsung[63]
			• More companies are getting leasing services for their IT products

Industrial electronics	• Demand for finite resource is high as manufacturing firms in the EU spend on average 40% on materials • Innovations are taking place in advanced manufacturing by using digital technologies to reduce waste in production	• Increased regulation such as the EU Circular Economy Action Plan, Eu industrial strategy, EPR policies and landfill taxes • REACH regulations for hazardous materials	• Growing awareness of negative impacts of waste and pollution among customers • Covid -19 increased instances of repair and remanufacturing to increase resilience to global shocks (e.g. ventilators)
ICT	• Increased demand for finite resources leads to an increase in urban mining and recycling efforts as demand for rare earth materials rises in electronic industry (only 1% of rare earth elements are being recycled)[64] • Operate shared data centres and network infrastructure through infra-as-a-service models • Companies like Google are applying circular economy principles to data centres by buying remanufactured services and refurbishing existing equipment	• Data centres are extremely energy intensive and they produce a lot of heat during their use. Thus more energy has to be used to cool them down. In an effort to recover that heat for other applications such as district heating, food production, many countries are trying to push for that change. For example, in the EU the Energy Efficiency and Renewable Energy directives promote energy recovery for data centres. In the Netherlands, certain municipalities have announced bans for new data centres to have tighter control.[65]	• Increasing digitalisation globally and connectivity which gives citizens access to digital platforms and markets[66] • Adoption of 5G could further enable IoT tech to support the circular economy[67] • Many ICT providers are switching to PaaS type of subscription model for their cloud computing services
Automotive electronics	• Continued shift to electrification of mobility reflects the high degree of innovation could extend to automotive electronics. • Industry already open to remanufacturing with an already existing secondhand market.[68] • For example, Toyota has implemented certified automobile dismantling facilities for car-to-car recycling.[69]	• Growing number regulations for vehicles in general such as Reusability, Recyclability, and Recoverability Directive 2005/64/EC setting minimum standards for reused, recycled and recovered vehicle parts. However, electronic components such as electronic control units and sensors are considered to be non-reusable and are out of scope. • Therefore, regulations are slowly requiring companies to implement more circular strategies in their operations but that has not extended to electronic components yet. It is, however, part of the Circular Economy Action Plan to revise these regulations.	• In many markets, one can notice the clear shift in how consumers perceive mobility and their views of vehicle ownership coupled with a rising number of Mobility as a Service offerings. This reflects the high consumer acceptance for circular business models such as PaaS in this area.

High potential for growth in the short-medium term

Increasing potential for growth in the short medium term

Emerging or limited potential for growth in the short medium term

Expanding Opportunities through Circular Business Models

In our model, we have focused on only including the incentives of transitioning to a circular economy from a cost savings perspective and from a CO_2 perspective. However, there are several other essential factors that support the shift towards a circular economy. As such, we will expand on the following five key enablers to the transition in the electronics industry.

1. **Regulatory push:** Governments worldwide are driving greater compliance with circular economy goals. The European Green Deal and undergoing circular economy roadmaps in countries such as Australia, China, and Chile underscore the importance of circular initiatives.

2. **Tax and subsidies:** Taxes and subsidies are another way governments can nudge and incentivise companies to adopt more circular economy practices and thus it is an important enabler to the transition.

3. **Digitalisation:** The era of digitalisation is leading to a strong growth for the electronics industry in all four industry sectors. On the other hand, digitalisation is a big enabler to the circular economy as it can help boost and facilitate the implementation of circular business models by helping to close the loop, slow material loop and narrow the loop with high resource efficiency.

4. **The need for collaboration:** With compliance and transparency becoming norms, companies need to collaborate more for effective data collection and systems support.

5. **Resource scarcity and supply chain disruptions:** Resource scarcity, particularly of critical raw materials, is compelling the electronics industry to adopt circular economy principles as these materials are essential for manufacturing electronic devices but are limited in availability. Embracing circular practices within the industry can reduce reliance on virgin resources, promote recycling, and enhance the overall resilience and sustainability of the electronics supply chain.

These five factors will be further developed in the following paragraphs to showcase other factors that support the transition to a circular economy in the electronics industry but that were not included in our model.

Regulations

Regulations are pivotal in fostering the adoption of circular practices and in trying to rectify the take-make-waste way of doing things. They establish frameworks, incentives, and mandates that drive businesses and individuals towards sustainable practices. Since e-waste is the fastest growing waste stream in the world, many regulators around various countries are trying to limit and prevent e-waste from occurring. A great example of this is regulatory pressure is the European Union trying to tackle the environmental impact of smartphones at all stages of its lifecycle (see figure 5). As we have touched upon before, regulations can either hinder the implementation of circular business models since they tend to be adapted to a linear economy or they enable their implementation.

While in the past regulations have mostly hindered the transition to a more circular economy, there has been a surge of global regulations in recent years that have emerged to bolster the principles of the circular economy, striving to amplify resource efficiency, curtail waste, and curbing environmental repercussions. These mandates encompass a wide array of industries and geographical areas, reflecting a united drive to depart from the conventional linear production model. For instance, countries like Japan have implemented legislation to propel prudent resource utilisation and waste reduction.

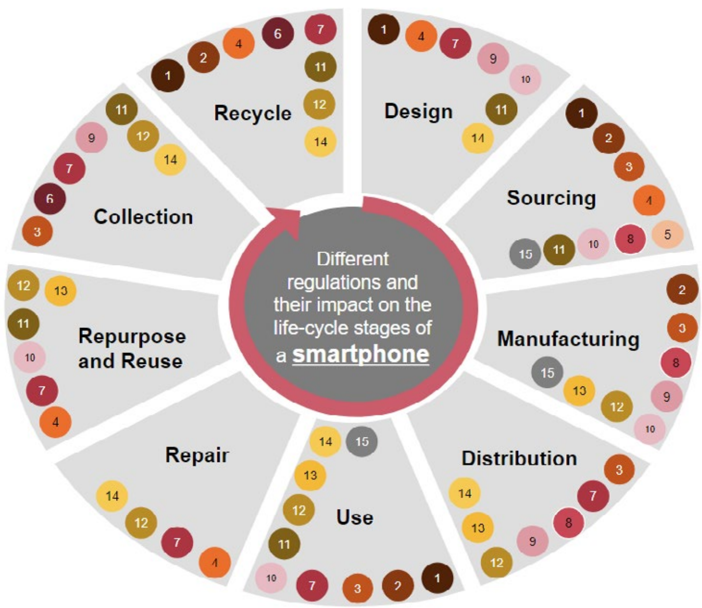
Furthermore, the Chinese government's circular economy development strategy emphasises sustainable production and consumption practices. As the pressing need to address resource scarcity and environmental concerns gains traction worldwide, these international regulations collectively underscore the imperative of transitioning towards circular economy frameworks to ensure a more sustainable trajectory.

Figure 5:
Case example for EU driving change for consumer electronics

Overview - applicable regulations

1	The REACH Regulation (1907/2006/EU)
2	The Restriction of Hazardous Substances (RoHS) Directive (2011/65/EU)
3	The Battery Directive (2006/66/EC) ***(expected to change in 2023)***
4	The Waste Framework Directive (2008/98/EC // ***Updated: 2018/852/EC)***
5	The Mining Waste Directive (2006/21/EC)
6	The Landfill Directive (1999/31/EC)
7	The Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU)
8	The Conflict Minerals Regulation (EU) No. 2017/821
9	The Ecolabel Regulation (EC) No. 66/2010
10	The Single-Use Plastics Directive (2019/904)
11	The Packaging and Packaging Waste Directive (94/62/EC)
12	The Extended Producer Responsibility (EPR) Regulations
13	The Energy Efficiency Directive (2012/27/EU)
14	The Indication of Energy Consumption and Labelling of Energy-Related Product Directive (2010/30/EU)
15	The Eco-design Directive (2009/125/EC)

And its impact on different smartphone life-cycle stages



Since the European Union and Europe has positioned itself as a circular economy leader with the adoption of many progressive circular economy-related regulations, we will focus on key trailblazing regulations that will have a global positive impact on the circular economy transition in the coming few years. Therefore, in the following paragraphs, we will go into more detail of three enabling regulations of the French Anti-Waste Law, the EU Circular Economy Action Plan, and the Corporate Sustainability Reporting Directive.

French Anti-waste Law

In 2020, France has adopted its comprehensive *Anti-waste Law* (Loi relative à la lutte contre le gaspillage et à l'économie circulaire). Its goal is to eliminate waste and pollution from the design stage and transform the whole supply chain from a linear to a circular economic model by tackling planned obsolescence, promoting better resource management and more transparent information to consumers. This law is worth mentioning as its policy measures are a world first as it is the first country to ban the destruction of unsold non-food products since companies will now have to reuse, donate or recycle their unsold products rather than landfill or incinerate them. Additionally, it is the first country to introduce a mandatory repairability index on electronic and electric products, such as smartphones, laptops, washing machines, and televisions. This measure aims to increase the proportion of products that get repaired, by making manufacturers consider repairability at the design stage and consumers aware of repair options when purchasing a device. Its target is to increase the proportion of repaired electronic and electric products from 40% to 60% by 2026 already. This law will enable the implementation of circular business models in consumer electronics such as repair, reuse, and remanufacturing.

EU Circular Economy Action Plan

At the European level, a *Circular Economy Action Plan* has been adopted in 2020 which includes a detailed set of measures to be implemented within the next five years. Within this action plan, the European Commission has targeted seven key product value chains to expand the market for circular products and one of them is the Electronics and ICT sectors as e-waste is the fastest growing waste stream in the EU and has low recycling rates. Within this sector, the goal is to include consumer electronics such as mobile phones, tablets and laptops under the *Ecodesign Directive 2009/125/EC* so devices are designed for energy efficiency, durability, repairability, upgradability, maintenance and reuse to thus extend the use phase of products.[70] (Energy labelling of smartphones: C(2023) 1672" and "Ecodesign requirements for smartphones C(2023) 3538"). This would not only require companies to provide information on the energy efficiency of their product but also the battery endurance per cycle, free fall reliability, battery endurance in cycles, EU repairability class and ingress protection rate. If these regulations are to be accepted by the European Parliament, they would come into force in mid 2025. These regulations are part of the wider Circular Electronics Initiative in the EU, derived from the Circular Economy Action Plan, that wants to adopt regulatory measures for electronics and ICT and ensure devices are designed for energy efficiency, durability, reparability, upgradability, maintenance, reuse and recycling.[71]

CSRD

Another Directive shaping the reporting landscape in Europe is the EU *Corporate Sustainability Reporting Directive (CSRD)*. It is a new piece of regulation which requires companies to make extensive, detailed disclosures about sustainability performance and related strategic implications. Disclosures are prescribed by the European Sustainability Reporting Standards (ESRS). The most significant shift resulting from the CSRD, we believe, will be a shift in the way that executives relate their business strategy to the sustainability agenda. From this regulation we can expect better data transparency through mandatory data point reporting on tonnes of hazardous materials and radioactive waste and tonnes of non-recycled waste. This is expected to create indirect pressure on companies to act and be more circular. This might directly push for the adoption of more circular inputs strategies.

Furthermore, the CSRD requires management to report how their strategy and plans deal with each sustainability topic that they consider material (according to an expanded definition of materiality, which we explain below). For example, if executives at an electronics company identify resource scarcity as material, then they would have to tie their strategy and goals to pertinent impacts, opportunities and risks. Electronic companies based in Europe could then use the circular economy as a new opportunity to embed into their core business.

Though some executives do integrate sustainability topics with their core strategies, the practice has not yet gone mainstream. Management can still base their strategy on more traditional concerns—customer needs, competitive dynamics, economic trends, technology advances and so forth—while handling sustainability topics such as climate change and human rights as matters calling only for legal and regulatory compliance. As a result, one company's effort to link sustainability with value creation can differ greatly from another's.

> "Policy and regulation play the role of a facilitator for better transparency and accountability among producers, manufacturers, recyclers, consumers and other stakeholders. They play a key role in the identification and development of benchmarks, targets and standards for leading the industry towards circularity.
>
> One important example being the EPR (extended producer responsibility) rules on e-waste, which has been driving circularity in the sector. In a country like India, with a large informal sector in the e-waste management ecosystem, effective policy support is necessary to formalise and modernise the ecosystem.
>
> Sangeetha Raghuram, PwC India"

Taxes and subsidies

Closely related to the discussion on regulations, taxes and subsidies can be a good way to incentivise or nudge companies to transition to a circular economy and is thus the second enabler we will focus on. As discussed earlier in the report, we've evaluated the value of a company, transitioning to circular business models in a vacuum. This means that the impact of taxes and other comparable levies, as well as the available incentives and subsidies are not fully taken into account. We hypothesise our results would likely be even more positive towards circular business models if taxes and incentives were considered.

Taxes and incentives are commonly designed to steer, nudge or influence behaviour ("carrot and stick"). Many environmental taxes and levies are based on a 'polluter pays' principle, implying that polluting companies face a higher tax burden. Tax credits and incentives work in the opposite direction. Through its European Green Deal, Europe is aiming to become the first climate neutral continent, and thus increasingly more taxes and regulations are introduced at a rapid pace to push companies and markets to reduce their environmental footprint. As a result, companies that stick with a business-as-usual model may face new taxes and levies, which will most likely increase cost prices and potentially reduce profits. This business risk itself urges businesses to reevaluate their current strategy and value chain transitioning to a circular business model. If companies act now, there might be incentives available which could reduce their implementation costs and could lead to a more sustainable and profitable business going forward. Governments are offering significant amounts of financial support to nudge companies into transition. Examples of such political pushes are the EU Industrial Plan and the Inflation Reduction Act in the United States.

Emphasising the significance of contemplating these aspects and engaging the legal and tax departments right from the beginning during the transition to a circular business model is vital. This is crucial for understanding all potential consequences, since these could result in real expenses that impact operational profits or obligations that directly affect the continuity of the business.The Ex'tax project together with Cambridge Econometrics and supported by PwC have published and developed a proposal for an EU Fiscal Strategy to Support the Inclusive Circular Economy.[72] This report illustrates the impact and financial implications of the Circular Economy in a taxation context.

Digitalisation

What is driving most of the electronics segment growth is the growing use of digitalisation in various sectors. Digitalisation is also a major enabler of transitioning to the circular economy as it can help close material loops by providing accurate information on product's availability, location and condition. Indeed, digitalisation is a big enabler to the circular economy and it helps boost circular business models by helping to close the loop, slow material loop and narrow the loop with high resource efficiency. Research shows that digital solutions such as IoT, Big Data and analytics enable a transition to a circular economy by: improving product design, attracting target customers, monitoring and tracking products, improving technical support, offering maintenance solutions, optimising product usage, enhancing renovation and end-of-life activities (Bressanelli et al.).[73] Digitalisation can thus help at every stage of the product life cycle. For example, digital solutions can be used in remanufacturing strategy by using data for predictive maintenance of the product and thus extending product life.

The management of materials and components in a circular way requires large amounts of data and it is often cited as a barrier to implementing circular strategies.[74] As a way to counter the current lack of readily available information, the European Union has adopted a new concept called ' digital product passport' as part of the Ecodesign Sustainable Products Regulation. This passport would provide all information about materials and act as an enabler to reuse strategies and for transitioning to a circular economy since each product has a unique identity that can be linked to data sources with information about the particular product. More specifically, a product passport would contribute to a more sustainable and circular economy by: providing consumers with information about the sustainability and circularity of the products; providing economic operators with standardised technical and sustainability-related information on products and components; enable industries to develop their own data ecosystems, contribute to establishing the Right to Repair and facility product upgrading, increased traceability and transparency.[75] [76]

Collaboration

The fourth major enabler to the circular economy is partnerships and collaborations since they are a crucial part of transitioning to a circular society. This is because the idea of business models is not that one company closes the loop but that the whole ecosystem does. However, providers are experiencing struggles when identifying the right partners to successfully execute the implementation of certain business models such as PaaS which require partnerships within the value chain for proper execution.

Partnerships that support circularity can create value for all stakeholders involved. Benefits of partnerships include: access to new and/or cheaper materials, reduced transportation and energy costs, knowledge sharing, new business offerings being created, share of risk and reward.[77] Furthermore, by forging partnerships with stakeholders you can share responsibilities and liabilities, reduce the financial and operational burden on individual companies. This type of collaboration can exist horizontally through collaborations vertically across the value chain or horizontally within the industry or with other industries.

> There's significant value in industry-wide collaboration to establish circular standards and best practices. By working together, companies can create systemic change, share costs, and make collective progress toward circularity.
>
> Andreas Nobell, TCO Development

Implementing circular business models to reduce emissions in one part of the value chain can often increase emissions in other parts, as seen in the model for most of the segments with emissions from the logistics phase increasing when there are take-back programs setup. To avoid shifting emissions from one stage to another, collaborating with upstream suppliers and with downstream retailers is a good way to ensure that the strategy being put in place reduces net emissions and that a systems view is adopted. To analyse this, a company could consider looking at their GHG Protocol emissions Scope 3. For example, a company designing their own products could collaborate with recycling companies to see how to design products to facilitate reuse of materials and recycling rates.

A concrete example of this in the electronics industry is the collaboration between companies such as Philips Monitors and Samsung, who have joined forces with Closing the Loop, a 'closed loop' service provider, to recover and recycle an amount of broken devices that exactly equals the number of devices these OEMs have put on the market. A global EPR concept known as 'One for One'.

Horizontal industry collaborations represent a powerful form of partnership engagement as they can impact the whole industry. As a way to experiment the use of new business models, larger companies can also collaborate and partner up with startups that can help implement new business activities. For example, in most projections in our models for remanufacturing and for PaaS, there would be an increase in costs and CO_2e at the logistics phase when getting products back to the company through for example reverse logistics. Many startups are emerging in this sphere and can offer great opportunities to try out these business models since it lowers initial costs for long established companies. Moreover, collaborations can be used to align on an industry level to push for regulatory change when certain regulations are hindering the implementation of circular business models.

Resource scarcity and supply chain disruptions

Lastly, another important enabler for the electronics industry to start implementing the circular economy is the fact that raw materials are increasingly becoming more scarce and supply chain disruptions. As previously explained, the electronics industry heavily relies on finite resources, including rare earth metals, precious metals, and other raw materials. It is said that complex electrical and electronic equipment can contain up to 60 elements.[78] The extraction and processing of these resources often have significant environmental impacts, such as habitat destruction, water pollution, and greenhouse gas emissions. As the demand for electronics continues to grow, there is a risk of resource depletion and increased environmental degradation. As seen in figure 6, there are many raw materials that are currently being used in the electronics industry that are on the way to resource depletion if we continue as business-as-usual.

> Electronics products use several rare earth and critical metals like lithium, cobalt, nickel, manganese, etc., and hence there is a need for circularity to ensure recycling and reuse of these metals in the economy. This will also lead to lower environmental impacts like pollution or GHG emissions, due to reduced dependency on mining and processing of materials.
>
> Sangeetha Raghuram, PwC India

Figure 6:
Projected depletion date of key non-renewable resources

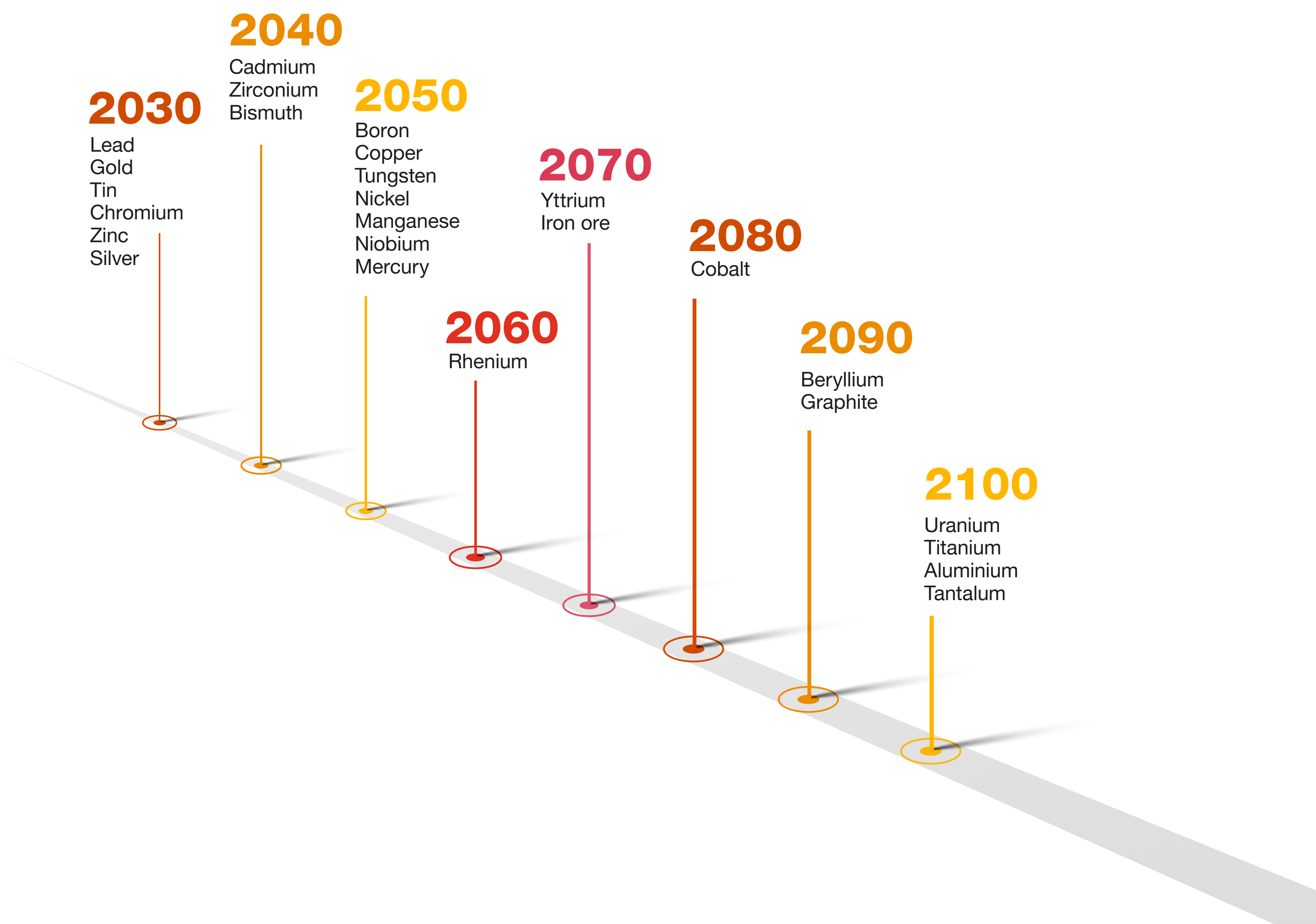
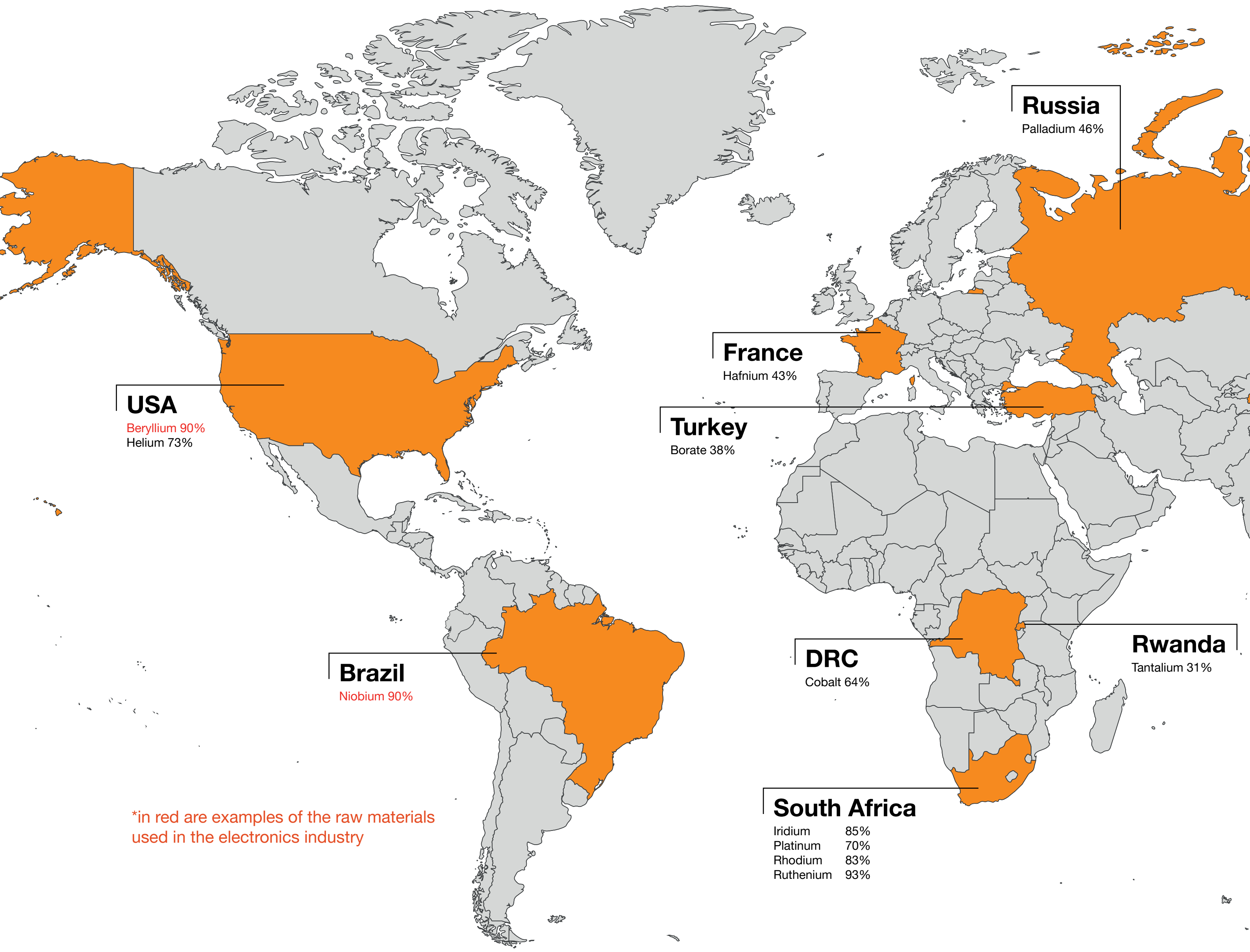
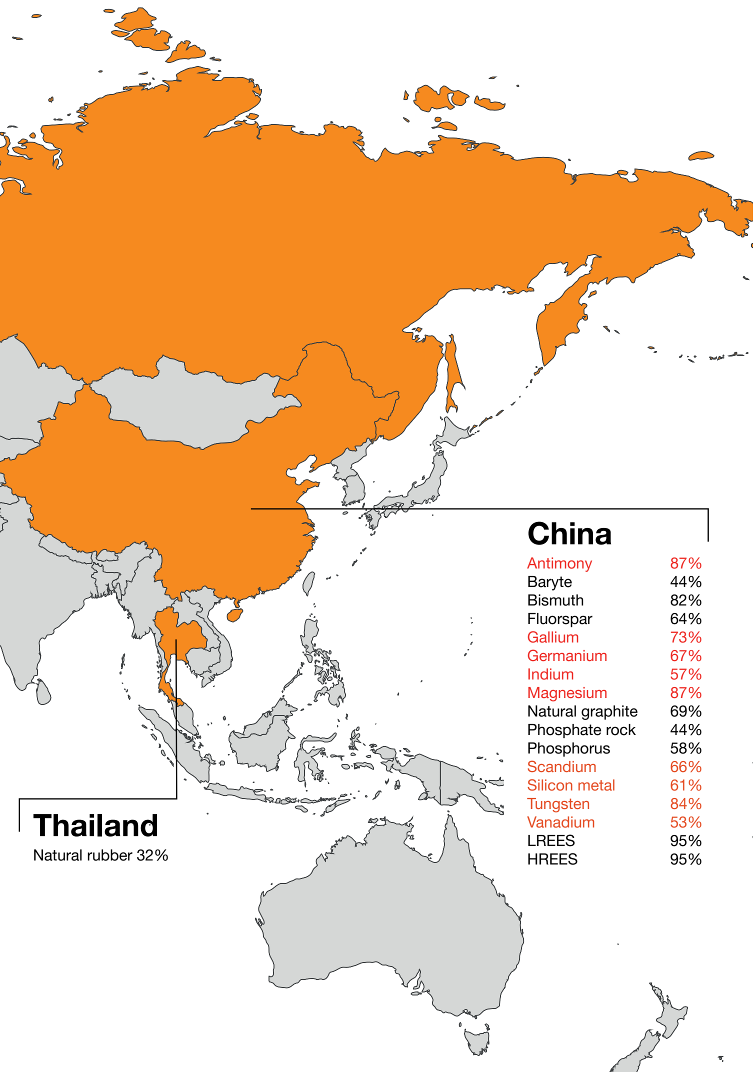


Figure 7:
Contribution of countries accounting for largest share of supply of primary CRMs to the EU (average from 2010-2014) (11)[79]





Source: The European Commission

Many of the materials used in electronics are considered to be critical raw materials. Critical raw materials are defined according to the EU as containing raw materials which reach or exceed threshold for both economic importance of the material for the EU economy and the risk of disrupting the EU supply of the many critical raw materials. For example, a smartphone can contain up to 50 different materials.[80] Critical raw materials are particularly important for high tech products and emerging innovations. It is said that the electrical and electronic equipment sector depend on a variety of critical raw materials including antimony, beryllium, cobalt, germanium, indium, platinum group metals, natural graphite, rare earth elements, silicon metal, and tungsten.[81]

One of the main consequences of digitalisation is that there will be a huge amount of data that needs to be produced and stored in data centres, enterprise infrastructure and endpoints like smartphones. Through new emerging technologies like the Internet of Things, connected robots, autonomous vehicles and sensors will be more and more used in industrial processes across the value chain as can be seen in figure 8. The global expansion of digital networks and services means that more people have and will have more access to the internet which increases the need for connected equipment and fibre optics. Digitalisation will also be accompanied with the sale of consumer electronics like smartphones which are expected to steadily increase from 130 million units sold in 2018 to 180 million in 2035.[82]

PwC's Role in the Circular Economy Transition

PwC Sweden is dedicated to empowering clients in their sustainability journey and facilitating transformative change. Our suite of services is tailored to meet the specific needs and starting points of each client, underpinned by our deep expertise in integrating sustainability into business models and best practices for implementation. We specialise in Sustainable Innovation processes, fostering innovative and eco-friendly solutions, while also offering Circular Business Modelling services to optimise resource efficiency and minimise waste. As part of our holistic approach, we conduct Circularity Maturity Assessments to gauge the circularity within clients' operations and pinpoint areas for improvement. Through our comprehensive offerings, we equip clients to embrace sustainability and drive positive change, particularly within the circular electronics industry.

Our team of sustainability advisors is highly skilled in delivering tailored services to support clients in implementing circular principles across their procurement practices. We assist in developing Circular Procurement Strategies, aiding clients in identifying sustainable sourcing options, prioritising circularity criteria, and seamlessly integrating circular principles into procurement processes.

Our expertise extends to Circular Product Design, where we collaborate closely with clients to optimise product design for longevity, reparability, and recyclability, ensuring alignment with circular economy principles. Furthermore, we offer guidance on Circular Supplier Selection, assisting clients in identifying and partnering with suppliers that prioritise sustainability, circularity, and ethical practices.

Additionally, we provide expertise in the governance and management of suppliers for Circular Procurement, helping clients establish robust frameworks and processes to ensure compliance with circularity standards, monitor supplier performance, and foster continuous improvement in their supply chain. With our comprehensive suite of services, we enable clients to embrace circularity throughout their procurement practices, thereby driving positive environmental and social impact in the electronics industry.

In parallel, PwC leverages its extensive in-house expertise to assist clients in navigating the recently approved Corporate Sustainability Reporting Directive (CSRD) in the EU and other critical aspects of the ever-evolving sustainability compliance landscape. Large companies affected by CSRD requirements, which encompass detailed ESG metrics reporting, benefit from our guidance on aligning with European Sustainability Reporting Standards (ESRS) and achieving limited assurance over this information. Our support includes conducting materiality assessments, aligning with CSRD assurance requirements, measuring baseline environmental and GHG performance, assessing social considerations, setting reduction targets, and monitoring KPIs at both the company and value chain levels. With the regulatory landscape increasingly emphasising ESG, PwC ensures that clients are well-prepared to meet these obligations and excel in future sustainability reporting, making the most of our extensive data and knowledge resources.

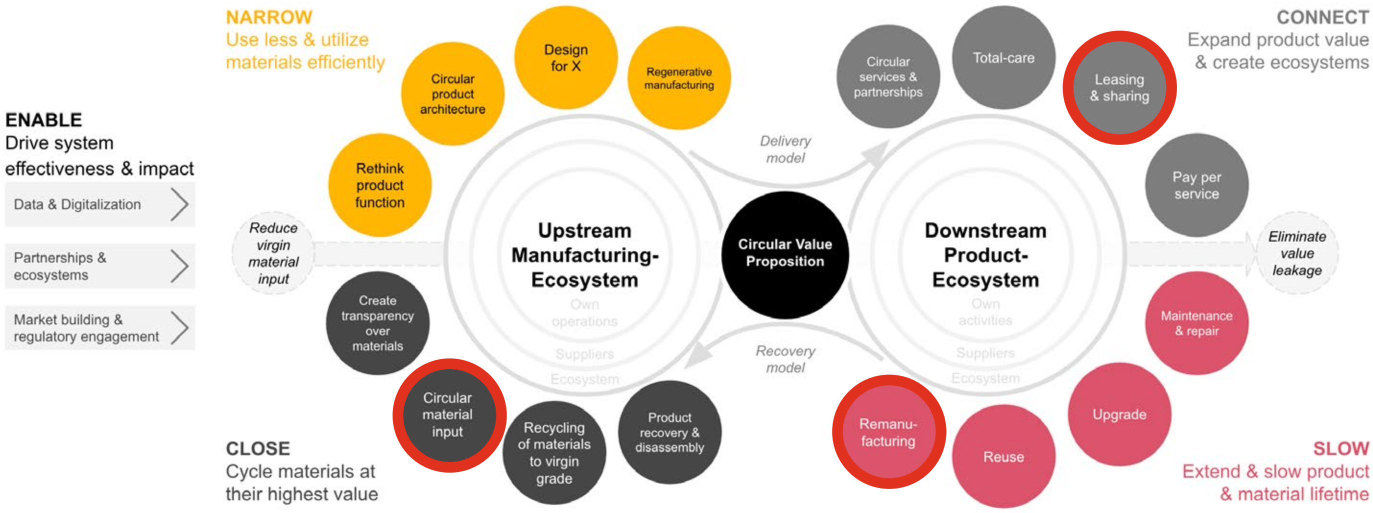
As we mentioned above, collaboration is critical when it comes to designing and implementing circular business models in an effective way. Without considering all the actors within a company's ecosystem, effective circular business model planning and implementation can be very difficult. This is why PwC has developed a tool to help companies understand their roles in the ecosystem and the dependencies they have with other stakeholders.

"Empowering key decision makers with data-driven insights is the cornerstone of a successful circular transition, where initial investments in circularity pave the way for long-term cost effectiveness and profitability"

David Ringmar, PwC Sweden

PwC's Circular Innovation Framework

Figure 8:
Circular Innovation Framework



PwC's Circular Innovation Framework was developed by PwC Germany. Its aim is to translate the latest scientific knowledge on the circulation of materials through biological and technical cycles into an action-oriented tool for the design of circular products and services. The framework offers strategies for adjusting material flows to support circular business concepts. It is used to develop circular business concepts which combine adjustments in a product's production-system with innovative adjustments in the product use-system. The circular business models are separated into four overarching strategies: narrow, connect, slow and close material flows. Within each, you can notice the 3 main strategies we have focused on within this report highlighted in red.

Key Takeaways

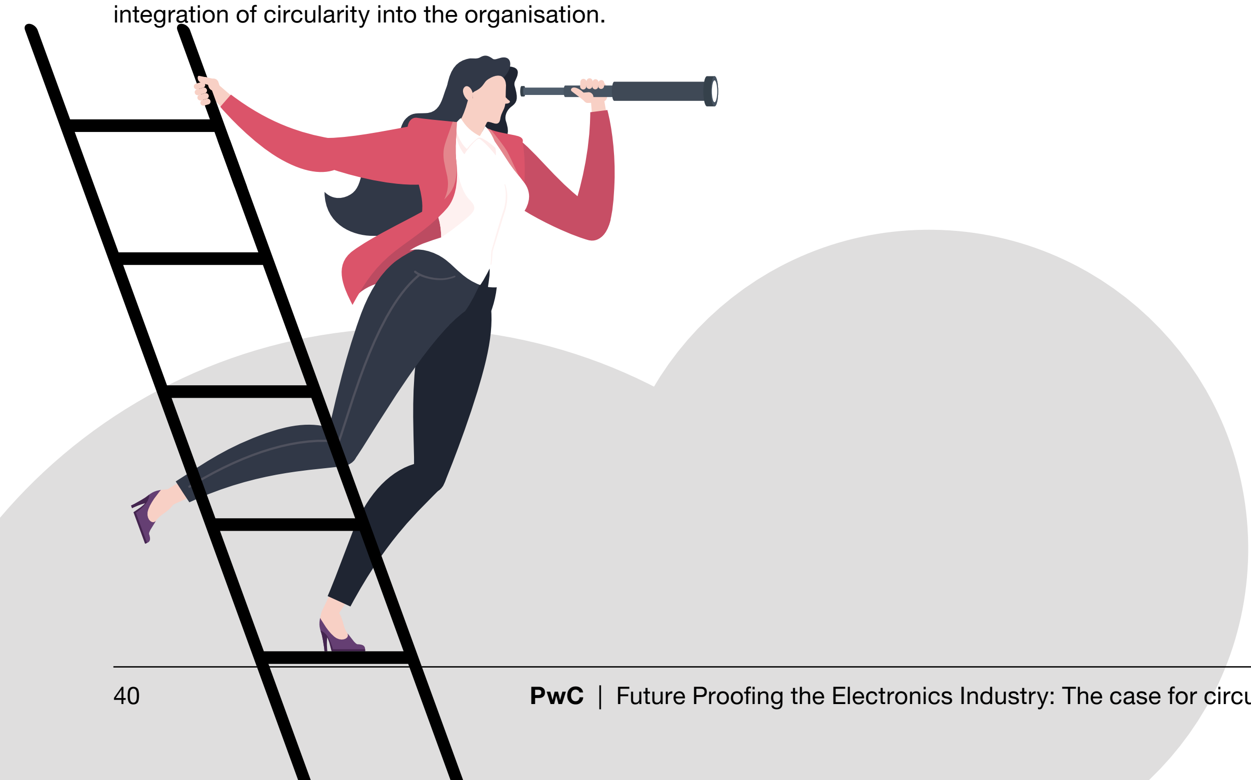
Our findings indicate which circular business model has the highest potential value both on which segment you are operating in, and whether your ambition is to optimise for CO_2e footprint reduction or cost reduction. Overall, implementing a circular strategy can lead to an estimated industry average of 12% in cost savings and 10% CO_2e emission savings. It is important to keep in mind that our results simply give an indication for a hypothetical average actor in the segment, and the reader must take into account their own context, capabilities, and level of ambition.

During this research, we have only focused on the three circular strategies of PaaS, circular inputs, and remanufacturing. As seen in figure 8, there are many other strategies that can also be utilised to transition in the electronics industry. Moreover, the strategies in practice are often not viewed and implemented in silos but can be implemented in combination to one another. For example, higher cost and CO_2e savings can be achieved through having circular inputs of products in the manufacturing phase and having a PaaS model during the use phase. When the product is broken, then it can be remanufactured and sold again. It is critical that companies align their exploration of circular business models with their sustainability strategy and level of ambition. As our model explains, PaaS (product-as-a-service) is an excellent option for various sectors. However, its initial implementation may pose some challenges. Many companies can reap the benefits by preparing for a series of transitions within circular business models, ultimately leading to the integration of circularity into the organisation.

Many companies can reap the benefits by preparing for a series of transitions within circular business models, ultimately leading to the integration of circularity into the organisation.

Finally, it is important to keep in mind that there are other aspects to consider than the CO_2e and cost savings potential we have evaluated. From the environmental side we have issues such as resource scarcity, water and land usage, and biodiversity among others. From the non-environmental perspective we have factors such as end-user expectations and demands, human rights in the supply chain, company supply chain strategy, go-to market strategy, regulatory demands, and even funds available to invest in making the strategic transition to a more circular business model.

These aspects can limit and create barriers to the implementation of business models and should also be taken into account when revising strategies. Indeed, implementing business transformations are complex, and transitioning to a more circular business model is further made challenging by the somewhat novel concept of implementing an ESG perspective and leveraging sustainability as a business advantage, the complex regulatory landscape, and growing customer awareness and expectations. To facilitate the implementation of these sort of business transformations, there are several frameworks one can leverage external tools such as PwC's Circular Innovation Framework and the Circularity Maturity Assessment. Moreover, organisations such as TCO Certified and partners with extensive expertise in the topic such as PwC can help provide you with overall guidance and with whom you can collaborate to ensure successful implementation.



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