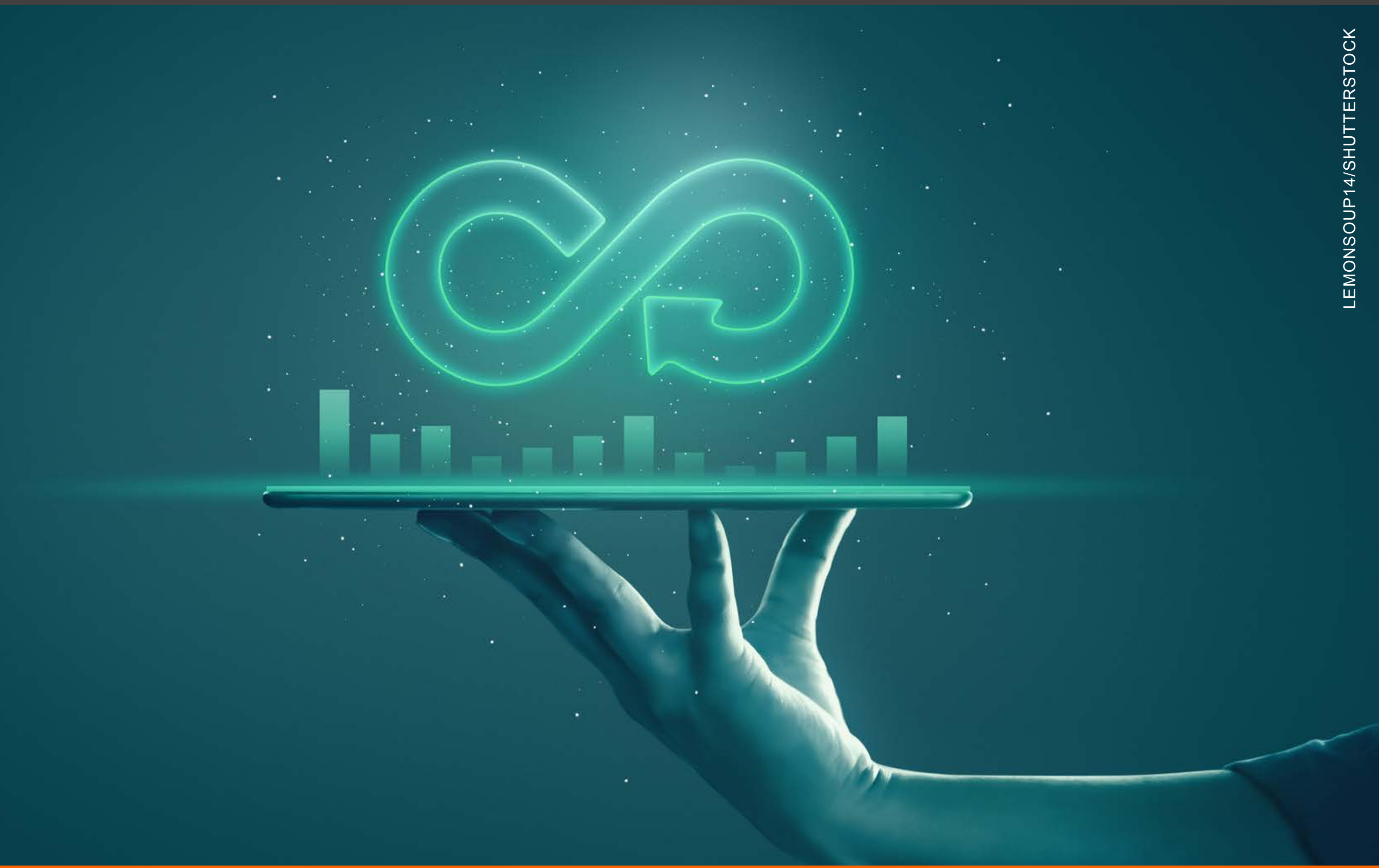

Reuters Events Sustainable Business

Towards a circular economy for industrial electronics

The design challenge

June 2023

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INTRODUCTION

Mountains of waste, decline in biodiversity and scarcity of resources: there are many good reasons for a circular economy. But how do you get there? This white paper shows why it makes sense to start with product design. Using Siemens as an example, it explains which aspects have the greatest impact, where the challenges lie, and why digitalization will boost the circular economy.

By 2050, it is projected that the world will need three Earth's worth of natural resources to satisfy demand

THE PROBLEM: WE ONLY HAVE ONE PLANET

Pollution, ecosystem collapse, declining biodiversity, climate change: there is no doubt that our planet is in a dire state, and the way our economy has thus far functioned is partly to blame. In a linear economy, which has hitherto been the prevailing model, a pattern of extraction, production and disposal of finite resources has dominated – and still does. By 2050, it is projected that the world will need three Earth's worth of natural resources to satisfy demand. Rates of consumption of biomass, fossil fuels, minerals and (metal) ores, for instance, are expected to double in the next 40 years, and waste generation could increase by 70%. Moreover, resource extraction and processing accounts for half of total greenhouse gas (GHG) emissions and more than 90% of biodiversity loss and water stress. According to the UN, humans have transformed more than 70% of the Earth's land area from its natural state, causing significant environmental degradation with far-reaching socio-economic effects.

A SOLUTION: THE CIRCULAR ECONOMY

Based on the realization that "business as usual" will inevitably lead to a planetary disaster, a counter-model has developed: The concept of the circular economy. In contrast to the "take, make, waste" of the linear economy, the goal of a circular economy is to use resources for as long as possible, avoid waste and pollution, and regenerate natural systems. This concept can only succeed if economic activity and resource consumption are decoupled, i.e. material cycles are created that are ideally infinite or nearly infinite.

In order to implement the concept of circularity, a fundamental restructuring of the economic system is essential. "Designing products that meet the demands of a circular economy requires a completely new way of thinking", says Caroline Cassignol, a materials scientist who works in Research and Development for Siemens. "This is challenging, but a unique opportunity to re-think products, processes and services to create a more sustainable future."

Today, the economy is still far from circularity. However, more and more companies are looking into creating products that are long-lasting, upgradable, and repairable, reusable, recyclable or compostable. They are trying to find ways to incorporate secondary materials into production and powering such production with renewable energy. Where services are concerned, business models centered around subscription, sharing and leasing are prioritized. The intention behind this is to minimize the number of products required, e.g. cars in car-sharing, and keep them in use for as long as possible.

FROM OBLIGATION TO OPPORTUNITY: WHY CIRCULARITY IS THE NEW BUSINESS IMPERATIVE

Realising a true circular economy won't just take the pressure off overstretched natural resources, it also presents a unique market opportunity – one worth $4.5 trillion, according to Accenture. Businesses, therefore, have the chance not only to be planetary stewards, but market leaders.

There are myriad reasons for companies across sectors to move towards circularity:

- Resource scarcity and supply chain problems are driving up prices for raw materials. A shortfall of copper is projected, for example. The metal is commonly used in electronics and in products such as circuit boards and electrical equipment. By 2026, average copper prices are expected to reach $9,750/tonne, exceeding the $9,317/tonne annual average of 2021. It is thus a competitive advantage to innovate around substitution, take-back systems, higher rates of recycling and more efficient use of the metal.

- Customers are increasingly looking for sustainable products and are more open to new business models such as products-as-a-service.

- On the investor side, more emphasis is being placed on sustainability. In interviews conducted by the Harvard Business Review, ESG (environmental, social and governance criteria) was "almost universally top of mind" for the 70 senior executives from 43 global institutional investing firms they spoke to.

- Other outside pressures are also growing. The regulatory environment, for instance: in 2015 the EU introduced the Circular Economy Action Plan, a comprehensive body of 54 legislative and non-legislative actions that were adopted or implemented by 2019. It was updated in 2020 and aims to make sustainable products the norm in the EU. It also focuses on sectors where the potential for circularity is high, such as electronics and information and communication technology (ICT), plastics, and construction and buildings.


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For companies that operate in industrial sectors – manufacturing, automation, building and energy services, and the like – the processes to determine how to most efficiently and effectively implement circularity may be particularly complex, but this does not mean that these industries are being left behind. One 2021 study published by the Journal of Environmental Management found that the utilities, consumer goods and industrial sectors are in fact leading the circular transformation. Firms in these industries, as well as those that make basic materials, "have the potential to play a critical role in the development of the CE because many of the technological developments that could accelerate circularity are within their sphere of operations," the authors state.

With outside pressures mounting, including from NGOs and civil society, the direction of travel is clear. "There's a big shift coming from the market itself, which is also driven by investors and regulations," says Marlon Hassel, Sustainability Manager at Siemens Smart Infrastructure.

Rather than simply responding to outside pressures, however, forward-thinking businesses recognize that a competitive advantage lies in investing in sustainability and circular strategies. A study by Accenture demonstrated that companies that focus not only on innovation but also on sustainability and trust, outperform their industry peers, with 3.1% higher operating profits and greater returns to shareholders.

DESIGN: THE KEY TO MORE SUSTAINABLE PRODUCTS

In theory, the concept of a circular economy sounds plausible, but how can it be implemented? Of particular importance in creating a foundation of circularity, is design. It has been estimated that 80% of a product's environmental impact can be influenced at the design phase. While this figure may vary across product type, decisions made by designers with regards to material type, variety and volume, as well as their ability to be disassembled, refurbished, or recycled, among other factors, are critical. Indeed, eco-design that is informed by careful lifecycle analysis – where impacts are evaluated in relation to a wealth of of input and output parameters – is a key lever in integrating circularity.

While designing for circularity is always going to be a complex process, within electronics industries, it is particularly multi-faceted. A smartphone, for example, contains around 60 different materials, including around 30 different metals and various types of plastic. The task of separating out these materials alone is a major challenge; while the metals could in principle be reused, this is not always possible for plastics.

Furthermore, a 2022 report by McKinsey found that as products become more sustainable, production usually accounts for proportionately more of their emissions. This is partly due to an increased demand from users for enhanced features and capabilities as well as more energy efficiency – such integrations tend to require more materials to produce. Domestic heat pumps, for example, require more materials than gas or oil boilers. The highly efficient electric motors they contain may be made from more carbon-heavy materials such as copper and rare earth magnets. "The variable-frequency drives that are used to optimize the control of these advanced motors need their own circuitry and semiconductor components," states the report. Eco-design thus necessitates a full lifecycle analysis, from production to the use phase, so that circularity isn't cancelled out by competing sustainability priorities.

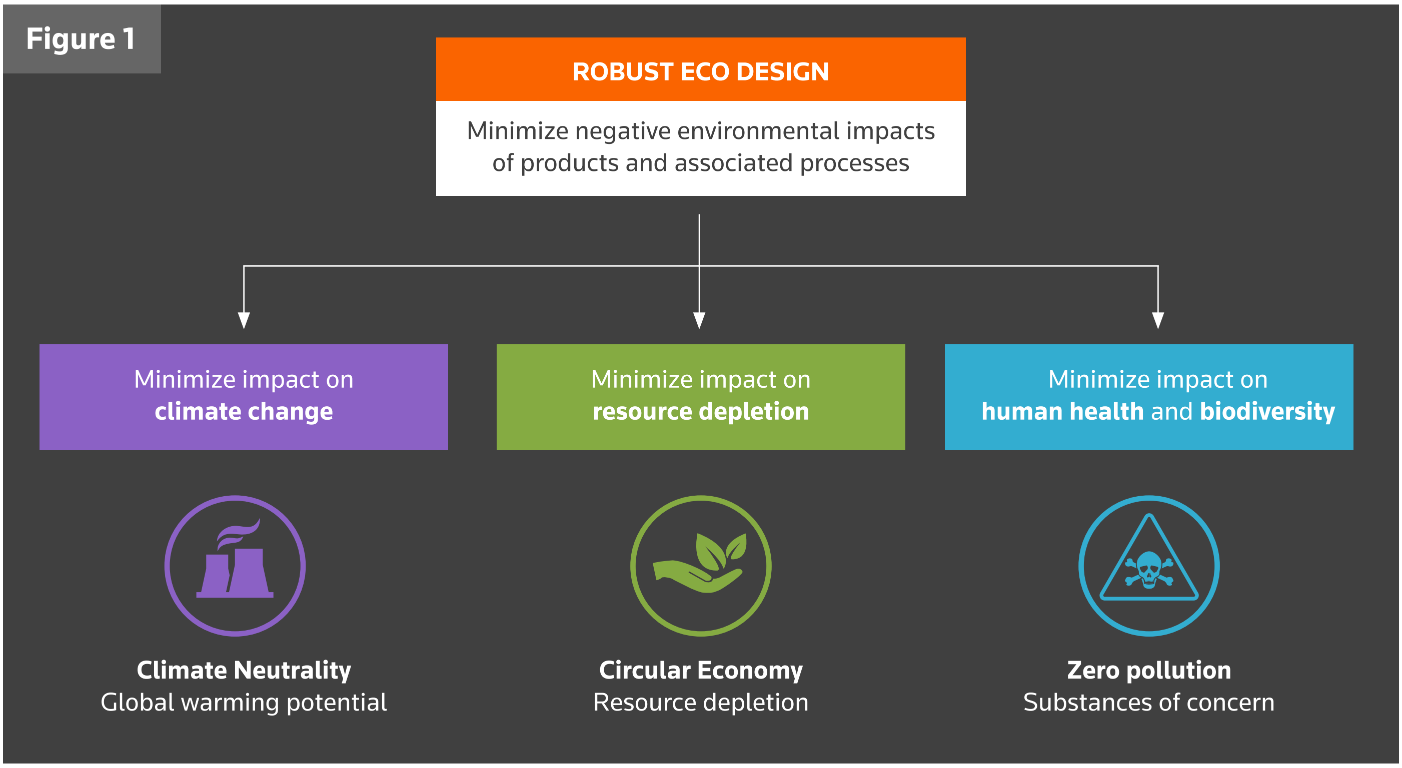
CREATING SUSTAINABLE PRODUCTS AT SIEMENS THROUGH ROBUST ECO DESIGN

So how does a technology company like Siemens, which offers hundreds of thousands of different hardware products, go about realising this circular vision? "The basic prerequisite is that you have clear objectives that set the direction in which you want to improve your products," says Marlon Hassel.

Siemens has defined guiding principles for product design as part of its comprehensive sustainability strategy, the so called DEGREE framework. By 2030, the company wants to apply Robust Eco Design (RED) to all relevant product families. "With RED, we have created a system by which we can improve our products in all areas of sustainability," says Hassel. Siemens RED principles were developed based on the international ISO standard IEC 62430 (Environmentally Conscious Design for Electrical and Electronic Products), as well as the company's own internal design principles. "The goal is to empower product managers to understand and improve their products' environmental footprints in the most appropriate way to their target application and market context," says Marlon Hassel, who has a background in product portfolio management. "There is no one-size-fits-all-solution," he adds.

At the heart of RED are life cycle assessments (LCAs), which measure a variety of impact indicators *(Figure 2)* based on product and operational data. LCAs ensure that every ecodesign measure is based on facts. However, because it can still be complicated for product managers to understand the direct link between their design decision and the product's environmental impact, Siemens has selected three leading indicators – climate change, resource use

Figure 1



RED principles and strategic action fields for product optimization at Siemens.

and ecotoxicity – from which specific design strategies have been derived *(Figure 1)*. "It is important to understand that improving the environmental impact of a product requires reducing input factors such as resources and energy, as well as output factors such as waste, emissions, or wastewater," says Hassel.

While carbon neutrality is mainly the result of efficient, flexible and clean energy consumption and lower emissions, the circular economy has a significant impact on climate change and resource depletion, both by reducing the need to extract and process new materials and by reducing the amount of waste. However, it is important to note that the elimination of harmful substances is a prerequisite for dismantling and therefore an important factor in the circular economy.

Already in the first year after the introduction of RED, 26% of the relevant Siemens product families were analyzed using this approach and teams are busy at work identifying and analyzing ways that it can be systematically, efficiently and cost-effectively applied across the company by 2030.

Figure 2 **Categories for Lifecycle Assessment (LCA)**

Impact Category	Description
Climate change	Potential global warming due to emissions of greenhouse gases into the air
Ozone depletion	Aerial emissions that destroy the stratospheric atmosphere
Acidification	Potential acidification of soils and bodies of water due to gaseous emissions of nitrogen and phosphorus compounds
Eutrophication – Fresh water	Enrichment of the freshwater ecosystem with nutritional components due to emissions of nitrogen compounds
Eutrophication – Oceans	Enrichment of the oceanic ecosystem with nutritional components due to emissions of nitrogen compounds
Eutrophication – Terrestrial	Enrichment of the terrestrial ecosystem with nutritional components due to emissions of nitrogen compounds
Photochemical ozone formation	Emissions of gases that affect photochemical ozone formation in the lower atmosphere catalyzed by sunlight (smog)
Abiotic resource depletion – Minerals and metals	Depletion of non-fossil resources
Abiotic resource depletion – Fossil fuels	Depletion of natural fossil resources
Human toxicity – Cancer	Effects of toxic substances released into the environment on humans
Human toxicity – Non-cancer	Effects of toxic substances released into the environment on humans
Ecotoxicity – Fresh water	Effects of toxic substances released into the environment on freshwater organisms
Water use	Relative amount of water used, based on regionalized scarcity factors
Land use	Change in soil quality (biotic production, erosion resistance, mechanical filtration)
Ionizing radiation – Human health	Damage to human health and ecosystems due to emissions of radionuclides
Fine particulate emissions	Potential incidence off illness due to particulate emissions

The dimensions of a product's environmental footprint (PEF): Categories for Lifecycle Assessment (LCA).

THE CHALLENGE OF CONFLICTING GOALS

A major challenge in implementing eco-design is to make decisions in the context of competitiveness. In addition to the transformation to more sustainability, a product must also be attractive in terms of performance and cost. Consequently, there are conflicting goals that need to be resolved. Conflicts can occur, for example, between

- different environmental aspects, e.g., better recyclability can lead to more CO_2 emissions (e.g. if thermosets are replaced by thermoplastics).
- different lifecycle stages of products, systems, solutions or services with respect to an environmental aspect. For example, a better carbon footprint in the use phase may come at the cost of a worse carbon footprint in manufacturing.
- environmental and economic benefits, e.g. when a product is manufactured in a more environmentally compatible way to extend its lifetime. This results in an environmental benefit because fewer resources are consumed and less waste is generated in the long term, but at the same time the acquisition cost may increase significantly.
- environmental, technical, and/or quality considerations. For example, design decisions can have a negative impact on the reliability and durability of a product, even if this generates environmental benefits.

These conflicting goals illustrate which challenges have to be tackled in order to design a product sustainably in a comprehensive way.

ROBUST ECO DESIGN IN ACTION

A central aspect in the reduction of environmental impact is, of course, the greenhouse gas emissions that a product causes. The example of electrical switchgear shows how changes in product design can massively reduce the ecological footprint.

Electrical switchgear is necessary in the transport of electricity. It is composed of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. For a long time, sulfur hexafluoride (SF_6) was used as an insulating gas in these products, as SF_6 has dielectric properties, which means it is difficult for electric current to flow through it. The global warming potential of SF_6, however, is hugely significant: more than 22,000 times that of CO_2.

Siemens has developed switchgear that uses 'natural components of ambient air' instead of SF_6 – its 'blue GIS' range. This clean alternative has a global warming potential of less than one and can be released into the atmosphere once the switchgear reaches end of life. "The use of blue

MEGA PIXEL/SHUTTERSTOCK

GIS significantly reduces the environmental footprint of the product," says Thomas Dürr, standards and regulations manager at Siemens. With the absence of greenhouse gases that need to be contained and responsibly stored, dismantling and eventual recycling of the switchgear at end of life is also made more seamless. Although the reduction of greenhouse gases was the main focus in the development of the blue GIS portfolio, the absence of SF_6 also has a positive effect on the circularity of the product by simplifying recycling.

Another area where RED principles are being applied is in the OpenAir damper actuator portfolio. Damper actuators are small motor-controlled devices that help to regulate and stop airflow and can commonly be found inside ducts or heating, ventilation, and air conditioning (HVAC) equipment, and systems.

In terms of energy efficiency, actuators have always played a key role – they can be controlled so that air conditioning, for example, is not on in an empty room or at night, with resultant energy savings in the range of 20%-60%, says Emmanuelle Billard, director of sustainability for Building Products at Siemens. This energy saving potential was therefore a key point of consideration when analyzing which field of action to concentrate on.

"In the lifecycle impact assessment, we identified that the most impact was in the use phase," she says. "After a product is installed, it will often run for 20 years or longer. During those 20 years, it will be consuming energy, so we immediately saw that we need to focus on this use phase – on power consumption."

In this way, the optimized OpenAir damper actuator portfolio will contribute to more sustainable building operation, and thus also has an indirect impact on the consumption of resources.

THE JOURNEY TOWARDS CIRCULARITY

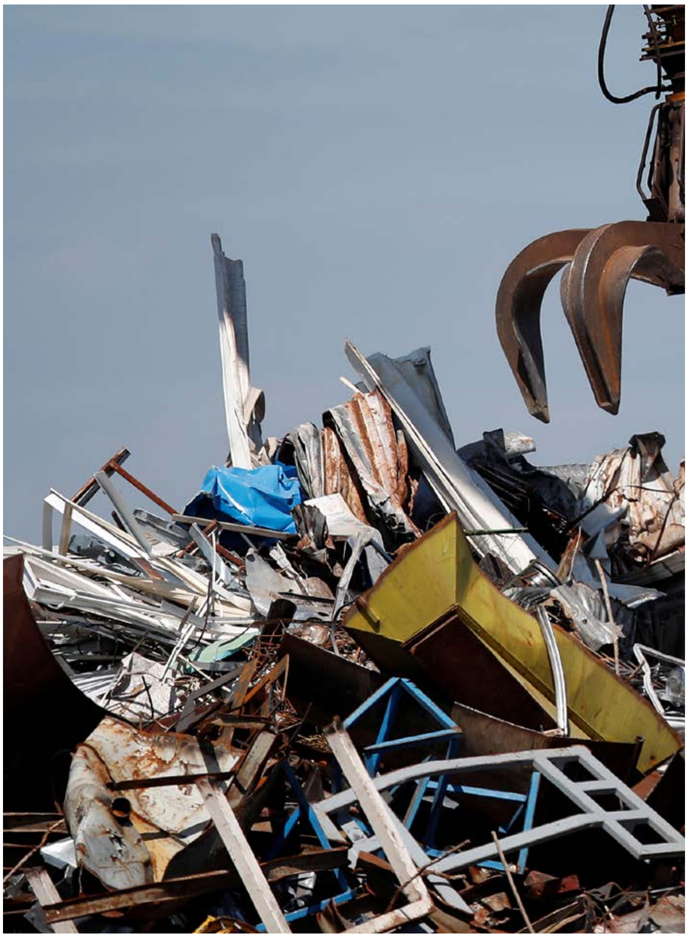
The OpenAir damper actuator portfolio and blue GIS examples show that product design is highly relevant to reducing a product's carbon footprint. However, this does not yet meet the requirements of a circular economy.

"Circularity requires a symbiosis between product design, operations and innovative business models," emphasizes René Bauer, Electrical Products portfolio manager at Siemens. "Our goal is to keep products, components, and materials in the highest value loop according to the circularity hierarchy. This requires a comprehensive shift in how we are doing business today," he adds. The more complex the product, the more challenging it is to implement circularity. Siemens is guided by a circularity hierarchy, which shows which criteria have the greatest impact on a product's environmental impact.

1 PRODUCT LIFETIME EXTENSION

The production of new materials and products always causes a greater environmental impact than the continued use of an existing product. Therefore, the highest sustainability potential is realized through high quality, reliable, maintainable, upgradeable and updatable products.

From a hardware perspective, modular design makes it easier to replace parts and conduct repairs, thereby extending product lifetimes. Siemens has applied this modular approach in the development of the new 3WA Air Circuit Breaker. In the new 3WA model, the application processor and the protective processor have been separated



CHRISTIAN HARTMANN/REUTERS

Figure 3

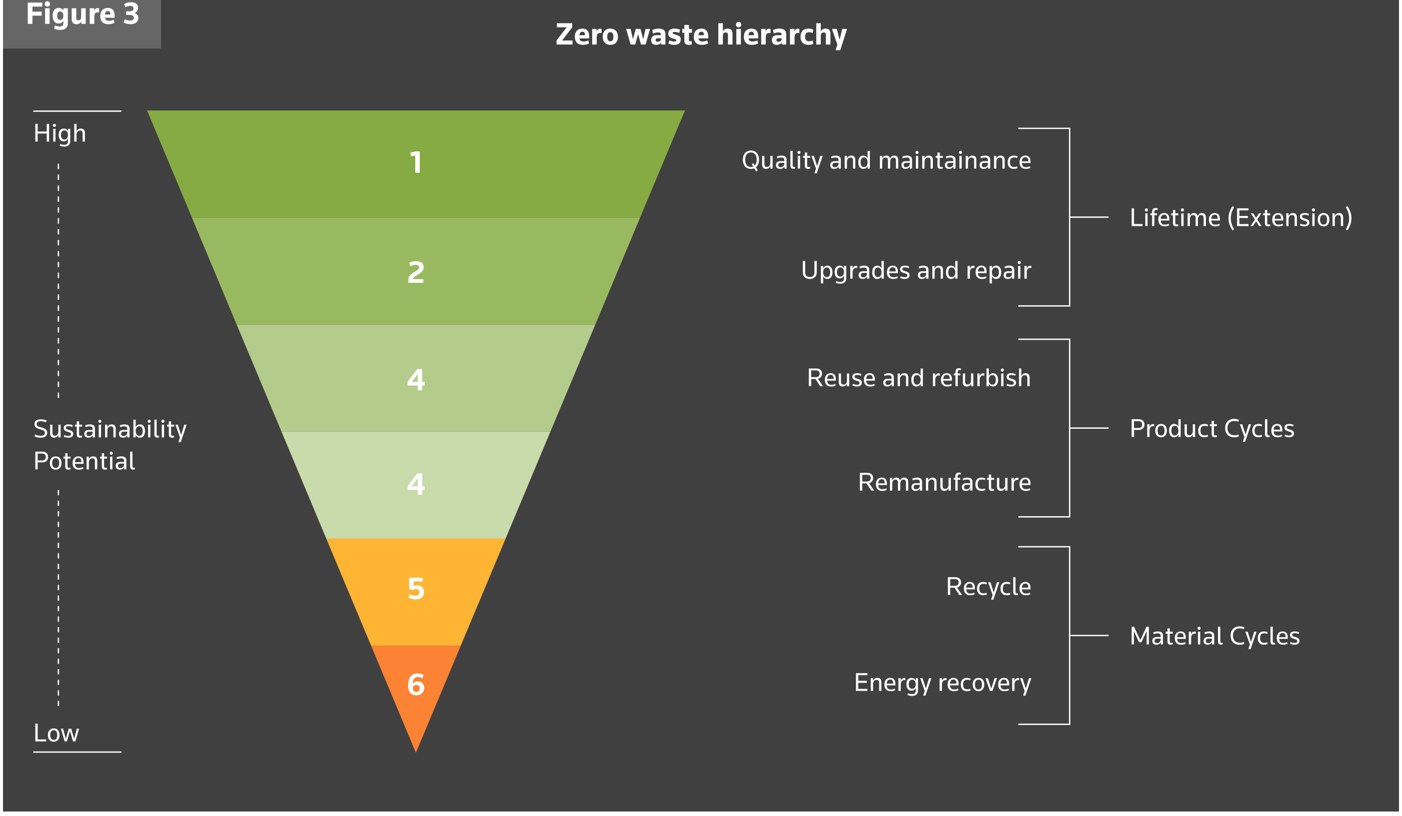


Figure 3: Which criteria have the biggest impact on product sustainability? This question is guiding Siemens in optimizing its products.

to improve the product's upgradability. "The new circuit breaker shows that even proven, high-quality products can be further optimized in terms of their service life," says Hassel.

2 ESTABLISHING PRODUCT CYCLES

Circular economy necessitates closed loop material flows. Ideally, product components and materials are kept at their highest utility and value, so they can go through several consumption circles. This means that products should be designed with refurbishment or remanufacturing in mind, but also appropriate logistics for return and redistribution, as well as refurbishment centers are required.

Siemens Healthineers has implemented this approach with their ecoline product portfolio: medical equipment used for magnetic resonance imaging, computed tomography or molecular imaging, for instance, are thoroughly refurbished to a level as good as new and resold. "With ecoline, we make our innovative technologies available at affordable prices by giving imaging systems and components a second life. This is also a strong contribution to a circular economy in healthcare, with currently over 6,000 ecoline systems already installed," explains Anne Liebenberg, Head of Marketing & Sales for Asset Lifecycle Development. To ensure high quality and a performance and look and feel like a new system, ecoline systems are manufactured and tested in the same production lines as new systems by the same team of employees. In addition, the same service options as available for new systems are offered. Also, the supply of original service parts is guaranteed for at least five years.

All sides benefit from this concept: the initial owners of the equipment receive attractive buy-back values; the second owners benefit from an affordable price. And by closing the loop, all sides contribute to the transformation toward a circular economy in healthcare.

3 ESTABLISHING MATERIAL CYCLES

When a product has reached the end of its lifecycle and can no longer be repaired or remanufactured, full or partial recycling is often the next port of call. Siemens, for example, has formed an association with other manufacturers to collect and recycle fuses. While copper and silver are recovered and sold to generate revenue for social initiatives, the waste left over from the ceramic body of the fuses is later used in road construction.

There are challenges, however. Plastics, for example, change their properties when reprocessed, with quality often suffering as a result. Availability and viability not only of reprocessing facilities but also supply of reprocessed material to incorporate into new products is also a factor.

Nevertheless, there are still significant potential environmental savings to be had. A test-case analysis on a Siemens circuit breaker, for example, showed that an increase of up to 37% recycled resins reduced the CO2 footprint of the product by 5.3%.

However, there are limits to reuse. Emphasis, therefore, must be on developing products that maximize the use of highly recyclable materials and minimize the use of materials for which recycling is more challenging.

A DIGITAL BOOST FOR CIRCULAR APPROACHES

An important driver of the circular economy is digitalization. A Sitra report that looked at industries with high emissions footprints, including buildings, found that transitioning to a circular economy with digitalization at its heart could mean as much as 296 million tons of CO2 cut per year in the EU by 2050.

Digitalization is an enabler in various ways:

- It facilitates the creation of new, circular business models in which products are offered as part of broader services (servitization, pay-per-use). An example are "X-as-service" models that are based on smart equipment and use big data, operational data and sensing to facilitate linking tangible and intangible elements while satisfying consumer needs. [1]

- Digital sharing platforms help to connect collaborative and temporary users of products and services and facilitate the mobility of unused products. In a similar way, cloud data and communication technologies allow companies to establish product, material, or waste exchange platforms.[2] Such platforms are already in place, e.g. for construction materials. Siemens Real Estate for example has worked with startup Concular to resell some of the building products inventory from a building slated for demolition through its digital exchange platform.

- Digitalization enables the complete documentation of material and product properties, from the origin of raw materials, transport routes, or the materials used in the product. This makes it possible to check how sustainable a product is. On the other hand, tags and/or digitally stored information can facilitate re-manufacturing, repair, and refurbishment processes as well as proper recycling at end-of-life.
  One way of implementing this approach is through digital twins of products and infrastructure assets: Siemens Real Estate, for example, develops all new building projects using a digital twin, which is an exact digital image of the physical building. These digital models are increasingly filled with material and product data, which at the end of the building's life will provide information about which components are still functional, what their reuse potential is, or how they can be recycled.

- Smart devices can be controlled remotely and are easier to update or upgrade, this can extend their service life.

SIEMENS

Digital models are filled with data, which at the end of a building's life will provide information such as components' functionality, reuse and recyclability

THE OUTLOOK

A circular future is a sustainable future, that much is clear. And all industries, be they consumer-facing or business-to-business, within fashion, food or electronics – can adapt. For some sectors, the process will be intuitive. For others, it will be highly complex – sophisticated methodologies will need to be developed to navigate the push-pull of competing sustainability priorities, and products will need to be reimagined and redesigned. Business processes and business models, meanwhile, will continue to adapt and evolve along not only a more circular – but increasingly more digital – path.

For Siemens, the way forward is clear. Targets that are accompanied by guiding principles and frameworks inform its circular vision and all business units are engaged. Emphasis is placed on lifecycle analysis and extension, closed loop material flows that precipitate new business models, as well as the use of secondary materials and recycling.

A circular economy will help to tackle rising GHG emissions, pollution and resource extraction, and ultimately will be the foundation of a new business paradigm. To get closer to this goal, an integral consideration of sustainability criteria in product design will play a key role.

[1] Source: Industry 4.0 as an enabler in transitioning to circular business models: A systematic literature review. In: Journal of Cleaner Production 393 (2023)
[2] Source: Industry 4.0 as an enabler in transitioning to circular business models: A systematic literature review. In: Journal of Cleaner Production 393 (2023)