Driving sustainable outcomes in design and manufacturing

New business opportunities through sustainability

AUTODESK

Driving sustainable outcomes in design and manufacturing

Humanity now uses 100 billion tonnes of resources every year, 90% of which are virgin materials extracted and processed from the Earth. Only 30% becomes something permanent and just 8.6% is recycled. The rest is discarded, thrown away or incinerated for fuel.[1]

Manufacturers, who process much of this massive quantity of resources, are responding to society's demands. By 2050, there will be 10 billion people living on Earth.[2] That means increased demand for buildings, phones, TVs, vehicles, everything—and the energy and materials required to make them. As a result, approximately 19% of global greenhouse gas emissions are from the manufacturing industry,[3] and by 2050 the growth in population will require at least twice the energy[4] and materials.[5]

Pressure to reduce the greenhouse gas (GHG) emissions associated with these demands is reaching intense levels. Governments around the world are introducing net-zero policies designed to ensure the amount of GHGs released into the atmosphere is equal to the amount removed.

More than 70 countries, including the biggest emitters – China, the United States, and the European Union – have set a net-zero target, covering about 76% of global emissions. Over 1,200 companies have put in place science-based targets in line with net zero, and more than 1,000 cities, over 1,000 educational institutions, and over 400 financial institutions have joined the Race to Zero, pledging to take rigorous, immediate action to halve global emissions by 2030.[6]

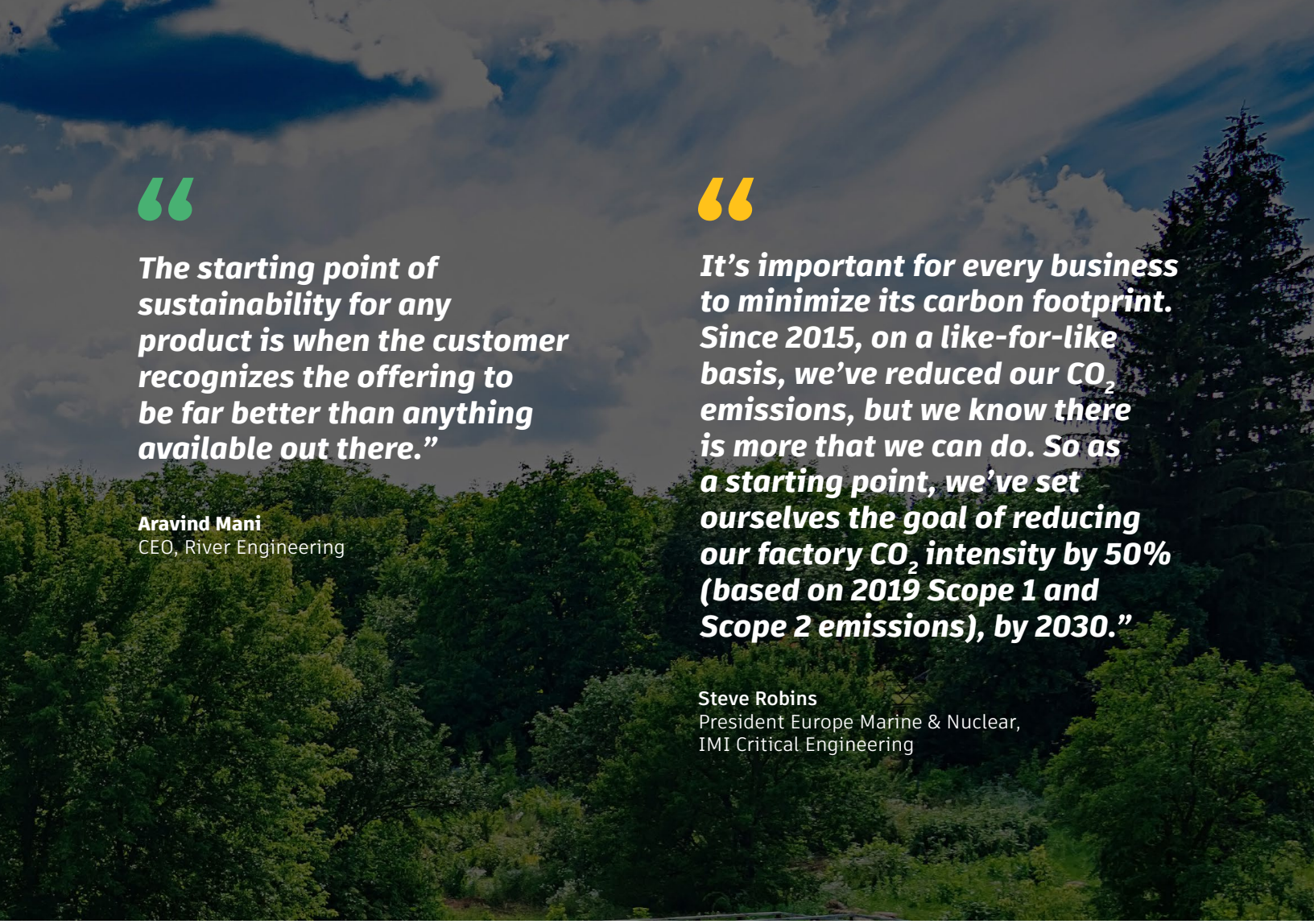
Business is responding: in a UN report, 99% of CEOs say they believe sustainability will be important to the success of their business.[7] And there is real progress being made in manufacturing. In the automotive industry, Jaguar Land Rover has already achieved carbon-neutral status for its UK manufacturing plants. Other European automakers are aiming for similar status in the next 10 years. South Korean manufacturer Hyundai Motor has committed to achieve carbon neutrality in its global products and operations by 2045.[8] In Indonesia, the electric vehicle and battery industry is now the major source of foreign investment, accounting for 70% in 2020.[9] Nevertheless, the public expects more. Seven out of 10 Americans say large businesses and corporations are doing too little to address climate change.[10]

Most large corporations now shape and cross-check their business strategies against the United Nations' (UN) Sustainable Development Goals (SDGs), which put sustainability and carbon reduction in a central role. Some remain skeptical about the Environmental, Social and Governance (ESG) initiatives deriving from the SDGs, but according to consultants Roland Berger,[11] ***"…businesses that don't take action may start to see a decreased demand for their products and services, in conjunction with a rise in CO_2 emissions costs. As such, these businesses will have lower margins, and could see up to 50 percent of their profits put at risk."***

This report looks at the options available to drive greater sustainability in product design and manufacturing, with an emphasis on decreasing energy and materials usage, reducing harmful health impacts, and creating greater resilience in society. It discusses examples where innovation and change are already happening. It looks at how data—and the insights derived from that data—can help product designers and manufacturers make more informed decisions to optimize design and manufacturing processes, helping to achieve sustainable outcomes.

A focus on sustainability throughout design and manufacturing processes helps businesses realize a host of positive outcomes—energy and material cost savings, faster product design and manufacturing times, greater predictability, positive brand image, market differentiation, customer loyalty, more durable and resilient products and many others. Sustainability, we believe, is not solely a cost, but an opportunity.

Srinath Jonalagadda
Vice President D&M Industry Strategy, Autodesk



"The starting point of sustainability for any product is when the customer recognizes the offering to be far better than anything available out there."

Aravind Mani
CEO, River Engineering

"It's important for every business to minimize its carbon footprint. Since 2015, on a like-for-like basis, we've reduced our CO_2 emissions, but we know there is more that we can do. So as a starting point, we've set ourselves the goal of reducing our factory CO_2 intensity by 50% (based on 2019 Scope 1 and Scope 2 emissions), by 2030."

Steve Robins
President Europe Marine & Nuclear,
IMI Critical Engineering

ACTION AGENDA

Join the movement. 21% of 2,000 of the world's largest public companies already have net-zero policies. That leaves 79% that do not—a proportion likely to be even higher outside of that top layer. Where does your organization fit here?

Manufacturing's extensive impact on carbon emissions means it is going to be at the forefront of change—whether that is self-regulated or mandated by governments. The first step is to define your path to sustainability. Autodesk provides a tool to benchmark your current sustainability strategy against global trailblazers. Armed with that insight you can start to audit existing policies, evaluate business model innovation, and set relevant KPIs.

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Contents

CHAPTER 1

The transition from a linear to a circular economy

To address sustainability challenges and meet their commitments, many manufacturers are implementing smarter and more efficient design and manufacturing approaches, increasing materials productivity, developing more circular business models, reducing energy use, and enhancing supply chain responsibility.

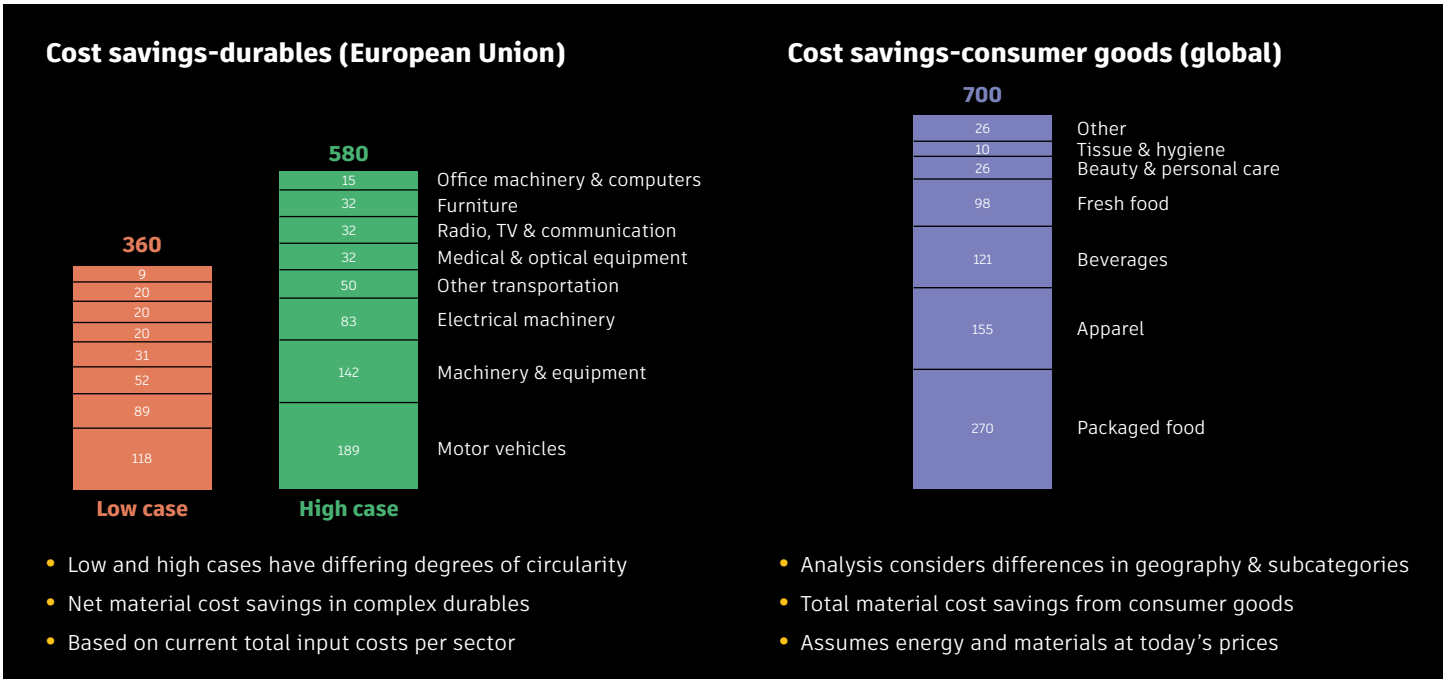
These are not mutually exclusive approaches. A circular model is emerging as a leading contender to contribute to the massive task ahead of reaching net-zero emissions. Circularity questions the very principles of our current consumption model, which are still largely based on a linear, throwaway economy in which resources are extracted, processed, consumed and discarded. A circular model eliminates waste and circulates resources driven by the refrain of 'reduce, reuse and recycle,' and regenerates nature under a second set of 3Rs: 'remediation, restoration and regeneration.'

An economy-wide transition to circularity could halve GHG emissions in Europe by 2030, according to the Ellen MacArthur Foundation, a leading proponent,[12] and governments globally are starting to explore and mandate circular approaches. China recently released a new multi-year plan to develop the country's circular economy, with the hopes of increasing resource efficiency, spurring innovation, and meeting climate commitments.[13] In Europe, the EU has launched a Circular Economy Action Plan[14] and the Dutch government has set a target to be 100% circular by 2050 with an interim 50% target by 2030.

From a business perspective, there are extremely solid commercial grounds for investigating circularity too. Globally, a transition to a circular economy could generate more than US$1 trillion in material cost savings by 2025[15], based on research by consultancy Roland Berger.

USD 1 trillion can be saved by transforming linear economies into circular economies

Estimated net material cost savings compared to the linear economy [USD bn]



Source: World Economic Forum, Ellen MacArthur Foundation, Roland Berger

We developed a smart meter that is based on the similar principles of a Fairphone, which is that every device can be taken out for repair, or to be changed, separately. If there's something wrong with the smart meter you don't have to throw away the entire product, and step by step, we're doing this in our entire supply chain."

Pallas Agterberg
Director of Strategy and Innovation at Alliander

Regulation is driving change

Governments are driving change towards sustainability and circularity by encouragement and funding—such as the European Green Deal[16] and Singapore's Green Plan[17]—and, increasingly, by regulation.

In China, a Green Manufacturing Initiative, as part of the Made in China 2025 industrial plan, aims to reduce high energy consumption and high pollution. Industry in China generated 70% of total pollution in 2015,[18] prompting the government to take far-reaching measures in 2017 to address the issue with an initiative to reduce smog in the areas surrounding industrial hubs by focusing on high-tech, advanced industries. Up to 40% of factories were closed in this period to assess the extent of the problem and instigate remedial action.[19]

In 2021, Beijing prioritized the development of China's circular economy as part of the Development Plan for the Circular Economy in the 14th Five Year Plan Period. The Plan contains goals to maximize resource use and the lifecycle of products in a new multi-year plan to develop the country's circular economy, with the aim of increasing resource efficiency, spurring innovation, and meeting climate commitments. Initiatives include promoting recycling, remanufacturing, green product design, and renewable resources.[20]

In Europe, the EU is imposing legislative frameworks as part of its Circular Economy Action Plan. The Ecodesign Directive and Ecodesign Working Plan are introducing a new focus on the repairability and durability of products, with measures anticipated to cut over 46 million tonnes of CO_2 equivalent.[21]

Within Europe, France's Anti-waste Law for a Circular Economy came into force in 2021, with a target to recycle all plastics by 2025, single-use plastics to be phased out entirely by 2040, a 'repairability index' indicating how easily products can be repaired, and manufacturers becoming responsible for their products when they are thrown away.

Similarly, in the USA, the White House is passing executive orders relating to supply chain and American manufacturing, including the notion of a 'Right to Repair.'[22]

The servitization of manufacturing

The servitization of manufacturing places greater emphasis on higher-margin services to support customers, so that the products they use remain in optimal condition and deliver maximum efficiency. On one level, it is a response to increasing competition and declining margins, which are driving a change of focus towards services. It is also a development well-matched to a circular ethos, as it encourages manufacturers to increase their products' durability and efficiency, and focus on the total lifecycle of products – including reuse and recycling.

The concept developed initially in business-to-business environments. Rolls-Royce, for example, sells 'hours in the air' via its TotalCare service, rather than aero engines. Airbus and Boeing have equivalent offerings. Philips sells lighting as a subscription service to hotels and offices. Michelin rents tires to aviation and military customers and other organizations with large vehicle fleets. Other examples include mechanical ground diggers sold based on tonnes of earth shifted, and elevators by operational hours.

In the consumer space, subscription models for manufactured goods are emerging, with small consumer electronics now routinely available this way from brands like Grover and Boulanger. The concept is likely to expand. Could carpet customers pay a monthly fee and lease flooring with a guarantee to keep it in good repair? This would create greater demand for manufacturers of high-quality products.

The servitization model implies a shift from manufacturing to maintenance and repair. This is a different skill set from conventional manufacturing and making that transition successfully requires careful management. However, it is an opportunity to provide greater value to the customer, to become a long-term partner, and to increase margins. Servitization is a significant business opportunity that is also good for sustainable outcomes.

How generative design contributes to sustainability

Over 80% of all product-related environmental impacts are determined during the design phase of a product.[24]

One reason for this is that engineers and designers are limited in time and resources to fully explore both the design and manufacturing options that may be available. Due to these constraints, they might resort to incremental improvements to previous design solutions, with the result that components are often over-designed.

Generative design is a new technology that upends design and engineering by removing the limitations of imagination or previous design history. It is a design exploration process through which designers or engineers input design goals into generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints.

Generative design then delivers hundreds of design alternatives for consideration and trade-off studies in less time than a human can develop and evaluate one or two alternatives. The value of generative design is its ability to expose the design team to a greater number of potential manufacturing-aware solutions to a specific set of design constraints, saving time and offering alternatives they wouldn't have otherwise imagined or considered.

The impact of generative design can be spectacular. In the USA, General Motors used the technology to reduce the number of components in a seat bracket from eight to one, while making it 40% lighter and 20% stronger.[25]

ACTION AGENDA

Is your company using circularity to drive down costs, production time and deliver more sustainable products?

There is a common misconception about circularity that it is simply recycling, rather than truly embracing the holistic idea of designing to reduce the need for virgin materials in the first place, and incorporating the potential for future reuse into every component and aspect of the product's lifecycle.

Circularity is all about ensuring products are designed with repair, reuse, and recyclability in mind. This means creating products that are easily repairable with standardized replaceable parts, options for adaptive reuse, and the capability to use parts from discarded products in another product. And then ease of recycling once at the end of their lifecycle.

Circularity is a mindset. Before designing a product, take a step back and assess the design as a whole. Being more thoughtful about how products are created and also understanding the downstream effects of the design can help to create something that is more sustainable.

Shifting from a linear economy to a circular economy means designing with durability, repairability, reusability, and recyclability in mind to keep the products, components, and materials circulating in the economy. Companies should always consider the different aspects of a product through to end-customer usage (hardware, packaging, disposal, etc.). The emphasis here is on how to create long-term value in a product beyond its traditional lifecycle.

Yuma Labs, for example, has created sustainable sunglasses made from recycled plastic bottles and nets discarded in the sea, with a simple process for customers to return used sunglasses, which are then made into new pairs.[23]

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CHAPTER 2

Reducing energy and materials usage

Materials use is a key environmental impact driver in manufacturing. As the data from Roland Berger shows, industries are sitting on a US$1 trillion opportunity to save by making the same products from streams of waste materials.

Reducing materials use and waste (through lightweighting and additive manufacturing, for example) and using lower-impact and more sustainable materials (such as recycled and renewable content) are important objectives for many product engineers and manufacturers. Aerospace manufacturer Airbus achieved an incredibly strong cabin partition in the Airbus A320 that is 45% lighter using generative design (see **How generative design contributes to sustainability**) and 3D printing (see **Additive manufacturing (3D printing) to reduce materials usage and improve product efficiency**, below) as part of the company's commitment to halve GHG emissions by 2050.[26]

Another approach to materials reduction is developing more circular product designs—through design for upgradability, repairability, reuse, disassembly, and recycling. BMW's concept car, the BMW iVision Circular, can be built from 100% recycled materials, enabled by alternative manufacturing methods. The metal body, for example, has a brushed finish instead of being painted, avoiding the use of chemicals and making recycling easier.[27] Other ways to boost circularity include transitioning to servitization (see **The servitization of manufacturing**, above).

> ***"We will start seeing governments pushing forward tender guidelines in terms of the sustainability metrics of materials used in the playground industry. There will be greater scrutiny on the constituent materials in a product and the end of life and recyclability."***
>
> **Barry Leahey MBE**
> CEO and Managing Director at Playdale

Image courtesy of Airbus

The ‘Scopes’ categories of total GHG emissions

Manufacturers’ impact on energy consumption is not limited to how their products are used. The energy used in making those products is important too. Manufacturers therefore seek to improve the performance of their factories and production machines, and supply chains, as well as their products, optimizing for energy consumption and reducing waste.

The different areas of energy use—and therefore potential GHG emissions savings—are sometimes referred to as ‘Scopes’, a terminology that was first used in the Greenhouse Gas Protocol of 2001.[28]

Scope 1 covers GHG emissions that a company makes directly—for example while running its boilers and vehicles. Scope 2 includes the emissions for which a company is indirectly responsible, such as energy bought for heating and cooling buildings. Scope 3 emissions are the total GHGs created in both directions in a value chain, including anything bought from suppliers in one direction, and by customers when they use the end product in the other.

There is also an emerging Scope 4, which attempts to account for avoided emissions. This is a complex area that looks at quantifying emission reductions outside of a product’s lifecycle or value chain, but as a result of the use of the product. Products that may have significantly avoided emissions include low-temperature detergents, as they reduce the amount of GHGs emitted by users, even though they involve energy consumption in manufacture.

“In order to promote sustainability, we must not only work on our own, but also involve our supply chain in a unified effort.”

Akira Sugawara
Chief Manager, Sustainability Promotion Dept., Kai Corporation

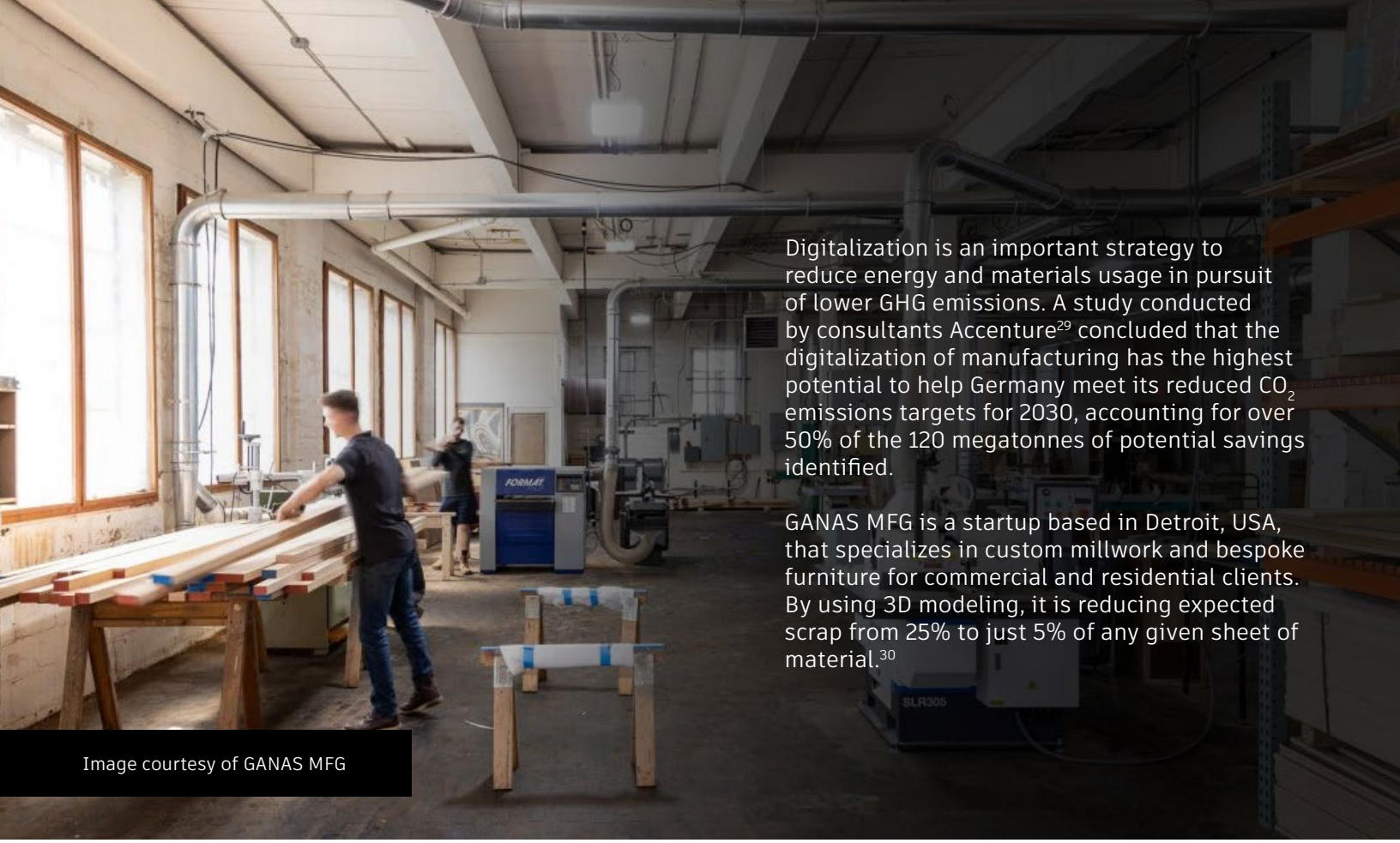


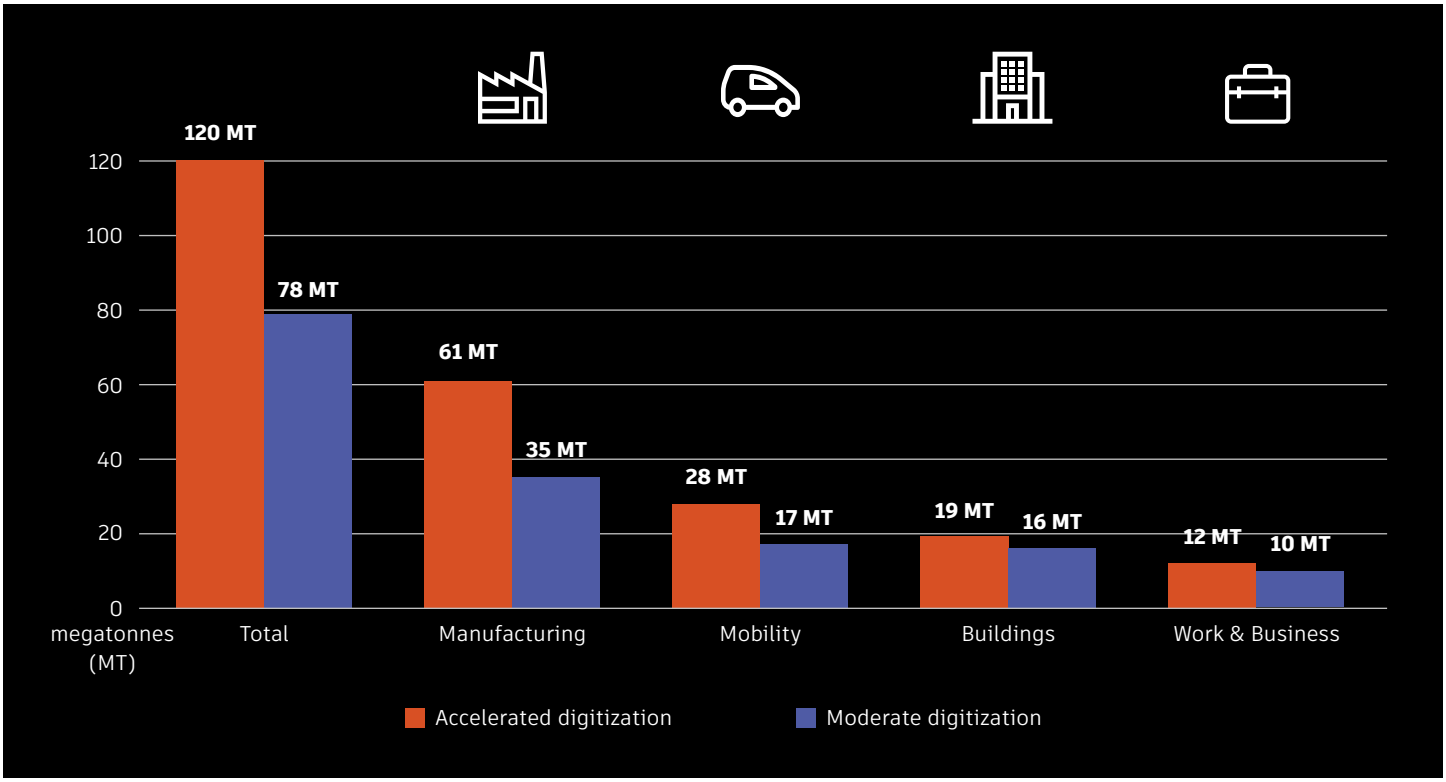
Image courtesy of GANAS MFG

Digitalization is an important strategy to reduce energy and materials usage in pursuit of lower GHG emissions. A study conducted by consultants Accenture[29] concluded that the digitalization of manufacturing has the highest potential to help Germany meet its reduced CO_2 emissions targets for 2030, accounting for over 50% of the 120 megatonnes of potential savings identified.

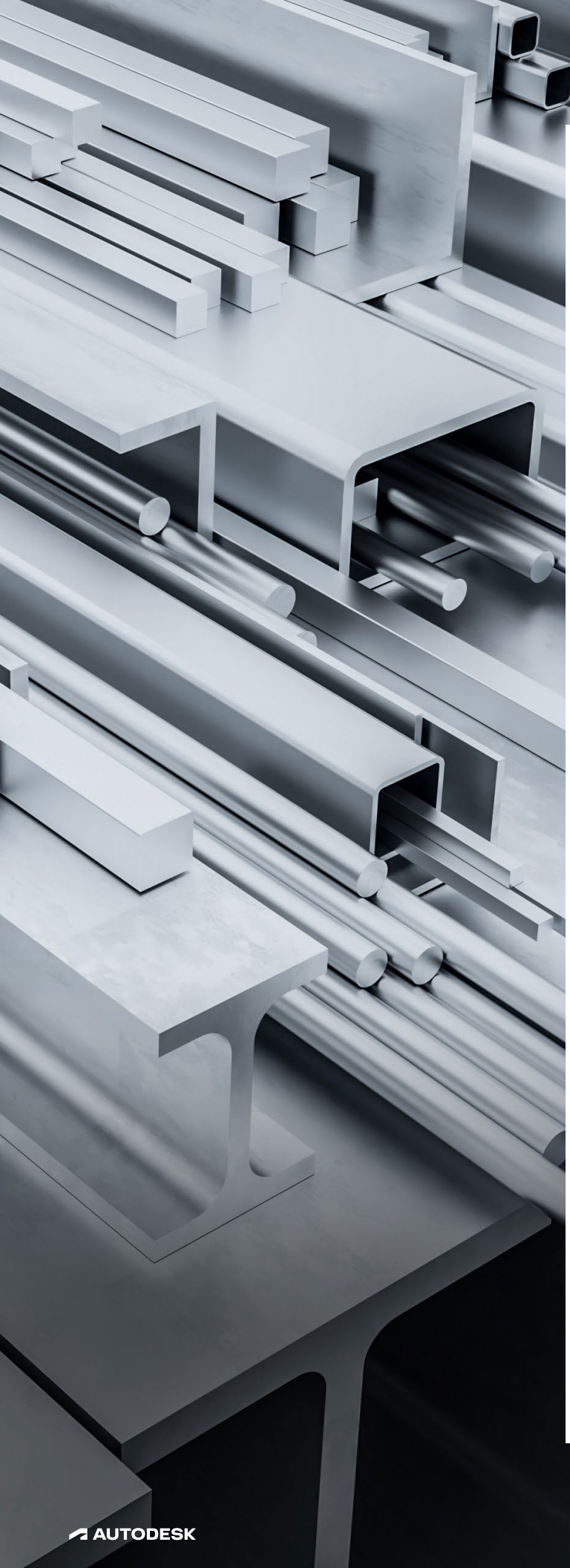
GANAS MFG is a startup based in Detroit, USA, that specializes in custom millwork and bespoke furniture for commercial and residential clients. By using 3D modeling, it is reducing expected scrap from 25% to just 5% of any given sheet of material.[30]

Digitization of manufacturing has the highest potential

How much carbon dioxide equivalent (CO_{2E}) can be reduced in 2030 in total?



Source: Bitkom study "Climate effects of digitization," conducted by Accenture



How ‘digital product passports’ accelerate circularity in manufacturing

Lack of visibility is one of the challenges facing manufacturers wanting to increase reuse of products and the raw materials in them. Right now, it is very hard to know—or find out—what has gone into what. That’s starting to change with the presentation of plans by the European Commission in December 2021 to introduce a ‘digital product passport’, which will contain information about the composition of products circulating within the European market.[31]

Passports will provide users and consumers across the supply chain with information about how to purchase, use and dispose of products and materials correctly and in a circular way, to help boost their chances of being reused and recycled. The initiative is itself part of the Sustainable Product Initiative.[32]

The product passport concept actually predates the EU’s push. Maersk Line, for example, provides trade and transport solutions, for which a reliable supply of low-cost steel, roughly 98% of the volume of a container ship, is extremely important.

Until now it hasn’t been possible to identify different material types and grades during the traditional disassembly process, so the mixed recycled steel loses the quality, properties and value of the original materials. Steel that was installed in seven different grades becomes a low-grade, low-price material.

Maersk is exploring how to prepare ships for quality recycling in the design phase, and developing a cradle-to-cradle passport to achieve that. The aim is to gain greater control over the materials they use, and ultimately make new ships from old. As a result, the materials—including the 60,000 tonnes of steel per ship—can be sorted and processed more effectively, maintaining their inherent properties and commanding a better price when re-sold.[33]

ACTION AGENDA

Have you planned to fully optimize sustainable outcomes in your factories?

To cope with the accelerating pace of change and added complexity, many companies have already adapted the ways they design, develop, and engineer their products. They are thinking about them in lifecycles and often adopting agile development methods, concurrent engineering, and systems engineering. In contrast, factories—especially brownfield sites—are often still designed and built in a very traditional way, as is the handling of data during operation and maintenance—area by area, discipline by discipline, data silo by data silo.

The steps already being taken in product design and engineering in terms of integration and collaboration are also leading the way for manufacturing operations. Integrated factory modeling, a process that combines BIM and digital factory planning to generate a digital representation of a facility and production equipment, is increasingly being adopted—enabling manufacturers to usher their factories into this new era.

The result is a digital representation of production facilities that includes the building itself and all its associated structural, mechanical, electrical, and plumbing information, as well as all the elements of the factory equipment from staging and production lines to assembly, finishing and beyond. This means all stakeholders are equipped with the information they need to make smart, sustainable choices that lead to improved business outcomes when the facility is constructed.

Manufacturers are already seeing the benefits of creating truly integrated digital factories. This cross-discipline approach to collaborating on one model helps teams reduce costly real-world errors and associated materials waste. It catches clashes in a digital environment, improves time to market, optimizes factory design, material use and production throughput, while maximizing energy performance and a host of other positive business outcomes.

To make its first electric sports car, The Taycan, Porsche used digital factory planning to create a smart facility where driverless transport systems help maximize flexibility. The factory is zero impact, not just on the CO_2 balance sheet—there is a holistic approach to environmental aspects that includes resource consumption, waste, and mobility for the entire site. The factory also has a green roof and is equipped with photovoltaic systems. The electrical energy comes from renewable sources, and the biogas-powered combined heat and power plants on-site supply the factory with heat and additional electricity.

Every factory detail is in the integrated planning model, which Porsche created long before the factory's foundation stone was laid. There is neither a garbage can nor robot in the factory that was not first approved on screen. In the model, all designers, planners, and suppliers speak the same language. For example, suppliers provide designs for things such as handling devices, which must be a 100% match with the building in the model that contractors use.[34]

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CHAPTER 3

Increasing health and resilience

Once designers bring circularity into their thinking, other benefits quickly emerge, especially in the areas of health and resilience.

Burning coal is clearly not viable long-term in a climate emergency. However, coal power stations seem likely to remain onstream, perhaps for several decades, until scalable alternatives are in place, particularly in China.

To mitigate the health impacts of coal burning, Vecor, a green-technology company based in Hong Kong, is recycling ash from coal power plants into high-quality tiles. Fly ash—a fine powder byproduct of burning coal—makes up more than half of coal waste, and 99% of it is filtered by power-plant exhaust stacks. But rather than divert that filtered ash to landfills, resulting in harmful substances such as arsenic, quicksilver, and lithium seeping into groundwater, the Vecor recycling process renders the ash not only safe for use but also viable as an ingredient in products such as concrete and wallboard, creating stronger materials than virgin sources.

Fly-ash tiles are now produced at Vecor's first factory in Zibo, China, in the Shandong province, where there are more than 40 coal power stations. Circular-economy practices like this protect the air and groundwater while using fewer resources.[35]

> *"Digital technology will massively improve industrial processes. You can see this happening already in safety, where you've got drones being used to do dangerous monitoring tasks. And AI technology could be applied to air emissions. You can use camera intelligence to capture, analyze, and even predict what is going to happen in terms of air emissions."*

Annie Heaton
Head of Sustainability Engagement and Disclosure, ArcelorMittal

Image courtesy of Vecor

In terms of enabling greater resilience through circularity, a Dutch company has developed a road surface product made from recycled plastic that is also addressing the country's acute challenge of rising sea levels.

It's no surprise that the Netherlands has to pay close attention to water levels. Almost half the country's total surface area lies less than one meter above sea level, and nearly a third is actually below sea level. However, global heating means that sea levels are now rising at a rate that is putting excessive stress on the country's infrastructure.

Dutch startup PlasticRoad is producing roads made out of recycled plastic, tackling two issues at once: plastic pollution and climate change. The plastic material mitigates flooding, is easier to maintain, and can itself be recycled up to seven times. It is also four times lighter and as much as 70% faster to build than conventional methods. Plus, it lasts three times longer and produces up to 72% fewer carbon-dioxide emissions than conventional roads.

What's more, the road requires no intensive excavation work, heavy foundations, environmentally detrimental concrete slabs and layers of asphalt, or drainage systems. Assembling the road is like LEGO: it takes just a few clicks, and everything is built in.

Two pilot projects—a pair of 100-foot cycle paths built in the Dutch towns of Zwolle and Giethoorn—have demonstrated the benefits: each lane contains 1,000 kilograms of recycled plastic—the equivalent of 218,000 plastic cups.[36]

Image courtesy of PlasticRoad

Additive manufacturing (3D printing) to reduce materials usage and improve product efficiency

Additive manufacturing has many potential applications and can reduce the use of materials, as there is no unused waste with 3D printing compared with subtractive methods. It can also improve product efficiency and enable the production of new, more sustainable products.

In India, production of electric vehicles (EVs) has not advanced as quickly as hoped. That's a problem for air pollution, among other factors, as 21 of the 30 cities with the worst air pollution in the world are in India. The government is determined to gain ground lost in EV production to the US, Europe, and China. It has set a 2030 target by when it wants EVs to account for 30% of all new car sales.

Bangalore-based Greendzine is using design modularity to create low-speed electric vehicles faster than anyone else in the industry. It launched Quark U, an electric moped differentiated from the electric two-wheelers which follow conventional petrol scooter form.[37]

Greendzine adopted what it calls 'fail fast and fail forward,' in which everything is designed modularly from the same basic platform. Parts and builds are prototyped quickly using 3D printing and abandoned without excessive loss of time or intellectual property if they don't work. It all leads to Greendzine's accelerated product-development strategy called 'concept to product in 90 days,' which it says is a necessity in today's economy.

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Image courtesy of Greendzine

ACTION AGENDA

Designing and manufacturing new products that can increase resilience and create health benefits requires new thinking and new approaches to unleash that thinking.

This can involve making lightweight, easy-to-use products and selecting and testing materials better suited to ensure the durability and resilience of a product.

Manufacturers can adopt these practices with the help of design software to build modular capability. As Greendzine's experiences with modularity demonstrate, validating or rejecting new forms quickly helps manufacturers move models into preliminary prototyping using 3D printing. Manufacturers can establish the physical form of the new product quickly and know whether it fits the project's requirements in terms of lightweighting, lower emissions, greater durability, or better recycling/reuse characteristics.

CHAPTER 4

The change opportunity

Faced on the one side with regulatory mandates to cut GHGs and customers' demands for change on the other, manufacturers have strong incentives to reinvent how they operate. Circularity is gaining ground as a business model that can be deployed to address the sustainability needs of customers and of society, while offering ways to reduce costs, increase efficiency and improve margins.

It's important to get this right. The UN's International Resource Panel has assessed the probable impact of moving to a resource-efficient material economy comparing two scenarios: No change in our use of materials versus comprehensive new policies to reduce the use of virgin resources.[38]

In the business-as-usual scenario, global resources extraction roughly doubles to 190 billion tonnes per year by 2060 and CO_2 emissions also double to 70 billion tonnes per year. In the more circular scenario, global resource extraction still grows, but by a lesser amount to 143 billion tonnes by 2060. However, global carbon emissions drop substantially, to just under 5 billion tonnes.

The report also concludes that people's standard of living can continue to rise in a circular economy. In other words, prosperity is not dependent on consuming ever more physical resources.

Manufacturing is one of the primary consumers of resources in the global economy and it is going to be a crucial player in the transformation to sustainability. Driving sustainable outcomes in manufacturing will require change, but substantial benefits will accrue to those who make the switch successfully. Companies that address these opportunities could tap into a market for new sustainable products and services estimated to be worth US$338 billion.[39] The digital tools and innovations described in this report are going to be vital in helping manufacturers reach toward and achieve their sustainability goals in ways that ensure a prosperous future.

> *"Many companies generally think that sustainability initiatives are hardly helpful to improve profitability…in the short term. However, SK ecoplant believes that its various initiatives to enhance sustainability leads to the company's profitability. We have been able to increase operating profit by improving energy recovery and steam supply, decreasing landfills and extending regular maintenance intervals."*
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> **Jae Yeon Cho**
> Vice President, Digital Transformation, SK ecoplant

38. https://www.resourcepanel.org/sites/default/files/documents/document/media/unep_252_global_resource_outlook_2019_web.pdf
39. Global Climate Change Analysis 2018, CDP, 2019, https://www.cdp.net/en/research/global-reports/global-climate-change-report-2018

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