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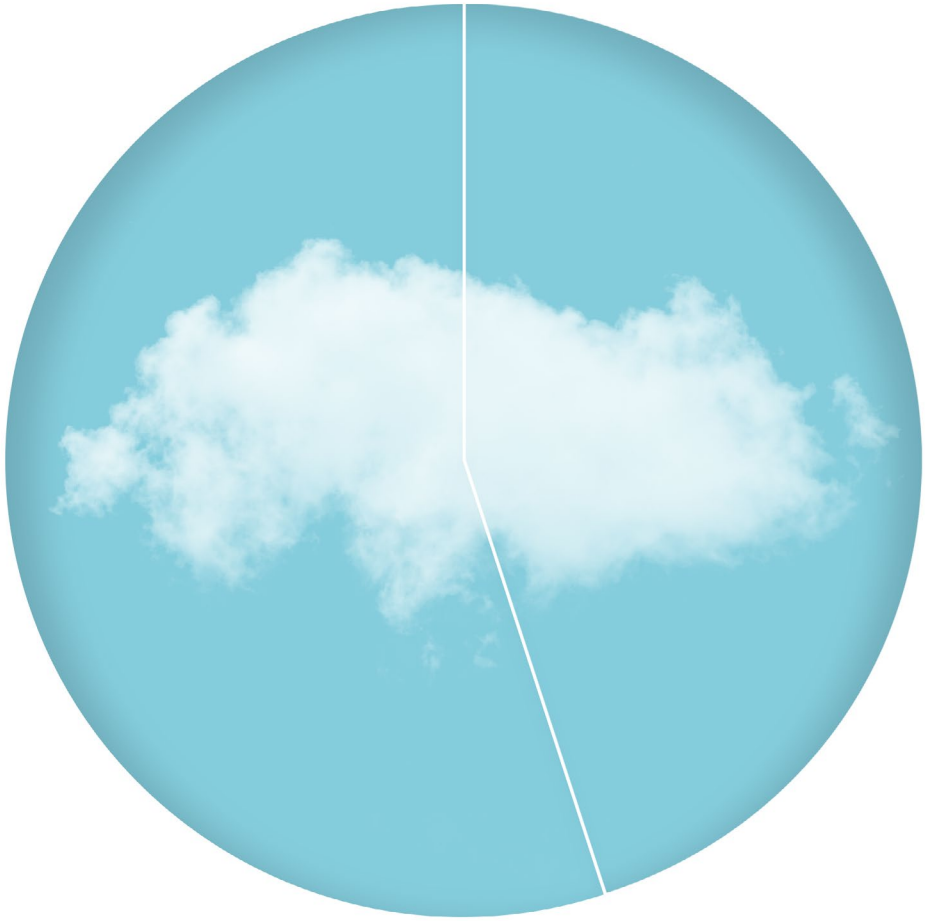
COMPLETING THE PICTURE
HOW THE CIRCULAR ECONOMY TACKLES CLIMATE CHANGE

ELLEN MACARTHUR FOUNDATION

MATERIAL ECONOMICS



ABOUT THIS PAPER

Completing the Picture highlights the indispensable role that the circular economy plays in tackling the climate crisis. It aims to demonstrate how circular economy principles and strategies significantly reduce greenhouse gas emissions. It sets out analysis on industry and the food system to illustrate how the circular economy transforms the way products are made and used, and how this transformation has the potential to reduce emissions. These insights have been drawn from two Material Economics reports – *Industrial transformation 2050* (2019) and *The circular economy: a powerful force for climate mitigation* (2018) – and the *Ellen MacArthur Foundation's Cities and circular economy for food* (2019) report. It discusses initial findings indicating that the circular economy offers a unique potential to increase resilience to the physical effects of climate change, and aims to initiate a deeper exploration of the subject. Finally, setting clear priorities, the paper calls on governments, businesses, investors, and academia to integrate their efforts to respond to climate change with those to accelerate the transition to a circular economy.

DISCLAIMER

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ABOUT MATERIAL ECONOMICS

Material Economics is a Stockholm-based management consultancy firm specialising in sustainability from a business strategy, technology and policy perspective. The firm has published leading reports on climate change and circular economy in collaboration with Ellen MacArthur Foundation, European Climate Foundation, Cambridge University, Wuppertal Institute, Climate-KIC, Sitra and others. With experience from more than 100 sustainability-related strategy projects in sectors such as buildings, transportation, packaging, manufacturing, chemicals and food, Material Economics advises world-leading businesses on how to reduce their environmental footprints and become more circular.

Further information: materialeconomics.com

MATERIAL ECONOMICS

ABOUT THE ELLEN MACARTHUR FOUNDATION

The Ellen MacArthur Foundation was launched in 2010 with the aim of accelerating the transition to the circular economy. Since its creation, the charity has emerged as a global thought leader, putting the circular economy on the agenda of decision-makers around the world. The charity's work focuses on seven key areas: insight and analysis; business; institutions, governments, and cities; systemic initiatives; circular design; learning; and communications.

Further information: ellenmacarthurfoundation.org • @circulareconomy

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In support of the paper

Carbon constraints actually represent huge ingenuity opportunities. That is true for every company, for every city, and any country. That is the direction in which we need to move, and this paper offers compelling figures to give confidence in our ability to optimise decarbonisation and economic development in mutual support of each other.

Christiana Figueres, Former Executive Secretary of the UN Framework Convention on Climate Change and Founding Partner, Global Optimism

'Completing the Picture' is fully consistent and complementary to the efforts of the UN International Resource Panel to decouple economic growth from resource use and environmental impacts. It is nicely fitting to the empty space of the effective climate change policy puzzle.

Janez Potočnik, Co-Chair, International Resource Panel; Former EU Commissioner for the Environment

The message of this paper is dynamite. Most people believe that climate mitigation is only about changing energy systems. Wrong. It is about materials, as well, and it is about land use. Materials such as steel, cement, aluminium, and plastics make up almost 20% of carbon emissions. And demand for such materials increase rapidly. Moreover, every time we put a plough in the land carbon is released. The good thing is: there are solutions. By going circular carbon emissions will be curbed, air and water pollution reduced, and money will be saved!

Anders Wijkman, Chair Climate-KIC, Honorary President Club of Rome

As countries work together to find solutions to climate change, this paper is a valuable contribution to the public conversation. Ensuring a stable climate for future generations is a vitally important challenge, but it is achievable. This paper helps lay the groundwork for governments and businesses around the world to take action.

Hon. James Shaw, Minister for Climate Change; Minister of Statistics; Associate Minister of Finance; Green Party Co-leader, New Zealand

This paper confirms the role of a circular economy to achieve climate goals and presents practical examples on how a circular economy offers a unique opportunity to reduce global emissions.

Carolina Schmidt Zaldivar, Minister of the Environment, Chile

As decision-makers we have too many problems and too few solutions. Here is a way to tackle climate problems and resource problems at the same time: the circular economy's potential to achieve climate targets is significant, yet it is not recognised enough as a key solution. Governments and businesses will find in this important paper strategies and pathways to achieve net-zero emissions while building greater prosperity and resilience. Time is pressing – this transition should be a clear priority.

Ida Auken, Member of Parliament, Social Liberal Party; Former Minister for the Environment, Denmark

Climate change and food systems resilience are interdependant. There is only one way forward: regenerative models of agriculture that are based on healthy and resilient soils, increasing carbon sequestration, protecting biodiversity and preserving fresh water, supporting a shift towards food practices that both curb public health costs and respect planet boundaries. Such models enhance natural systems instead of killing them, as life cycles start and end in soils. We've developed several partnerships and initiatives to support this transition towards sustainable food diets – for example in France and in the US – and it is urgent we continue engaging with all stakeholders about innovative, budget-efficient ways of financing social and climate built-in business solutions for the future.

Emmanuel Faber, Chairman & Chief Executive Officer, Danone

At Solvay, we are adapting our use of resources and boldly decoupling our growth rate from our emissions to reach our goal in emissions reduction in absolute terms by 2025. This initiative makes us rare among our peers in the industry who we call upon to join us. As shown in this paper, the circular economy is an essential lever to help us collectively achieve the Paris Agreement to protect our planet for future generations.

Ilham Kadri, Chief Executive Officer, Solvay

At Intesa Sanpaolo, we strongly believe that with financial strength comes a broader responsibility towards society and the environment. Enabling a rapid shift towards a circular economy that benefits people and the planet is an important part of this responsibility. Moreover, it is vital to achieving the climate targets set by the Paris Agreement, while also enhancing companies' resilience and unlocking new business opportunities. We look forward to playing an active role in the new European Green Deal envisaged by the European Commission.

Carlo Messina, Chief Executive Officer, Intesa Sanpaolo

As a Global Partner of the Ellen MacArthur Foundation, DS Smith is supportive of the wide-ranging and timely circular economy recommendations outlined in this paper. Today, we face huge challenges to mitigate the effects of climate change and achieve agreed global warming targets. By improving circularity of resource use, as well as decarbonising energy production, business and society can work together to deliver carbon reduction goals. The paper highlights that 45% of the target can be tackled through better adoption of a circular economy. At DS Smith, we are committed to redefining packaging for a changing world and have therefore developed a robust circular business model. We use renewable resources, which support carbon capture, and after our paper and cardboard has been used across a wide-range of applications it can be recycled up to 25 times.

Miles Roberts, Group Chief Executive, DS Smith

This paper provides highly important and policy-relevant information on the potential of the circular economy in tackling climate change. It gives practical examples on circular economy solutions to significantly reduce global GHG emissions as well as increase resilience to climate change. This is a much-needed paper for all policymakers to guide us on our way towards a carbon neutral and circular future.

Sarianne Tikkanen, Senior Specialist on Circular Economy, Ministry of the Environment, Finland

UK expertise, commitment, and investment to address climate change – across government, business, and communities – is clear and strong. Adopting a circular economy is key and we are working with like-minded partners such as Singapore's Ministry of Environment and Waste Resources to support their Year Towards Zero Waste. All these efforts, internationally and back home, underpin why the UK has been nominated to co-host the UNFCCC COP26 – an opportunity to be the game changer in the way we approach the climate crisis together.

Her Excellency Kara Owen, British High Commissioner to Singapore

The paper states it clearly: the circular economy is the winning strategy. Circularity is needed to reach the 1.5˚C target, build resilience, and increase the quality of life. However, the transition must happen fast. We are racing against the clock.

Mari Pantsar, Director, SITRA

The opportunity to accelerate climate action by combining circular economy and net-zero approaches is significant. A focus on energy efficiency and decarbonisation alone in a system where so many of our resources exist in a take-make-and-throwaway economy does not meet the challenge. This important work from Material Economics and the Ellen MacArthur Foundation shows how integrating these two approaches can help meet the goals of the Paris Agreement and increase the resilience of our economies.

Marc Engel, Chief Supply Chain Officer, Unilever

To solve the greatest threat humanity has faced requires that our species look deeply and critically at the ways we do, well... everything. The good news is that the solutions already exist. This paper clearly shows how designing a circular economic model provides win-win benefits that help shift the way humanity does business towards a better, regenerative future.

Chad Frischmann, Vice President and Research Director, Project Drawdown

The depletion of natural resources, the pressure on forests and their biodiversity are not the only impacts resulting from the human exploitation of materials. It also contributes to global warming and confirms the interconnections of environmental issues. In this context, expectations for the transport sector are high and legitimate. Groupe Renault has understood what is at stake and has been working for a long time on the industrial development of various circular economy business models, as described in this paper, such as remanufacturing, developing short loops for textiles and strategic materials, and extending the lives of EV batteries. Our target, which is the reduction of the Group's carbon footprint per vehicle by 25% between 2010 and 2025, includes the lifecycle of materials.

Jean-Philippe Hermine, VP Strategic Environmental Planning, Groupe Renault

Since 2015, Google has been a global partner of the Ellen MacArthur Foundation and has shared a common vision to accelerate the transition to a circular economy. When we consider that since July 29, 2019 we have reached Earth's natural resources budget for the year, and that every day since we have been drawing down local resource stocks and emitting more carbon into the atmosphere than can be absorbed, the unwavering linkage between the circular economy and climate change is clear. We believe global businesses like Google should lead the way in improving people's lives, while reducing or even eliminating our dependence on raw materials and fossil fuels. We believe this can be done in a way that makes business sense, provides economic returns alongside societal benefits and positive environmental impacts. We celebrate this paper as an important contribution to this conversation.

Mike Werner, Sustainability and Circular Economy Lead, Google

The fashion industry will not exist in the future if we continue producing and using fashion in the same way. The climate crisis requires us to take great steps to transform our whole industry. This paper clearly shows how shifting to a circular economy and treating waste as a resource enable us to drastically reduce our footprint and reach our goal to become climate positive.

Anna Gedda, Head of Sustainability, H&M Group

It is evident that the use of raw materials and climate change are fully linked. Nonetheless, this appears to be collectively ignored and response to climate change still seem to be patchy. Tackling the issue cannot be done without an all-inclusive approach in which the circular economy is an obvious, necessary, and systemic addition to the climate change repertoire.

Carol Lemmens, Director and Global Advisory Services Leader, ARUP

The challenges of decarbonising the global economy and simultaneously building resilience to climate change and its impacts are too often addressed separately. To have a reasonable chance of minimising the damage that climate change will cause, the measures we deploy must systematically integrate mitigation and adaptation measures, recognising their interconnectedness. This paper provides a valuable overview of how the circular economy approach can incorporate and strengthen climate change mitigation and resilience, potentially providing an overarching framework to support their practical implementation.

Will Bugler, Senior Consultant, Communications, Acclimatise

The paper highlights that a system-led approach is essential and actions that mitigate climate impacts and build resilience are critical to the delivery of future emissions targets.

Philip Selwood, Chief Executive of the Energy Saving Trust, Trustee of the Ellen MacArthur Foundation

Contents

Executive summary

The current response to the global climate crisis represents an incomplete picture. This paper argues that putting in place a circular economy is a fundamental step towards achieving climate targets. Such a shift moves us beyond efforts to minimise emissions in our extractive linear system. It offers a systematic response to the crisis by both reducing emissions and increasing resilience to its effects. The benefits encompass meeting other goals such as creating more liveable cities, distributing value more widely in the economy, and spurring innovation. These attributes make the circular economy a potent contributor to achieving zero-carbon prosperity.

The world has woken up to the climate crisis, the effects of which are already being felt. The greenhouse gas emissions causing climate change are a product of our 'take-make-waste' extractive economy, which relies on fossil fuels and does not manage resources for the long-term. A step-change is needed to put the world on track to achieve zero emissions by 2050 to meet the 1.5˚C target set out in the Paris Agreement. Even if this target is met, costs to the global economy relating to climate change are projected to reach USD 54 trillion by 2100 and rise steeply with every further temperature increase. The incentive to meet the challenge is unquestionable.

To date, efforts to tackle the crisis have focused on a transition to renewable energy, complemented by energy efficiency. Though crucial and wholly consistent with a circular economy, these measures can only address 55% of emissions. The remaining 45% comes from producing the cars, clothes, food, and other products we use every day. These cannot be overlooked. The circular economy can contribute to completing the picture of emissions reduction by transforming the way we make and use products.

To illustrate this potential, this paper demonstrates how applying circular economy strategies in just five key areas (cement, aluminium, steel, plastics, and food) can eliminate almost half of the remaining emissions from the production of goods – 9.3 billion tonnes of CO_2e in 2050 – equivalent to cutting current emissions from all transport to zero.

In industry, this transformation can be achieved by substantially increasing the use rates of assets, such as buildings and vehicles, and recycling the materials used to make them. This reduces the demand for virgin steel, aluminium, cement, and plastics, and the emissions associated with their production. In the food system, using regenerative agriculture practices and designing out waste along the whole value chain serve to sequester carbon in the soil and avoid emissions related to uneaten food and unused by-products.

This paper further finds that the circular economy has the potential to increase resilience to the physical effects of climate change. For example, in keeping materials in use, businesses can decouple economic activity from the consumption of raw materials vulnerable to climate risks, and therefore build greater flexibility. In the food system, regenerative agriculture improves the health of soil leading, for instance, to its greater capacity to absorb and retain water, increasing resilience against both intense rainfall and drought. More research on the size and nature of the opportunities in this area could reveal even greater potential.

As well as tackling both the causes and effects of climate change, the circular economy can help meet other UN Sustainable Development Goals, chief among them SDG12 (responsible consumption and production). It has been shown that the circular economy framework can improve air quality, reduce water contamination, and protect biodiversity. Its principles offer businesses a raft of innovation opportunities that reduce materials costs, increase asset utilisation, and respond to changing customer demands. Together, these attributes make a compelling case for seeing the circular economy not just as one option to consider in the quest to meet climate targets, but as a powerful solutions framework for a prosperous future.

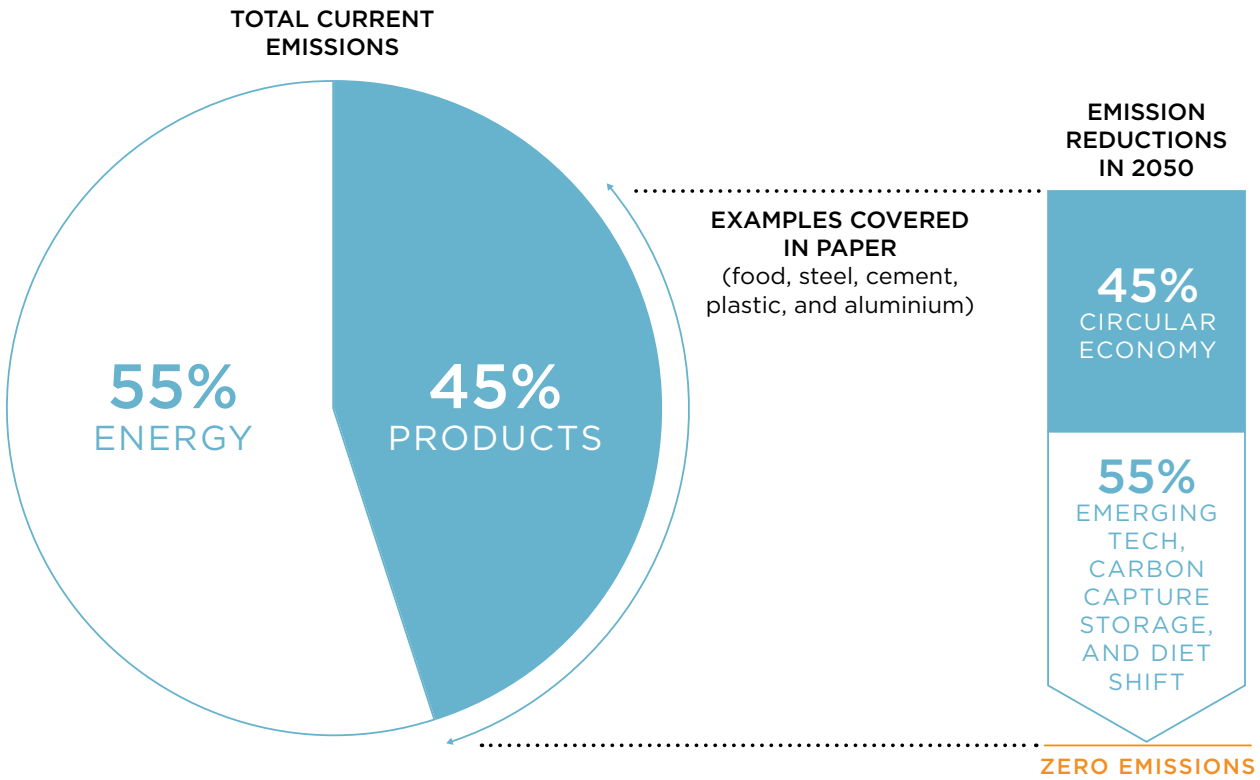
Achieving the transformation will require concerted effort: no organisation can go about it alone. International institutions can put the circular economy squarely on the climate agenda, and give it the prominence afforded other important emissions-reduction activities such as energy efficiency and reforestation. Governments and cities can weave circular economy principles into their climate strategies. Businesses can scale opportunities that simultaneously create value in new ways and respond to climate change. Investors can mobilise capital towards businesses that actively reduce climate risk in their portfolios.

A complete picture of a thriving, zero-emissions economy is coming into focus: the mission now is to make it a reality.

Key findings

Today's efforts to combat climate change have focused mainly on the critical role of renewable energy and energy-efficiency measures. However, meeting climate targets will also require tackling the remaining 45% of emissions associated with making products. A circular economy offers a systemic and cost effective approach to tackling this challenge. This paper shows that when applied to four key industrial materials (cement, steel, plastic and aluminium) circular economy strategies could help reduce emissions by 40% in 2050. When applied to the food system the reduction could amount to 49% in the same year. Overall such reductions could bring emissions from these areas 45% closer to their net-zero emission targets.

COMPLETING THE PICTURE: TACKLING THE OVERLOOKED EMISSIONS



1

Meeting climate targets requires a transformation in the way we produce and use goods

A shift to renewable energies can tackle 55% of global greenhouse gas emissions, but what about the other 45%? These are the harder-to-reduce emissions that arise from the management of land and the production of buildings, vehicles, electronics, clothes, food, packaging, and other goods and assets we use every day. This paper shows that a circular economy is indispensable in reducing such emissions by transforming the way we design, produce and use goods. The circular economy is underpinned by a transition to renewable energy and so provides a more complete picture of what is required to respond to climate change.

1.1. THERE IS AN URGENT NEED FOR CLIMATE ACTION: THE GLOBAL GREENHOUSE GAS EMISSIONS CURVE IS NOT YET BENDING

Our 'take-make-waste' linear economy is heavily extractive, resource intensive, and produces greenhouse gases (GHGs) that are causing the climate crisis. Companies extract materials from the earth, apply energy and labour to manufacture a product, and sell it to an end user, who then discards it when it no longer serves its purpose. This linear approach, which relies on fossil fuels and does not manage resources such as land, water, and minerals for the long-term, emits GHGs that are causing a global climate crisis. According to the World Economic Forum, the most important long-term risks facing the global economy relate to climate change, both in terms of probability of occurrence and economic gravity.[1] The global economic damage with a 1.5°C rise above the pre-industrial levels has been estimated at USD 54 trillion in 2100, increasing to USD 69 trillion with a 2°C rise.[2]

The world is still not close to being on track to limit the temperature rise to 1.5˚C in 2100. This is despite commitments to that effect being made by the 195 countries that signed the 2015 UN Paris Agreement and actions to reduce emissions being put in motion. According to a 2018 UN report, the current ambitions set by countries in their Nationally Determined Contributions (NDCs) will by 2030 cause an overshoot of around 29–32 billion tonnes of CO_2e compared to the level consistent with meeting the 1.5˚C target – a gap that is greater than ever.[3] Current emissions show no sign of peaking any time soon and are instead leading to an increase of 3˚C by 2100, or even 4˚C with an unchanged energy system.[4]

There are powerful economic forces behind the damaging increase in GHG emissions. The trend has been driven by the rapid industrialisation[i] of emerging economies and mass consumption in developed economies. This pattern is set to increase in future. By 2050, the global population is projected to reach 10 billion. It is predicted that an emerging-market middle class will double its share of global consumption from one-third to two-thirds, and the world economy is expected to quadruple.[5] This welcome, broad-based rise in prosperity will cause emissions to exhaust the available carbon budget[ii] by a large margin. The related impacts put further pressure on the other planetary boundaries, for example biodiversity loss. In fact, recent studies have demonstrated that around 1 million species of animals and plants are already at risk of extinction, with climate change one of the threats to their survival. Overall, resource extraction and processing are responsible for more than 90% of land- and water-related environmental impacts (water stress and biodiversity loss) with agriculture being the main driver.[6]

Urgent coordinated action and far-reaching transformations will be needed. Systemic change of energy and industrial systems, land management, buildings, and infrastructure will be needed to put the global economy on track to reach net-zero emissions by 2050 and therefore limit global warming to 1.5˚C with no or limited overshoot.[7] NDCs are currently estimated to reduce global emissions in 2030 by 3-6 billion tonnes CO_2e compared to a continuation of current policies. Nations will therefore have to increase their ambitions fivefold to meet the emission targets consistent with the 1.5˚C scenario.[8]

1.2. BEYOND A NECESSARY ENERGY TRANSITION, A FUNDAMENTAL CHANGE IN THE WAY GOODS ARE MADE AND USED IS REQUIRED TO MEET CLIMATE TARGETS

Decarbonisation of the energy system is necessary and needs to accelerate. Renewable energy and energy efficiency are key, and could provide over 90% of the reduction in energy-related CO_2 emissions by 2050.[9] The cost of generating electricity from wind, solar, and battery technologies are now lower than fossil fuel alternatives in more than two-thirds of the world, with renewable sources projected to supply more then 60% of global electricity in 2050.[10] Emerging technologies such as the 'power-to-x solution' are being developed, which show the game-changing potential of creating carbon-neutral energy systems that are able to convert surplus energy from renewables (into

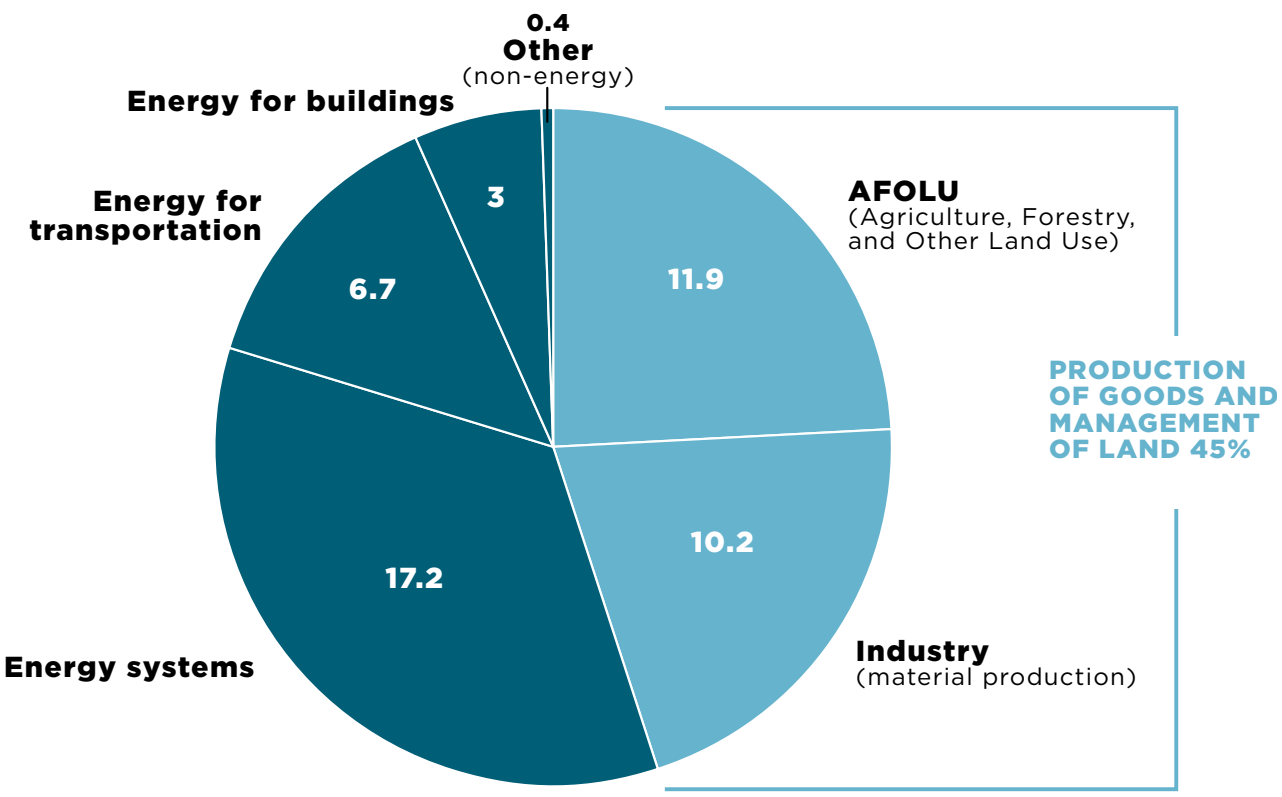
i About 80% of CO_2 emissions are caused by industrialisation and the remaining by land use such as deforestation. Stephenson, J., Newman, K., and Mayhew, S., Journal of Public Health, Population dynamics and climate change: what are the links? (2010)

ii The carbon budget is the amount of CO_2 the world can emit while limiting warming to the internationally agreed temperature goals.

gas or liquid e-fuels) and store them over longer periods of time.[11] However, investments today are still not moving quickly enough.[12] Meeting the 1.5˚C climate target requires an annual decarbonisation rate of the energy system of 11.3% - seven times the current rate. Cumulative investment in the energy system to 2050 would have to increase by around 30%, renewable energy scaled six times faster than currently, the share of electricity in total energy doubled, and investments in fossil fuels reduced significantly.[13]

A transformation is also needed in the way goods are produced and used. While the supply of energy,[iii] and its consumption in buildings and transport, together generate 55% of global GHG emissions, the remaining 45% are directly linked to the production of goods and the management of land.[iv,14] A similar finding has been made in a recent report published by the International Resource Panel (IRP).[v,15] Two sectors: industry; and Agriculture, Forestry, and Other Land Use (AFOLU) each contribute around a quarter of global GHG emissions.[16]

FIGURE 1: 45% OF GLOBAL GHG EMISSIONS CAN BE ATTRIBUTED TO THE PRODUCTION OF MATERIALS, PRODUCTS, AND FOOD, AS WELL AS THE MANAGEMENT OF LAND



Note: 'Industry' and 'AFOLU' include their own energy-related emissions but not indirect emissions from electricity and heat production.
Source: IPCC, "IPCC's Fifth Assessment Report (AR5)" and Material Economics analysis.

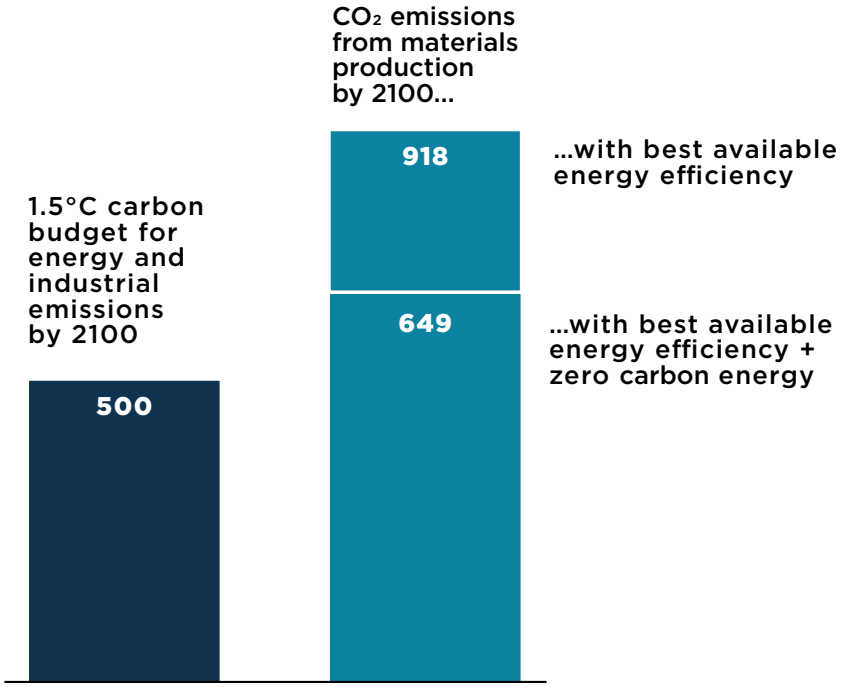
iii "Energy systems" refers to the production of electricity and heat as well as fuel extraction, refining, processing, and transportation.

iv This 45% figure includes fossil fuels burned at facilities for energy.

v The International Resource Panel (IRP) has calculated that resource extraction and processing make up about half of total GHG emissions. The difference between their findings and the split outlined in this paper are due to a difference in scope. The IRP report looks at resources such as materials, fuels, and food (not including climate impacts related to land use). The 45% referred in this paper includes the production of goods and the management of land, but does not include fuel extraction, refining, processing, and transportation. IRP and UNEP, Global resources outlook 2019: natural resources for the future we want (2019)

Failing to make such a transformation will make climate targets unachievable. By 2050, the global demand for industrial materials such as steel, cement, aluminium, and plastics is projected to increase by a factor of two to four, while global food demand is projected to increase by 42%.[vi] This increase in demand will have major implications for GHG emissions. Even with ambitious strategies to increase energy efficiency and move to zero-carbon energy sources, emissions from the production of steel, cement, aluminium, and plastics alone will reach, cumulatively, 649 billion tonnes CO_2 by 2100. This exceeds the remaining carbon budget for industry and energy emissions of 420–580 billion tonnes consistent with meeting the 1.5˚C target (see Figure 2, which shows the mid-point of this range). In parallel, the GHG emissions from food production are also projected to increase 35% by 2050, reducing the chances of meeting the climate target even further unless transformative interventions are made.[vii]

FIGURE 2: MATERIALS PRODUCTION WILL RESULT IN 649 BILLION TONNES OF CO_2 EMISSIONS BY 2100 EVEN UNDER A SCENARIO THAT INCLUDES RENEWABLE ENERGY AND ENERGY EFFICIENCY



Source: Tong, D. et al. *Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target*, Nature **572**, 373-377 (2019); Material Economics, *The Circular Economy – A Powerful Force for Climate Mitigation* (2018)

Addressing emissions in industry and the food system presents a particularly complex challenge. In industry, a growing demand for materials coupled with a slow adoption rate of renewable electricity and incremental process improvements, make it especially difficult to bring emissions down to net-zero by 2050.[17] In the food system, significantly reducing emissions will also be challenging and will require changing the consumption habits of billions of people, changing the production habits of hundreds of millions of producers, and decarbonising long and complex food supply chains. This makes industry and food system emissions the main roadblocks to reaching overall net-zero emissions.[18] Finding solutions that can cut these hard-to-reduce emissions will therefore be critical in meeting climate targets.

vi The increase in global food demand is derived from the FAO food basket development estimation (adjusted for base year), which assumes no dietary shifts.

vii This is based on the projected increase in food production (42%, 2013–50), and takes into account projected improvements to agricultural productivity. Ellen MacArthur Foundation, *Cities and circular economy for food: technical appendix* (2019)

2

The circular economy has a major role to play in meeting climate targets

The circular economy completes the picture of what is required to tackle the climate crisis. It offers an approach that is not only powered by renewable energy, but also transforms the way products are designed and used. This framework cuts GHG emissions across the economy through strategies that: reduce emissions across value chains; retain embodied energy in products; and sequester carbon in soil and products.

To meet climate targets, a fundamental shift will be needed in the way the economy functions and creates value. It will require moving away from today's 'take-make-waste' linear model towards an economy that is regenerative by design. In such an economy natural systems are regenerated, energy is from renewable sources, materials are safe and increasingly from renewable sources, and waste is avoided through the superior design of materials, products, and business models. A circular economy offers a positive way forward by redefining value creation to focus on society-wide benefits. It addresses the shortcomings of the current system, while creating new opportunities for businesses and society. Circular economy principles present unique opportunities to help tackle the climate crisis by reducing GHG emissions along supply chains; preserving the embodied energy of products and materials; and increasing carbon

sequestration through the regeneration of natural systems. Previous reports by the Ellen MacArthur Foundation have shown that in Europe, India, and China, a circular economy could reduce GHG emissions by 22–44% in 2050 compared to the current development path, when implemented in sectors such as the built environment, mobility, food, electronics, and textiles.[viii]

In addition to reducing GHG emissions, a circular economy offers a wide array of system benefits. It presents a multi-trillion-dollar economic opportunity that provides better access to goods, increased mobility and connectivity, and lower air pollution. In so doing, it responds to other big challenges of our time including biodiversity loss, resource scarcity, waste, and pollution. It therefore acts as a delivery mechanism for several UN Sustainable Development Goals (SDGs). In fact, by contributing to responsible consumption and production (SDG12) and developing resource-smart food systems, a circular economy contributes to at least 12 of the 17 SDG goals outlined in the UN's 2030 Agenda for Sustainable Development.[19]

2.1 WHAT IS THE CIRCULAR ECONOMY?

The circular economy is a systems-level approach to economic development designed to benefit businesses, society, and the environment. A circular economy aims to decouple economic growth from the consumption of finite resources and build economic, natural, and social capital. Underpinned by a transition towards renewable energy sources and increasing use of renewable materials, the concept recognises the importance of the economy working effectively at all scales. This means it features active participation and collaboration between businesses both small and large, and from countries and cities to local communities and the people within them. Such a distributed, diverse, and inclusive economy will be better placed to create and share the benefits of a circular economy.

It is built on three principles:

Design out waste and pollution

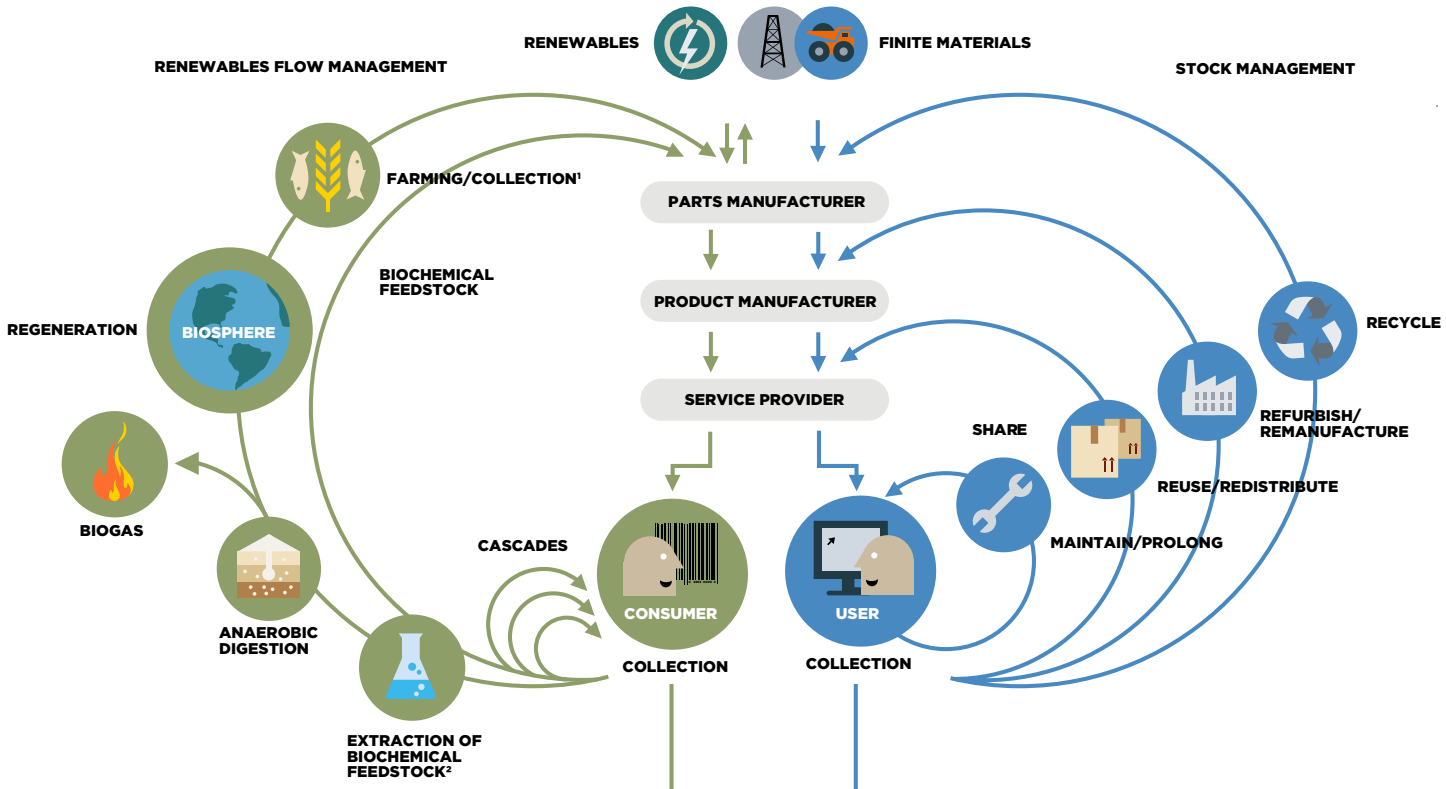
Keep products and materials in use

Regenerate natural systems

The model distinguishes between technical and biological cycles (See Figure 3). In biological cycles, food and biologically based materials (e.g. cotton or wood) feed back into the system through processes such as composting and anaerobic digestion. These cycles regenerate living systems (e.g. soil), which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through strategies including reuse, repair, remanufacture, or (in the last resort) recycling. Digital technology has the power to support the transition to a circular economy by radically increasing virtualisation, dematerialisation, transparency, and feedback-driven intelligence.

viii The findings were modelled by the Ellen MacArthur Foundation for Europe, India, and China. These reports have not only looked at circular economy opportunities that decrease material demand, but have also considered those that directly decrease energy demand and stimulate the use of renewables. Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, Growth within: a circular economy vision for a competitive Europe (2015); Ellen MacArthur Foundation, Circular economy in India: rethinking growth for long-term prosperity (2016); Ellen MacArthur Foundation and Arup, The circular economy opportunity for urban and industrial innovation in China (2018)

FIGURE 3: CIRCULAR ECONOMY SYSTEM DIAGRAM



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

2.2 HOW DOES THE CIRCULAR ECONOMY REDUCE GREENHOUSE GAS EMISSIONS?

Applying circular economy principles to transform the way goods and materials are produced and used in the economy would offer significant potential to reduce GHG emissions. These can be summarised as follows:

Design out waste and pollution **to reduce GHG emissions** across the value chain

Keep products and materials in use **to retain the embodied energy** in products and materials

Regenerate natural systems **to sequester carbon** in soil and products

Within the three circular economy principles are a set of key strategies to unlock the emission reduction potential. The following section presents these strategies in more detail, explaining what makes them circular and how they contribute to reducing GHG emissions.

1/ DESIGN OUT WASTE AND POLLUTION

The circular economy is a framework for preventing negative impacts of economic activity that lead to the waste of valuable resources and cause damage to human health and natural systems. GHG emissions are one of these negative effects designed out of the system. Others include the pollution of air, land, and water, and the underutilisation of assets such as buildings and cars. Within this principle there are three key strategies that serve to reduce GHG emissions.

DESIGNING FOR CIRCULARITY

Design plays a key enabling role for any circular economy ambition. It is essential in removing negative impacts, as well as ensuring that products and materials are made from the outset to be kept in use and/or regenerate natural systems. When it comes to food, designing meals and products that use surplus food or by-products, for example, can help ensure these do not go to waste and also conserve the embodied energy within the selected ingredients. However, many goods contain materials or ingredients which make them, or their by-products, unsafe to reuse as inputs for new cycles. Design should therefore also consider designing out substances of concern from products. For most plastic packaging, for example, its very design means it is destined for landfill, incineration, or to escape into the environment after a short single-use. When recycling, mixing and downgrading effects are particularly serious problems for plastics, making a large share of used plastics literally worthless. Without fundamental redesign and innovation, about 30% of plastic packaging will never be reused or recycled.[20] If 'refill' bottle designs and models were to be applied to all bottles in beauty and personal care as well as home cleaning, packaging and transport savings would represent an 80–85% reduction in GHG emissions compared to today's traditional single-use bottles.[21] To allow for the increased utilisation and circulation of products, components and materials/nutrients, circular economy principles should be integrated at the design stage of goods to enable high-value recovery and to develop new circular economy business models. This approach will require products to be designed for disassembly, modularity, repairability, flexibility or biodegradability, and to enable reuse, remanufacturing, refurbishment or regeneration.

ELIMINATING WASTE

Design can play an important role in eliminating waste. By designing for material efficiency, material input can be reduced, while designing for optimised supply chains can reduce waste generation; both offer effective ways of lowering the amount of energy and materials used per dollar of GDP. For products and assets, one approach is minimising the waste resulting from overspecification.[ix] Currently, in construction projects, around 35–45% more steel is used than is strictly necessary.[22] There are also opportunities to reduce waste by tailoring products better to specific uses. For example, the average European car is parked 92% of the time and when the car is used, only 1.5 of its 5 seats are occupied.[23] To improve utilisation, business models and assets should be designed to be fit for purpose. For example, many of the cars in shared car fleets may not need a four-passenger capacity. Smaller cars, for one- to two-passenger trips in the city, may be sufficient to deliver their service. Apart from products, waste can also be designed out of systems. When it comes to supply chains, waste generation can be minimised by reducing the amount of material lost during production. For example, half the aluminium produced each year does not reach the final product but becomes scrap, while some 15% of building materials are wasted in construction. When it comes to food waste today, one out of every four food calories intended for people is not ultimately consumed by theme. In other words, 24% of food calories produced for human consumption are lost or wasted across the value chain.[24] Measures

ix One main reason for overspecification has been attributed to rationalisation, i.e. providing extra material to reduce labour costs. Cost concerns and focussing on making processes more efficient has, for example, led to specific designs being reused in different areas where the same amount of material may have not been necessary. Moynihan, M. J., and Allwood, M., Utilization of structural steel in buildings in 'Proceedings: mathematical, physical, and engineering sciences (2015)

and emerging technologies such as process optimisation, 3D printing, and can be applied to reduce waste generation during production. Cutting this waste would also effect a reduction in GHG emissions.

SUBSTITUTING MATERIALS

Material substitution refers to the use of renewable, low carbon, or secondary materials as alternative inputs to new production. These provide the same function but contribute to lower emissions. The use of renewable materials can be particularly interesting for replacing inputs that are hard to make emissions-free. It can offer opportunities to bind carbon in products and act as carbon sinks. For example, some bio-based plastics have been shown to have a negative emissions potential with -2.2 kg CO_2e per kg of bio-based polyethylene (PE) produced, compared to 1.8 kg CO_2e per kg of fossil-based PE produced.[25] When using renewable materials, such as wood, it is critical to ensure that they are sourced from sustainably managed plantations, as illegal logging permanently destroys vast natural carbon sinks and their associated biodiversity, which cannot be easily restored.[26] Furthermore, using non-sustainably harvested wood products is more environmentally detrimental than the benefits of using low-carbon materials in buildings.[27] A good example of a fast-growing renewable material is bamboo. Both living biomass and long-lived bamboo products have the potential to sequester 2.6 tonnes of carbon per acre annually, while offering the compressive strength of concrete and the tensile strength of steel.[28] New timber technologies are another example. These offer the potential for saving 62% of mineral construction materials used in buildings, while also offering the potential for carbon sequestration.[29]

Apart from renewables, other low-carbon material substitution options can be considered such as using secondary materials (e.g. recyclates), high-performance materials that reduce virgin material input requirements, or materials with properties that enable reuse (e.g. recyclability, durability). For example, although cement makes up just 7–20% of concrete, from an emissions perspective it is the key constituent, with 95% or more of the CO_2 footprint.[30] It is in principle possible to substitute up to around 50% of the clinker (binder) needed to make cement with advanced filler materials that emit less CO_2 and provide the same performance.[31] When it comes to food, selecting and using ingredients which emit less carbon in their production (e.g. plants over animal ingredients), or better still sequester carbon (e.g. perennial versus annual crops), can mean a wider choice of low-, zero-, or carbon-positive products and meals.

2/ KEEP PRODUCTS AND MATERIALS IN USE

The circular economy favours activities that preserve value in the form of energy, labour, and materials. This means designing for durability, reuse, remanufacturing, and recycling to keep products, components, and materials circulating in the economy. Circular systems make effective use of biologically based materials by encouraging many different economic uses before nutrients are returned safely to natural systems. This framework offers two key strategies whose main outcome are the preservation of the embodied energy in products and materials:

REUSING PRODUCTS AND COMPONENTS

Reuse measures have one purpose and that is to conserve the embodied energy and other valuable resources used to manufacture products, components, and materials. The more a product is utilised, the larger the savings should be in terms of resources that are already embodied into the product such as material, labour, energy, and capital. Moreover, by keeping products and materials in use, GHG emissions associated with new material production and end-of-life treatment are avoided. As such, reuse-based business models not only require less material input but also emit less GHGs to achieve the same benefit for society. As an example, a Splosh shampoo container that can be reused more than 20 times lowers material usage by more than 95%, and as a direct consequence significantly reduces the energy required for packaging production.[32] For garments, doubling the amount of time items are worn has the potential of avoiding 44% of GHG emissions, by not letting valuable garments go to waste.[33] In the case of Renault's Choisy-

le-Roi facility for the remanufacturing of spare parts, energy savings - totalling as much as 80%,- are the result of avoided production and end-of-life treatment (e.g. incineration).[34]

RECIRCULATING MATERIALS

Recirculation refers to the recycling of materials in the technical and biological cycle. GHG emissions are reduced from avoiding new virgin material production and end-of-life treatment, such as incineration and landfill. Moreover, while measures that increase product utilisation and extend a product's lifetime contribute the most in retaining the embodied energy within products, recycling activities which release energy, still require much less energy input than the production of virgin materials. Steel recycling for example uses 10–15% of the energy required in the production of primary steel.[35] For plastics, recycling 1 tonne could reduce emissions by 1.1–3.0 tonnes of CO_2e compared to producing the same tonne of plastics from virgin fossil feedstock.[36] Recycling therefore cuts not just emissions from energy use, but also those from production processes – which are among the trickiest emissions to address. Furthermore, it is easier to use electricity and other low-carbon energy sources to facilitate recycling, compared to new materials production, and therefore it aligns to the target of a net-zero economy. In the food system, recirculating materials means valorising discarded organic resources such as food by-products and unavoidable food waste, reimagining them as feedstock for the circular bioeconomy. The effectiveness of the collection system and the purity of waste streams are a strong determinant of the type of new products that can be produced. Purer waste streams can be transformed into new structural materials, textiles, or even new food products. More mixed waste streams can be composted or undergo anaerobic digestion to produce energy and soil fertility products. These value-adding transformation processes avoid direct GHG emissions from landfilling as well as the energy use associated producing renewable material. When the valorised products are composted or returned to soil in another form, this also contributes to the regeneration of natural systems.

3/ REGENERATE NATURAL SYSTEMS

The circular economy favours the use of renewable resources and aims to enhance natural systems by returning valuable nutrients to the soil. This regenerative approach offers opportunities for carbon sequestration.

REGENERATIVE AGRICULTURE

Regenerative agriculture refers to crop and livestock production approaches that enhance the health of the surrounding natural ecosystem. Regenerative farming methods can not only reduce GHG emissions but also sequester carbon in soils and plant matter. Key mechanisms for unlocking the potential of regenerative agriculture are minimising soil disturbance and increasing soil carbon content. Regenerative agriculture leads to a cascade of systemic benefits such as improving soil structure to enable better water storage and promoting more biologically active soils that generate their own soil fertility without the need for synthetic inputs. Examples of regenerative practices include using organic fertilisers, planting cover crops, employing crop rotation, reducing tillage, and cultivating more crop varieties to promote agro-biodiversity. Farming types such as agroecology, rotational grazing, agroforestry, silvopasture, and permaculture all fall under this definition.

Combined, these circular economy strategies represent a set of opportunities that can be applied to the wider economy to help tackle climate change. To illustrate how such strategies can significantly reduce emissions, the following sections demonstrate the opportunity for two key sectors with hard-to-abate emissions: industry and the food system.

3

The circular economy opportunity for industry

The circular economy can reduce global CO_2 emissions from cement, steel, plastic, and aluminium by 40% or 3.7 billion tonnes in 2050, thereby achieving almost half of their zero emissions target. This opportunity comes from making better use of products and materials within key sectors such as built environment and mobility. These solutions are cost-effective and offer system-wide benefits.

Industry is responsible for around 21% of overall global CO_2 emissions.[37] The production of four materials - cement, steel, plastics, and aluminium account for 60% of these emissions. The use of these materials in passenger cars and buildings can be said to account for 73% of the emissions from producing these four materials. The main sources of CO_2 involved in producing these materials include high-temperature processes, production emissions, and end-of-life emissions.[38] These have long been considered hard to abate. High-temperature requirements for core processes of melting and forming steel, steam cracking, and clinker production cannot yet be tackled sustainably. Although electricity is already used for some processes, such as in steel recycling, in most cases neither the technologies nor the economics are currently in place to do so. Process emissions are also challenging to tackle since carbon is not only used for energy but is also inextricably linked into current production processes, either as a building block of the material (plastics) or in the process chemistry of their production (cement, steel, aluminium). Lastly, the vast majority of materials today, with the exception of metals, are incinerated at end-of-life, releasing the large amounts of carbon that are built into the material.

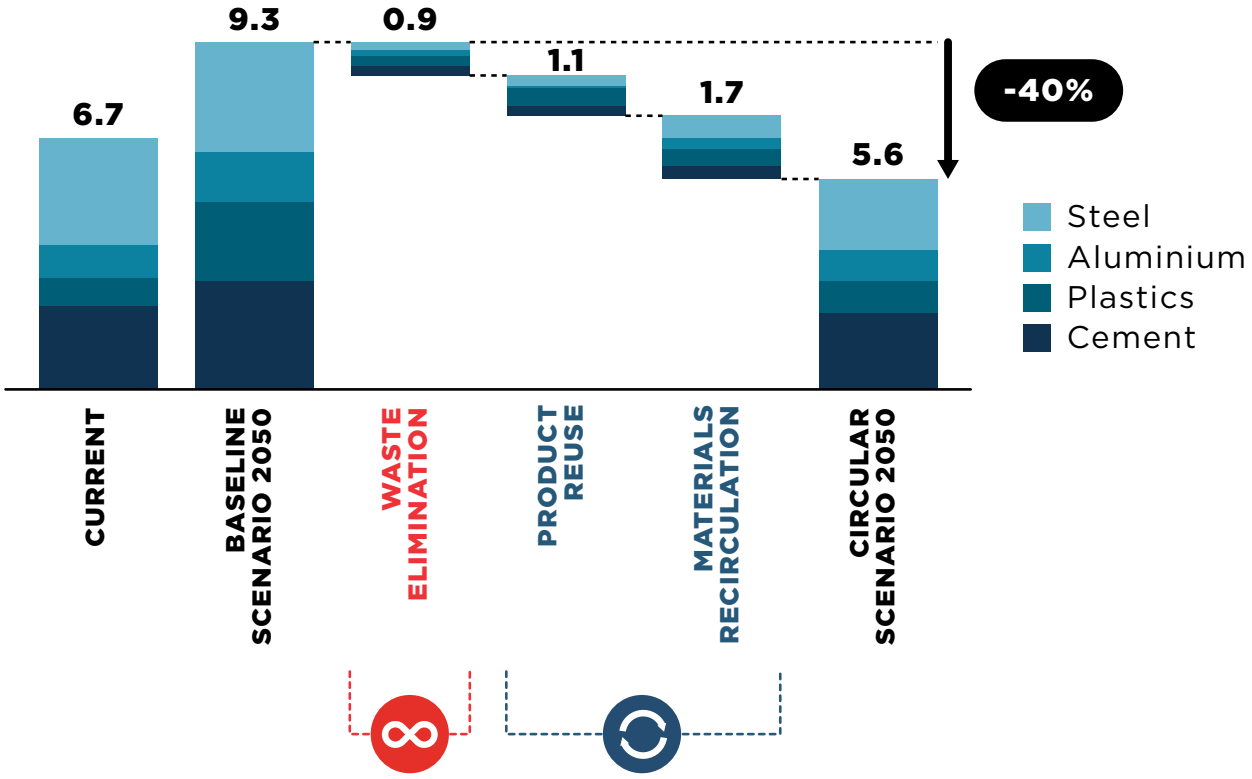
The circular economy offers an opportunity to tackle hard-to-abate emissions and accelerate the transition towards a net-zero carbon economy. Circular approaches shift emissions away from hard-to-abate, costly industrial processes towards activities that are much easier to decarbonise. Notably, recirculation bypasses the emissions of new production as well as end-of-life incineration, eliminating some of the hardest-to-abate emissions. Products designed with alternative feedstock materials, that are either low-carbon or renewable, ensure that emissions are avoided from the outset. Furthermore, unlike today's primary materials production, many of the processes crucial to a circular economy, such as remanufacturing and refurbishing, can be powered by renewable electricity.

3.1. CIRCULAR ECONOMY STRATEGIES FOR REDUCING EMISSIONS IN INDUSTRY

A circular economy approach could reduce global CO_2 emissions from key industry materials by 40% or 3.7 billion tonnes in 2050. Key in achieving this opportunity are business models that keep assets, products, and components in use while making productive and efficient use of resources. Both of these are underpinned by two core circular economy principles:

FIGURE 4: A CIRCULAR ECONOMY COULD REDUCE ANNUAL GLOBAL CO_2 EMISSIONS FROM KEY INDUSTRY MATERIALS BY 40% OR 3.7 BILLION TONNES IN 2050

Global CO_2 emissions from four key materials production
Billion tonnes of CO_2 per year



Source: Adapted from Material Economics analysis for the Energy Transition Commission, "Mission Possible - Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century" (2018).

DESIGN OUT WASTE

- **Eliminating waste (0.9 billion tonnes CO_2 per year):** Eliminating waste generation across value chains and in the design of products offers opportunities for avoiding GHG emissions. The modelled scenario looks into measures such as material-efficient designs for buildings, industrialised construction processes, and lightweighting designs for vehicles. Together, these circular economy strategies reduce the amount of material input in products and assets, and reduce waste generation during construction. This offers the opportunity to reduce global CO_2 emissions by 0.9 billion tonnes CO_2 in 2050. For a deep dive on how these circular economy opportunities for reducing GHG emissions manifest themselves in the built environment and mobility (passenger cars), see deep dives at the end of this chapter.

KEEP PRODUCTS AND MATERIALS IN USE

- **Reusing products and components (1.1 billion tonnes CO_2 per year):** Service-based business models such as renting, sharing, and pay-per-use can increase the utilisation (i.e. intensity of use) of products and assets, as well as extend the lifetime of products through activities such as reuse, refurbishment, and remanufacturing. By keeping products and components in use within the economy at their highest value and utility at all times their embodied energy is preserved for longer, and the need for new production and end-of-life treatment is reduced. This significantly reduces GHG emissions that would otherwise have resulted from the production of new products. Modelling this opportunity showed that global emissions could be reduced by 1.1 billion tonnes CO_2 in 2050 due to a decrease in the amount of cement, steel, plastics, and aluminium needed. For a deep dive on how these circular economy opportunities for reducing GHG emissions manifest themselves in the built environment and mobility (passenger cars), see deep dives at the end of this chapter.

- **Recirculating material (1.7 billion tonnes CO_2 per year):**[x] The circular economy scenario also explores the opportunities of new business models that stimulate collection, sorting, and recycling activities. The scenario envisages an increase in recycling rates and input/output quality. It also forecasts an increase in demand for recycled materials contributing to an accelerated uptake of recycled materials and an increase in economies of scale. Through recycling activities, emissions from production and end-of-life incineration would be avoided by bypassing the need for new material production and using less energy-intensive facilities compared to the production of virgin materials. In this case, some of the hardest-to-abate emissions would be avoided. Achieving the modelled opportunity would require different measures for steel, cement, plastics, and aluminium. For steel, recycling is already well established, with a largely electrified process. However, current product design, end-of-life dismantling, and scrap-handling processes are polluting and degrading the quality of steel. Increasing recycling rates would therefore require measures that prevent the downgrading of the steel stock. For plastics, increasing recycling rates can be enabled by improving uptake and quality. Key measures include improving recyclability, collection, and sorting processes, as well as reducing contamination of recycling streams and exploring the potential of chemical recycling in upcycling to virgin-quality. For cement, the reuse of concrete 'fines' (particles with a small diameter) as a substitute for new cement can reduce process emissions. It is also possible to recover some unreacted cement from existing concrete and to use this in place of new cement. Other alternatives include the use of fly ash, blast furnace slag, and calcined clays.[39] For aluminium, less leakage and mixing of different alloys will be crucial. The models for embracing circular economy opportunities of this kind showed that global CO_2 emissions could be reduced by 1.7 billion tonnes CO_2 in 2050. Of total production, this would require secondary production to increase to 48% for steel, 48% for aluminium, and 18% for cement,[xi] as well as a mechanical and chemical recycling rate of 28% and 21% for end-of-life plastics.

x The 1.7 billion tonnes CO_2/yr also includes the impact of substituting a share of plastics with alternative low CO_2 materials, e.g. replacing plastics with bio-based materials in packaging.

xi Cement is not as easy to recycle, although it is possible to reuse some unreacted cement.

3.2 ADDITIONAL INTERVENTIONS WILL BE NEEDED TO FURTHER REDUCE INDUSTRY EMISSIONS

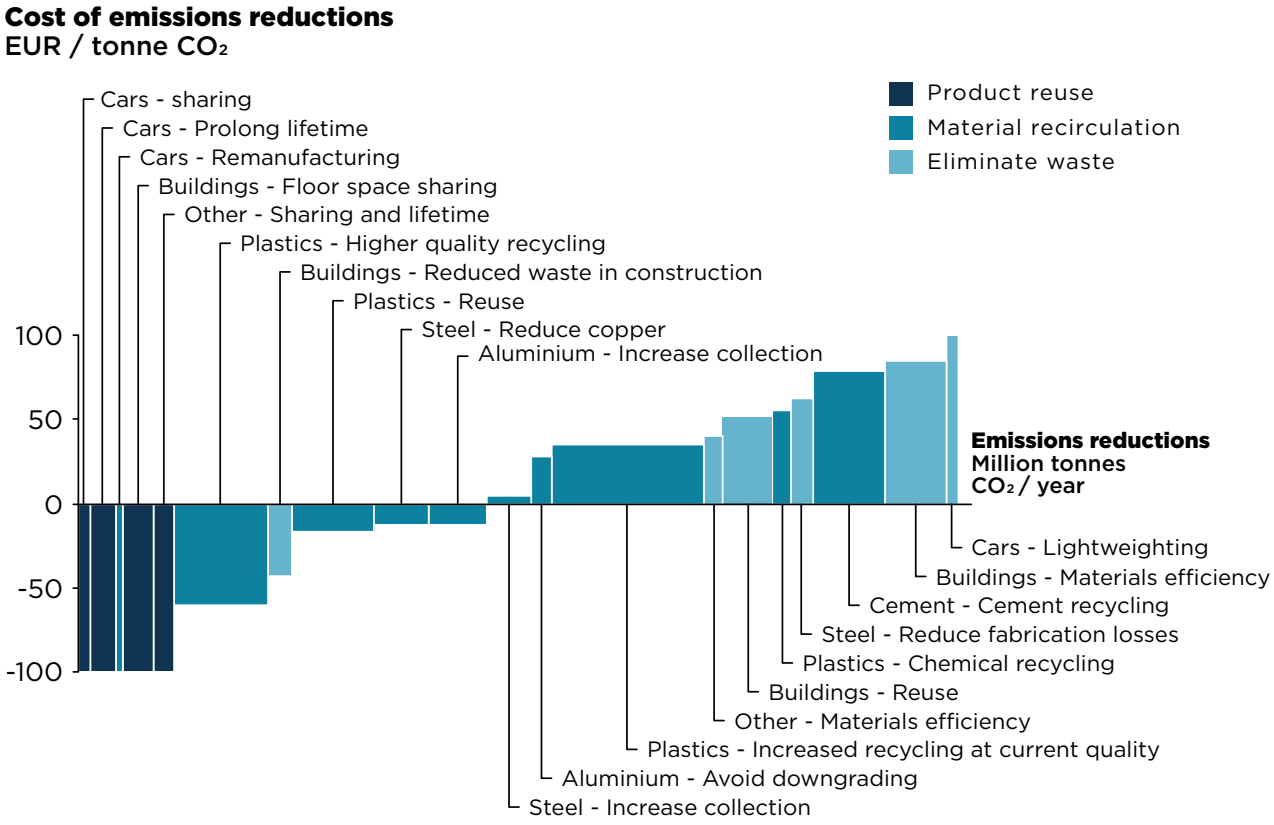
While a transition towards a circular economy for key industry materials could reduce global emissions by 40% in 2050, additional measures will be needed to close the remaining emissions gap. These include measures such as innovative industrial processes and carbon capture and storage/use (CCS/U).[40] For example, new low-emissions industrial processes will contribute to emissions reduction by fundamentally changing the underlying production processes and feedstocks. The objective is to eliminate fossil fuels from the outset and to replace them with renewable sources, e.g. decarbonised electricity, hydrogen, and biomass. For the rest of the emissions gap, that cannot be closed through material productivity improvements and renewable energy technologies, non-circular economy measures such as carbon capture and permanent storage can play a role in capturing the remaining CO_2 that is emitted from production, feedstock production, or end-of-life emissions. These approaches have the opportunity to capture up to 90% of the CO_2 emissions from burning fossil fuels. Opportunities have also been investigated whereby capture carbon is reintroduced as feedstock in the production of, for example, chemicals for the making of new materials. In a net-zero economy, CCS/U would need to provide equivalent certainty that the carbon will not be released as CO_2 emissions. However, key challenges face CCS/U including social acceptance, high costs, the need for large field demonstrations, access to suitable and extensive transport and storage infrastructure, and the scaling-up of the technology to a level large enough to address climate challenges.

For a fully net-zero economy, circular economy opportunities will need to be complemented by a transition to clean production processes. However, there is a need for substantial innovation and investment before zero-carbon steel, aluminium, plastics, and other materials can be made available. By reducing the amount of new materials required, a more circular economy makes a substantial move to address this challenge. In these respects, a circular economy plays a similar role for industry as energy efficiency does for the energy transition. By cutting emissions on the demand-side, the challenge of the transition on the supply-side is much smaller. This can help accelerate the transition, while requiring lower level of investment.

3.3 THE CIRCULAR ECONOMY APPROACH IS COST EFFECTIVE

A circular economy offers cost-effective ways of achieving the deep emission cuts modelled below. These cost benefits are made possible by ensuring that products and materials are not wasted, and loss of value is minimised across the value chain. For example, in today's system 95% of the material value in plastic packaging or USD 80–120 billion annually is lost to the global economy after a short first use.[41] A circular system, capable of reusing a greater share of this material, would prevent this economic loss and this can be beneficial to both the producer and the user. Furthermore, like energy efficiency, circular economy solutions often can be highly cost-effective compared to cutting GHG emissions through emerging technologies that are still expensive and as yet untested. See Figure 5 for a CO_2 abatement cost curve illustrating the potential of a number of circular economy opportunities. Circular economy measures, such as sharing business models, durable designs and high-quality recycling, can even have the potential to come at no net cost. In some cases. For measures such as recycling, emissions can cut abatement costs fall often below USD 50 / t CO_2. By comparison, many measures required for zero-carbon materials production cost more than USD 100 / t CO_2 to implement.

FIGURE 5: EMISSIONS REDUCTION POTENTIAL FROM CIRULAR ECONOMY BUSINESS MODELS[xii]



Source: Material Economics, "The Circular Economy – A Powerful Force for Climate Mitigation" (2018)

Some of the most economically attractive options are to be found in circular economy strategies that focus on increasing the utilisation and lifetime of products. One reason for low costs is the sheer productivity improvements of some circular economy systems. This is because they involve making large systemic improvements to boost productivity in value chains. For example, a shared and circular mobility system could reduce the cost of travel by as much as 70%.[42] Shared vehicles that are designed to be optimised for intensive use and to have longer lifetimes may need higher upfront investments, but would spread the cost of cars over a much greater number of kilometres – with much lower costs in the long term as a result. Material use is reduced as a consequence of an overall much more productive use of resources.

When it comes to material efficiency measures, using less materials could mean requiring alternative feedstock, which may demand higher investment costs. Higher investment costs may for example arise from increased labour inputs, increased inventory, and logistics costs, etc. As for example, optimising concrete elements or steel beams to reduce total materials use, often comes at the cost of increased complexity and coordination, and a need for increased prefabrication. In general, however, the cost of this opportunity is lower than that of many low-carbon production opportunities.[43] When it comes to eliminating waste generation from production and construction, technological advances can drastically lower the cost of reducing waste. A prominent example is 'additive' manufacturing methods such as 3D printing, which can almost eliminate production scrap.

xii This cost curve is indicative, with many uncertainties, and must be followed up with deeper analysis to improve the estimates.

For material recirculation, the economic attractiveness of recycling will depend largely on the scaling potential and the capacity to retain the original material value. It will be necessary to reduce the cost of collection, develop new markets, create economies of scale, and preserve the value of secondary materials produced. Under such circumstances, the recycling of plastics could for example become profitable and take off on a larger scale.

3.4 THE APPROACH OFFERS SYSTEM-WIDE BENEFITS

Additional benefits to society are also gained from implementing a circular economy. Beyond significantly reducing GHG emissions, circular economy strategies also present economic opportunities and a wide array of benefits to society and the environment. For people, a circular economy could lower the cost of accessing goods and services. Cost reductions are brought about through, for example, offering new business models favouring access over ownership, replacing primary with high-quality secondary materials inputs, and leveraging digital technology to address structural waste in supply chains. The operational costs per vehicle-km are reduced by the improved utilisation of vehicles, through convenient public transport options and sharing platforms, and by introducing more electric and material efficient vehicles into the fleet. Apart from cost savings, the benefits of these opportunities are wide ranging. For example, shared multi-modal systems can reduce travel time and congestion. A sharing economy enabled by digitisation could offer residents increased connectivity and improved access to food, goods, and services. In sum, a circular economy offers the opportunity for economic activity to be gradually decoupled from resource consumption, while delivering greater prosperity and a better quality of life within planetary boundaries.

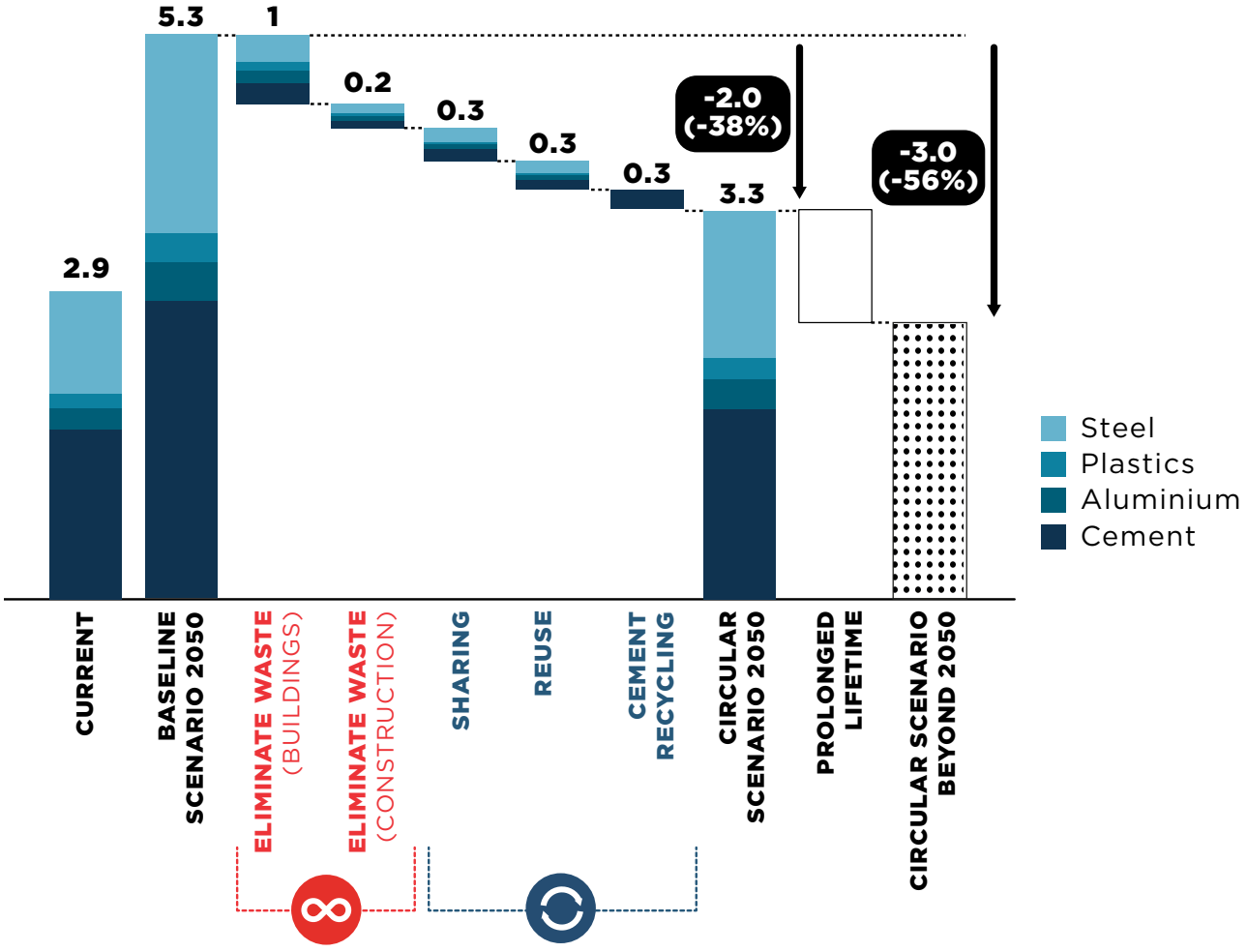
These system-wide benefits make the circular economy an important delivery mechanism for the global goals. The 17 SDGs are wide ranging, they are also interdependent. Several bodies have noted that a circular economy is key to achieving SDG12 (responsible consumption and production), and that success in this area will have benefits for the wider SDGs and can help to mitigate many trade-offs.[44] This makes a compelling case for the circular economy not just as one option to consider in the quest to meet climate targets, but as an invaluable part of the transformation we need for a prosperous and sustainable future.

In the section that follows, two deep-dives on built environment and mobility illustrate in more detail how the modelled circular economy opportunities to reduce emissions manifest themselves.

Deep dive: the opportunity for the built environment

FIGURE 6: A CIRCULAR SCENARIO FOR THE BUILT ENVIRONMENT COULD REDUCE CO_2 EMISSIONS BY 38% IN 2050 (OR 56% BEYOND 2050)

Emissions from four key materials used in buildings
Billion tonnes of CO_2 per year, globally



Source: Adapted from Material Economics, "The Circular Economy – A Powerful Force for Climate Mitigation" (2018).

The built environment uses almost half of the world's materials extracted every year and current projections estimate that by 2060 across the world the equivalent of the city of Paris will be built each week.[45] If current urbanisation trends continue, it has been estimated that material consumption by the world's cities will grow from 40 billion tonnes in 2010 to about 90 billion tonnes by 2050 – exceeding what the planet can sustainably provide.[46] Moreover, de-densification trend of 2% per year threatens to increase global urban land use in 2050, putting agricultural land and food supplies at risk.[47] With such trends, by 2050, CO_2 emissions from construction will be responsible for almost half of total new building emissions, compared to 28% today.[48] Therefore, in addition to a transition to renewable energy and energy efficiency, how we design, construct, and use buildings will matter greatly if we are to meet future climate targets.

A circular scenario for the built environment could reduce global CO_2 emissions from building materials by 38% or 2.0 billion tonnes CO_2 in 2050, due to a reduced demand for steel, aluminium, cement, and plastic. The modelled scenario depicts a built environment that offers residents improved access to goods, services, and housing, as well as improved outdoor air quality in which to live and work. The system would integrate durable, mixed-use buildings designed in a modular way and constructed with reused and non-toxic materials. They would be highly utilised, thanks to shared and flexible office spaces and flexible, smart, and modular homes.

How the circular economy opportunities modelled in Figure 6 contribute to a significant reduction in GHG emissions is described below:[xiii]

DESIGN OUT WASTE

- **Eliminating waste from building designs (1.0 billion tonnes CO_2 per year)**: Construction projects often use more materials than is actually needed. For example, it is often possible to achieve the same structural strength using only 50–60% of the amount of cement that is currently being used.[49] This could be achieved by both reducing the cement content of concrete and by using less concrete in structures. Designing buildings with less material can be stimulated through less over-specification, improved design, and using high-strength materials. For example, high-strength steel along with techniques such as post-tensioning could reduce material needs by 30%.[50]

- **Eliminating waste in construction (0.2 billion tonnes CO_2 per year)**: Up to 40% of urban solid waste is construction and demolition waste (CDW) and 54% of CDW in Europe is landfilled.[51] Industrialising construction processes such as prefabricated building elements, off-site construction, and 3D printing have the potential for reducing material demand and waste generation, while offering up to 60% in material cost savings.[52] For example, moving modular construction activities offsite into a controlled environment allows manufacturers to achieve high quality standards, high productivity and better overall waste minimisation. This could reduce on-site waste generation by up to 90%, compared to traditional construction.[53]

KEEP PRODUCTS AND MATERIALS IN USE

- **Sharing business models (0.3 billion tonnes CO_2 per year)**: Buildings are often underutilised. In Europe, for example, 60% of office space is unused even during working hours, while in the UK 49% of homes are 'under-occupied' with at least two bedrooms in excess.[54] In the circular economy, service-based business models, such as sharing, increase the utilisation of underused buildings, spaces, and construction components. For example, in London peer-to-peer renting, better urban planning, office sharing, repurposed buildings, and multi-purposed buildings increase the value of new buildings and can double the utilisation of 20% of the city's buildings by 2036, saving over GBP 600 million annually.[55]

- **Prolonging lifetime (1.0 billion tonnes CO_2 per year, beyond 2050)**: A building built in a traditional way has an expected technical lifespan of 50–100 years, but usually after 20–30 years it is no economically valuable.[56] Demolition is often then the go-to solution. In the circular economy, the economic value of a building is maintained by extending its 'functional' lifespan. Longevity in buildings can be stimulated through modular, flexible, and durable designs. Such design approaches also ensure a building is capable of being adapted to changing user needs

xiii The list provides a selection of circular economy solutions that decrease material demand. Those solutions that directly reduce energy demand, such as improving energy efficiency building, have not been presented due to the scope of the paper.

as well as offering easier maintenance and renovations. Modular design typically reuses 80% of the components in a building's exterior so that it can stand for 100 years or more, coupling modularity with durability.[57]

- **Reusing building materials (0.3 billion tonnes CO_2 per year)**: Only 20–30% of CDW is recycled or reused. This is often due to poor design and lack of information about a building's material composition.[58] Designing materials for reuse ensures that they can be reintroduced at their highest value, eliminating the need for new primary material. For example, in Amsterdam, improving the reuse of materials in the construction of 70,000 new apartments before 2040 could lead to a saving of 500,000 tonnes of materials.[59]

- **Recycling materials (0.3 billion tonnes CO_2 per year from cement recycling)**: To scale materials recycling will involve designing materials for disassembly and high-value recycling to ensure that they can be used as inputs for new production when they reach their end-of-life. For the built environment, recycling can be applied to materials that come from end-of-life buildings. The use of recycled materials reduces the demand for virgin materials, while the processing of recycled aggregates can generate 40–70% fewer CO_2 emissions compared to virgin aggregates.[60] Designing recyclable materials, upscaling recycling volumes, and improving the quality of secondary materials would be essential for such a scenario. While this is already well-established for steel, improvements are needed for the recycling of cement and plastics. For plastics in particular, the design of recyclable materials within a system where products can be effectively collected, sorted, and recycled at high value will be key in achieving the stated ambitions.

OPPORTUNITIES AND BENEFITS FOR CITIES: URBAN PLANNING

Cities play an important role in influencing the way in which building structures are designed and used. They are uniquely placed to stimulate the above-mentioned circular economy opportunities due to the high concentration of people, resources, capital, data, and talent that reside in them over a small geographical territory. Apart from the scenarios that have been modelled in this paper, cities offer additional circular opportunities in the built environment for reducing GHG emissions. For example, applying circular economy principles to urban development can make the physical design of the city and its infrastructure more conducive to the effective reuse, collection, and redistribution of resources such as water, organics, industrial by-products, building elements, and household recyclables.[61] This can be enabled by designing compact cities with mixed-use developments,[xiv] which can reduce urban sprawl. In Europe for example, reducing urban sprawl could make more productive use of assets, saving up to 30,000 km^2 of land by 2050, compared to the current development scenario.[62] Since carbon emissions are closely connected to urban density and structure, compact cities can significantly contribute to reductions in GHG emissions by minimising the new construction of roads, sewers, water lines, and other infrastructure. Compact cities can reduce GHG emissions by a factor of two or more.[63] Cities like Barcelona and Atlanta, which have similar income levels and populations, exemplify how different urban densities lead to different levels of emissions. Barcelona's higher urban density means its transport area is 26 times smaller and its CO_2 emissions 10 times lower than Atlanta's.[64] City densification may offer additional societal benefits. It has been estimated that city densification can increase the productivity of the urban system by as much as a factor of four to ten. This in turn could help urbanisation take place in a way that creates wealth and eliminates poverty, while reducing the pressure exerted on the planet.[65] Moreover, circular economy measures that revegetate the built environment reduce pollution levels and make cities both healthier and more liveable. Lastly, opportunities stimulating the better utilisation of urban space, assets, and materials (such as those modelled above) would also offer societal benefits. Such circular strategies for cities have the potential to reduce the societal costs of harmful emissions from particulate matter (PM2.5 and PM10) by 61%[66] and reduce household costs by around 15–50% in 2050,[67] when compared to the current development path.[xv] For the city, cutting "consumption-based GHG emissions" through such circular economy that use existing buildings more efficiently and avoid new construction have the potential to save USD 11 billion (in a city like London).[68]

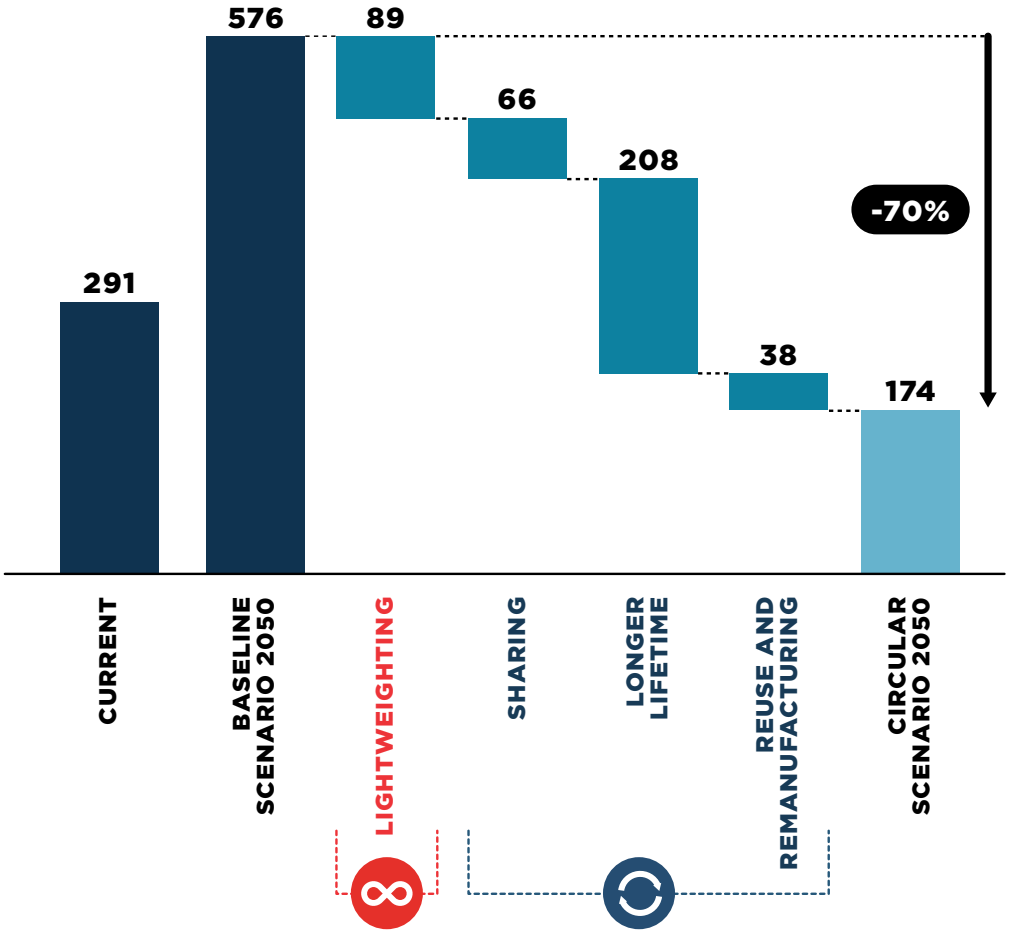
xiv Mixed-use developments refer to the co-location of commercial, residential, and recreational space.

xv The findings were modelled by the Ellen MacArthur Foundation for Europe, India, and China. The reports have not only looked at circular economy opportunities that decrease material demand, but have also considered those that directly decrease energy demand in the use phase, e.g. improving energy efficiency in buildings.

Deep dive: the opportunity for mobility

FIGURE 7: A CIRCULAR SCENARIO FOR PASSENGER CARS COULD REDUCE CO_2 EMISSIONS BY 70% IN 2050

Emissions from all materials used in passenger cars
Million tonnes of CO_2 per year, globally



Source: Material Economics, "The Circular Economy – A Powerful Force for Climate Mitigation" (2018). International Energy Agency, "Energy Technology Perspectives - Transport" (2017).

Road travel alone now contributes to 75% of global emissions from the transport sector, when taking energy consumption into account, and by 2050, the global number of cars is set to increase by more than two-fold.[69] These are currently dominated by emissions from the use phase. However, over time, the increased penetration of hybrid, plug-in hybrid, and electric vehicles will reduce emissions from the use of vehicles, though emissions from the manufacture of cars could increase.[70] The latter will become the dominant source of life cycle emissions for new cars in only 5-10 years.[71] With electrical vehicles in sight, how we design, produce, and use vehicles will matter greatly if we are to meet future climate targets.

A circular scenario for passenger cars could reduce global CO_2 emissions by 70% or 0.4 billion tonnes CO_2 in 2050. The modelled scenario depicts a shared multi-modal mobility system in which different modes of transport are on offer that can be shared, electrified, autonomous, and interconnected. In such a scenario, passenger cars would increasingly be shared as a service, and designed for durability and reuse. Combined, these changes would mean fewer, better-utilised cars with additional positive outcomes such as less congestion, lower maintenance costs, less land and investment committed to parking and roads, and less air pollution. In this system, cost per average passenger-km could drop by as much as 77% in 2050.[72]

How the circular economy opportunities modelled in Figure 7 contribute to a significant reduction in GHG emissions is described below:[xvi]

DESIGNING OUT WASTE

- **Designing for lightweight vehicles (89 Mt CO_2 per year)**: Current trends show that the total weight of vehicles has been increasing over the years despite efforts to reduce weight in order to lower fuel consumption.[73] Material innovation in this area can help discover materials that perform just as well, if not better, but in smaller quantities. The Riversimple's Rasa is a hydrogen fuel-cell powered car with a chassis made of very lightweight fibre composites: it weighs less than 40 kg.[74,xvii] Not only does the lower material demand means a reduction in GHG emissions, but the innovative material itself offers better aerodynamics and a much longer lifespan.

KEEP PRODUCTS AND MATERIALS IN USE

- **Sharing business models (66 Mt CO_2 per year)**: The mobility system today is not used optimally and produces a great deal of structural waste. For example, on average in Europe cars are parked 92% of the time.[75] Public and private sharing services can tackle this challenge by increasing the utilisation of vehicles while offering convenient access to diverse forms of transport. Heavy rail transit, such as subways and metros, produces around 76% fewer CO_2 emissions per passenger/km than an average single-occupancy vehicle.[76] The more passengers riding a train, bus or car, the fewer vehicles are needed on the road, and the lower the emissions per passenger/km.

- **Designing for durability (208 Mt CO_2 per year)**: While revenue is being made from the selling of vehicles, there is little incentive for businesses to design vehicles with greater durability. However, designing for durability is particularly beneficial for service-based business models where the cost of maintenance falls on the business and not the client. In such cases, designing vehicles that are modular and can be easily maintained and repaired helps retain the value of vehicles. It allows for the direct replacement of broken or outdated single components, enabling fleets to last up to 10 times longer.[77] This can maximise returns for businesses offering leases or vehicles as a service by prolonging the use of their assets.

- **Designing for reuse and remanufacturing (38 Mt CO_2 per year)**: Vehicles today are not designed and managed for reuse. This means that at end-of-life valuable components and materials are wasted, when they could be put to better use. In a circular economy, vehicles designed for modularity, reuse, and remanufacturing can help prolong the life of assets. Such

xvi The list provides a selection of circular economy solutions that decrease material demand. Those solutions that reduce energy demand have not been presented due to the scope of the paper. These include, among others, energy efficiency and scaling up zero-emission forms of propulsion such as hydrogen and electric vehicles.

xvii Fibre-reinforced composites, unlike other composites, can be recycled up to 20 times, allowing scrap FRC to be reused again and again. Suvarnaraju, B., and Subrahmanyam, A., Comparison of mechanical properties on composite fiber material prepared by hand lay up method and fiber reinforced plastic method (2016)

measures increase the value of the components as well as avoid the production of new ones, thereby saving raw materials and GHG emissions. Other benefits include avoiding the depreciation and obsolescence of vehicles, facilitating maintenance, and supporting the localisation of production which can in turn shorten the supply chain. Renault has applied such measures and managed to reuse 43% of its vehicle carcasses.[78] Michelin has shown that 85% of worn-out tyres can be reused, and an estimated 60 kg of CO_2 emissions can be avoided each time a tyre is retreaded.[79] When it comes to remanufactured automotive engines, on average 73–87% less CO_2 is emitted, compared to the traditional manufacturing processes for new engines.[80]

- **Recirculating materials**:[xviii] When most vehicles reach their end-of-use, they are wasted. In Europe, for example, end-of-life vehicles constitute 8–9 million tonnes of waste every year.[81] However, recycling is becoming much more common. The European End-of-Life Vehicles Directive has already set a target of 95% recyclability per vehicle per year.[82] The challenge is that current recycling processes lead to significant degradation of material and value. However, Renault has shown high levels of recyclability are possible by designing 85% of the models/vehicles to be recyclable. Though this is the case, 48% of carcasses are in fact recycled for the production of new parts, while the remainder are put to better use by being either reused (43%) or valorised (9%).[83] Combined, these measures can reduce energy demand by 80%.

OPPORTUNITIES AND BENEFITS FOR CITIES: A MULTIMODAL MOBILITY SYSTEM

Cities play an important role in influencing the way in which residents travel and how this travel impacts their health and livelihoods. Urban density and land-use patterns heavily determine transport habits. Cities that are compact, transit-oriented, and dense with mixed-use neighbourhoods, create favourable conditions for both shared mobility (e.g. buses, trams, ride-shares) and active mobility options (e.g. walking, bicycling). For certain economies, such as Europe, a shared multi-modal mobility scenario could lead to an almost entirely decarbonised mobility sector, i.e. electrified and powered by renewable energy. Some minor emissions would likely remain in the production phase but would be reduced by extending the average vehicle's lifetime, and reusing components and materials. This could decrease the extraction of virgin materials by 95% to achieve an almost fully circular system.[84] Such a scenario would improve the wellbeing and quality of life for residents considerably. Fewer cars and less traffic would reduce accidents and stimulate greater activities in streets which can strengthen social cohesiveness and local economies. A shared multi-modal system would also facilitate access to services and jobs, and reduce travelling time, especially when supported by digital platforms and artificial intelligence. Such a system can play a significant role in amplifying the opportunities around access, connectivity, resource savings, and reduced congestion and pollution. For example, an OECD study has estimated that when integrating autonomous vehicles with mass-transit, nine out of ten cars in European cities could be, in theory, removed. This could in addition lead to the freeing up of a significant amount of parking space.[85] For example, reducing vehicle ownership in C40 cities, could lead to the release of 170 million m^2 of on-street parking back to the public realm, providing enough space for 2.5 million trees and 25,000 km of cycle lanes.[86] Such a circular mobility system has the potential to offer additional societal benefits such as reducing congestion costs by 50–60%, and reducing the societal costs of harmful emissions ($PM_{2.5}$ and nitrogen oxide pollutants) by 20–30%, when compared to the current development path.[xix,87]

xviii Recycling has not been modelled since the focus of this deep dive is on the 'product' level (cars). The recycling of materials is however treated in in Figure 4

xix The Ellen MacArthur Foundation modelled the findings for Europe, India, and China. The reports have not only looked at circular economy opportunities that decrease material demand, but also at those that directly decrease energy demand, e.g. scaling up zero-emission forms of propulsion such as hydrogen and electric vehicles.

4

The circular economy opportunity for the food system

Using circular economy principles to reduce emissions generated by the food system is crucial for tackling climate change and could yield a harvest of further system benefits. A circular economy applied to the way we produce and manage food resources could reduce emissions by 49% or 5.6 billion tonnes CO_2e – almost halving emissions from this sector in 2050. This opportunity is driven by measures that design out waste and keep materials in use, coupled with the expansion of regenerative agriculture practices.

The AFOLU sector is responsible for 24% of overall GHG emissions. Emissions from Agriculture, Forestry and Other Land Use (AFOLU) come from deforestation and agricultural activities related to livestock, soil and nutrient management, arising from the production of food, fibres, fuel and the way we manage land. Food production is a large component of AFOLU, but is just one element of a broader food system that connects all activities concerned with the food we eat (growing, harvesting, processing, packaging, transporting, marketing, consuming, and disposing of food and food-related items).[88] Calculating food system emissions is made even more complex because living matter and soils are an integral part of the planetary carbon cycle, both emitting and fixing carbon. To estimate a baseline for this paper, the food system is defined as comprising food production, logistics (transport, storage, and processing), and direct food waste emissions.[xx]

xx Other sources of food system emissions not modelled for this paper include land use change; energy use in farming equipment and fertiliser production; emissions of wastewater treatment plants; and those arising from deforestation and land use.

Total food system emissions are expected to increase from 8.4 billion tonnes CO_2e by over a third to 11.4 billion tonnes CO_2e in 2050. Over 60% of this total relates to food production, arising from a number of different sources. For example, beef production generates large quantities of methane through enteric fermentation (cow burps) and poor management of manure stockpiles. Rice growing can produce methane due to anaerobic conditions found in permanently submerged paddy fields, to the extent that globally rice cultivation is responsible for 10% of food production emissions.[89] Excess tillage exposing soil organic matter to air releases locked-in soil carbon to the atmosphere. Overuse of fertilisers releases nitrous oxide, a powerful GHG with a high global warming potential, as well as emissions associated with the production of agricultural input chemicals such as ammonia.[xxi]

Aside from production, a high proportion of food system emissions are associated with energy use along the food logistics chain such as in processing, transportation, and refrigeration. Food waste also generates emissions, both direct, during decomposition, and indirect, associated with processing, transport, storage, and overproduction. The volume of food thrown away all along the supply chain adds up to about 30% of overall production, making food waste a major contributor to food system emissions.[90]

A circular economy could reduce emissions by sequestering carbon in soil and minimising carbon emissions in the supply chain – by designing out waste, keeping materials in use, and regenerating natural systems. Reducing food waste and valorising organic waste flows from our towns and cities can drive a low-carbon bioeconomy as well as help build soil fertility. By adopting regenerative practices, farmers can go even further, moving from carbon reduction to carbon sequestration. In this way, the soil and plants we use to feed a growing population can be transformed into a major tool to address the climate crisis. Technology company Indigo Ag recently estimated the enormous potential for carbon sequestration through improved farming methods. According to its calculations, if the organic matter content of all the world's farmland was increased from a current average of 1% to a pre-industrial level of about 3%, the effect would be to soak up 1 trillion tonnes (1 teraton) of carbon – equivalent to all the industrial emissions produced since the Industrial Revolution.[91] No other economic sector has this game-changing potential to soak up so much atmospheric carbon.

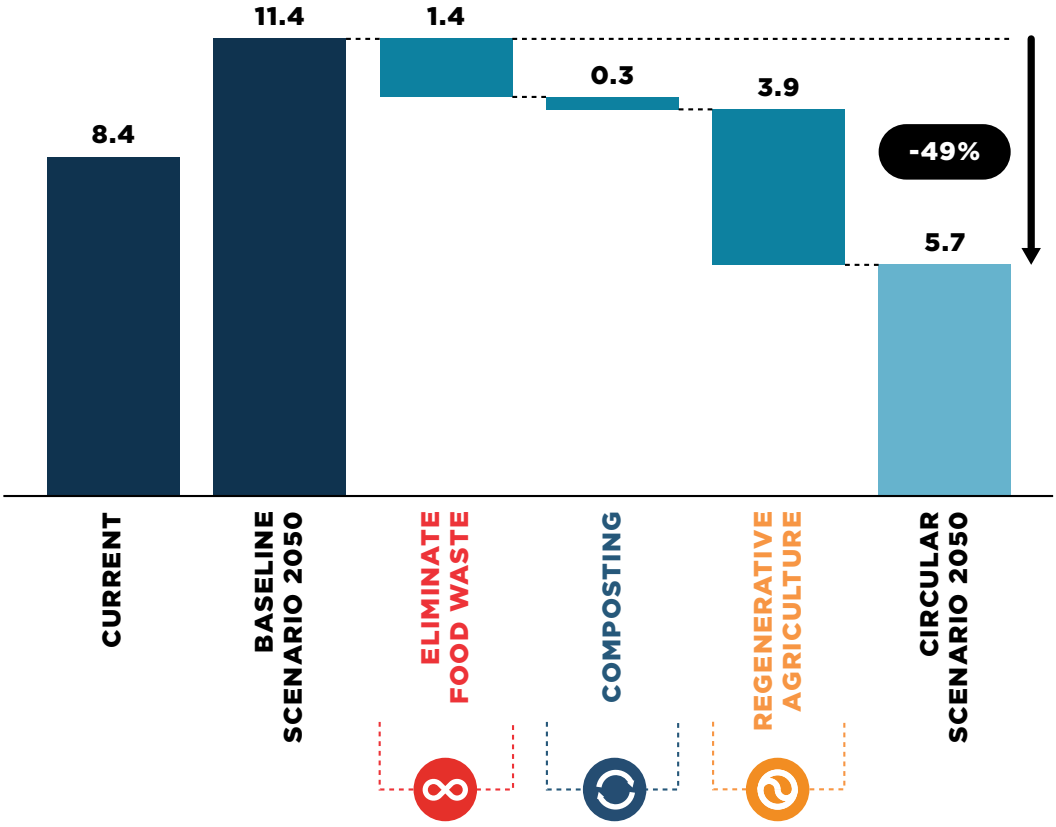
xxi According to the IRP (2016), global average nutrient efficiency for nitrogen and phosphorus is only around 20%.

4.1. CIRCULAR ECONOMY STRATEGIES FOR REDUCING EMISSIONS IN THE FOOD SYSTEM

Circular economy strategies could reduce emissions by 5.6 billion tonnes CO_2e, corresponding to a 49% reduction in the projected 2050 total food system emissions. Achieving this means shifting to more nature-enhancing farming systems and making more effective use of the food that is produced. These strategies are underpinned by three core circular economy principles:

FIGURE 8: A CIRCULAR SCENARIO FOR FOOD COULD REDUCE ANNUAL CO_2e EMISSIONS BY 49% IN 2050

Emissions from the global food system
Billion tonnes of CO_2e per year



Source: Adapted from Ellen MacArthur Foundation, "Cities and Circular Economy for Food" (2019)

DESIGN OUT WASTE

Every second around the world approximately six garbage trucks of edible food are thrown away, most of which ends up in dumps or landfills, giving off methane as it decomposes. Food waste prevention has surfaced as a major global agenda item, formalised in the United Nations' SDG 12.3, which sets an ambition to halve per capita food waste and losses globally by 2030. There are many different mechanisms that can be employed to achieve this target, as detailed below.

Chefs, product developers, and other food designers can also contribute to designing out emissions in other ways, such as by selecting and using ingredients that generate fewer carbon emissions in production. One example is the use of more plant-derived ingredients, which are generally associated with lower production emissions.[92]

For this paper, only the emissions benefits from food waste reduction have been modelled:

- **Food waste reduction (1.4 billion tonnes CO_2e per year)**: Food value chain players, especially those located in cities, can undertake a range of food waste prevention interventions. For example, retailers can contribute by better matching supply with fluctuating demand for different food types, to discounting soon-to-expire products and using produce that has gone beyond its shelf-life date in in-store restaurants. Innovative companies can develop new business models: for example, MIWA provides an online service for customers to buy precise amounts of food in reusable packaging, allowing its customers in the Czech Republic to avoid food waste. Food brands can use 'ugly' fruits and vegetables as ingredients for food products, such as baby food and spreads, while also ensuring expiration dates reflect the true shelf-life of products. Digital technology and supporting policy initiatives can play an important role in ensuring any surplus edible food is redistributed for human consumption, helping divert food waste from landfill, and providing high-quality nutrition to food-insecure neighbourhoods. Redistribution initiatives are already being championed by organisations such as Feedback (UK) and Food Shift (US), enabled through digital platforms such as Denmark's Too Good to Go.

Scaling up these types of interventions, combined with important measures to encourage behavioural change, can contribute to reducing edible food waste by 50% by 2030 with a potential annual emissions reduction from across the food value chain totalling 1.4 billion tonnes/CO_2e.

KEEP PRODUCTS AND MATERIALS IN USE

However well food resources are managed, surplus organic material will always be generated via agricultural by-products, food preparation leftovers (peels, bones, spent grains, etc.), urban landscape management ('green waste'), and municipal sewage flows. The world's cities, the biggest consumption hubs for food, are major producers of these materials. Each year cities generate more than 600 million tonnes of organic waste,[93] with only 2% of this looped back to productive use.[94] In a circular economy, these organic materials are viewed not as waste but as feedstock for other parts of the economy: they are transformed from a costly waste stream into new forms of potential value. If waste streams are relatively pure, the materials can be used to produce high-value products such as fabrics for clothes (e.g. Orange Fiber, DueDiLatte), structural material for packaging and furniture (e.g. Ecovative, RiceHouse), or innovative new food products (e.g. Canvas Drinks, Planetarians).

For mixed waste streams, nutrient-looping can be employed, producing soil enhancement products that can support regenerative food production, particularly in peri-urban areas. If sufficient feedstock quantities and appropriate infrastructure are available, this can be complemented by energy recovery through anaerobic digestion or other means. Nutrient-looping could be particularly impactful when applied to the design and operation of carbon-emitting wastewater treatment plants (WWTPs). In Europe these consume 1% of national electricity production. In developing countries, energy demand by WWTPs is set to increase by 20% in the next 15 years.[95]A number of forward-thinking utilities have proved that WWTPs can be operated as a net energy producer. For example, Aarhus and Odense WWTPs in Denmark have both demonstrated energy positivity greater than 200% by recovery of biogas through anaerobic digestion of sludge.[96] Further carbon benefits are achieved as the nutrient-rich biosolids left over from this process can be spread over local farmers' fields.

For this paper we have modelled emissions reduction associated with nutrient-looping of food by-products and green waste without energy recovery:

- **Composting of by-products and green waste (0.3 billion tonnes CO_2e)**: Composting is mainly an aerobic process generating CO_2, which has a much lower global warming potential than methane. Besides carbon, compost contains other nutrients that can nourish and strengthen soils, so that using compost in food growing can mean fewer chemical fertilisers and less irrigation are required. This consequently reduces emissions in sectors such as mining (mineral extraction), industry (ammonia production), and energy (pumping power for irrigation). For this paper, we have modelled the emissions-reduction potential as 0.3 Gt CO_2e per year in 2050 based on the high organic material recovery potential (>70%) demonstrated by cities such as San Francisco.

REGENERATING NATURAL SYSTEMS

Regenerative agriculture represents the greatest opportunity to turn the food system from a major contributor to climate change to a major actor in the solution. The broad definition of regenerative farming is growing food in ways that improve soil health, agro biodiversity, and local ecosystems. How this is done in practice depends on the context, scale, and other factors. However, all approaches share a mindset that views the farm as part of a larger mutually supportive ecosystem, as well as the critical importance of building soil organic content. The effect of the latter is to improve the soil's physical structure and nurture beneficial microbes, leading to a cascade of system benefits: not only carbon sequestration, but also better water retention and reduced reliance on synthetic fertilisers. For our analysis, which is significantly informed by data from Project Drawdown – an ongoing initiative that has identified the 80 most powerful interventions to combat global warming – global farmland is divided into two broad types: pastureland (3.3 billion hectares) and cropland (1.5 billion hectares).[97] Carbon sequestration is possible on both these types of land, but the specific practices that can be employed depend on the climate, soil type, slope, and other factors.

On pastureland, the main drive is to build levels of organic matter on the land using livestock and plant growth. Key ways of achieving this are through managed grazing (modelled for this paper, see below), or other methods such as silvopasture which integrate tree crops within the grazing area. For cropland, carbon benefits are achieved through minimising soil disturbance and the reduction or even elimination of synthetic inputs. Croplands can also sequester carbon in the root mass of perennial crops or through the application of organic fertilisers, biosolids, and other green wastes to the soil. Regenerative agriculture on cropland covers a wide array of approaches such as conservation agriculture, agroecology, permaculture, zero-budget natural farming, multi-strata agroforestry, and others. For this paper, we have modelled the carbon benefit using a broad category term that encompasses a number of these approaches.

- **Managed grazing (1.4 billion tonnes CO_2e per year)**: This approach uses livestock as a tool for building soil fertility by carefully controlling timing of grazing and resting of pastureland. If managed well, the outcome is improved soil health, carbon sequestration, increased water retention, and higher forage yields. The approach entails a number of different grazing techniques such as optimising livestock density, the use of a wider variety of grass species, and regular rotations of animals through pastures and paddocks. Approximately 40% of the world's 3.3 billion hectares of grazing land could theoretically use these techniques.[98] Currently the land under managed grazing is about 80 million hectares. Applying a conservative adoption rate of around half of this remaining land area leads to an annual carbon benefit of 1.4 billion tonnes CO_2e in 2050. This estimate represents the net sequestration of carbon versus emissions related to enteric fermentation and degradation of manure on pasture.

- **Regenerative cropland (2.5 billion tonnes/ CO_2e per year)**: This term refers to a set of techniques on arable land that reduce GHG emissions associated with different crop types as well as increase soil carbon capture. Regenerative cropland approaches use a number of different methods including minimising soil disturbance (no-till), the use of cover crops, intercropping, and the use of organic fertilisers. These address climate change in different ways, sequestering carbon in roots and microbes, preventing soil carbon losses through low- or no-till, and reducing the need for carbon-intense inputs such as farm machinery, water

pumping, and synthetic inputs. The total cropland suited to regenerative agriculture is about 800 million hectares,[99] with about 40 million hectares already being farmed in this way. Assuming 80% of the remaining land adopts regenerative agriculture this could lead to an annual carbon benefit of 2.5 billion tonnes CO_2e.

4.2 ADDITIONAL INTERVENTIONS WILL BE NEEDED TO FURTHER REDUCE FOOD SYSTEM EMISSIONS

The adoption of the above circular economy strategies could reduce overall food system emissions by 49%. To achieve the remaining reduction, other interventions will be needed such as further improvements in farming methods besides those modelled for this paper, the continuing development and scaling of emerging technology and measures to encourage behaviour change.

Emerging technology encompasses a wide range of promising interventions such as precision agriculture and scaling up the use of methane inhibitors in cattle feed. Precision agriculture techniques facilitate the reduction of agricultural inputs (seeds, water, or chemicals) required for each unit of crop output. The most important application of this technology, in relation to climate change, is to address the overuse of fertilisers. In 2010, overuse of fertilisers was responsible for 19% of agricultural production emissions.[100] The overuse of nitrogen fertilisers is particularly harmful as, when applied to soil, there is a release of nitrous oxide – one of the most powerful GHGs – and these emissions increase exponentially with each excess kilogram of fertiliser.[101] Reducing fertiliser use also results in a reduction of industrial emissions associated with their production.

Methane inhibitors are supplements derived from natural sources (seaweeds, tannins, oils) or synthetic chemicals that when mixed into feed have been proven to reduce enteric fermentation by up to 30% in ruminant livestock.[102] Enteric fermentation is the number one source of GHGs from agriculture, so there is an urgent need to find ways of making cows produce less gas or identify breeds of cattle that naturally produce less methane after feeding.

In the digital technology space, artificial intelligence (AI), the internet of things (IoT), algorithmic gene-editing, and other Fourth Industrial Revolution technologies[103] could also play a role in addressing food system emissions. Interventions include simple data collection systems, such as AI-enabled food waste kitchen scales that automatically collect food waste data, allowing better decision-making for restaurant or hotel food procurement. The use of AI could extend to more advanced applications, for example, helping identify more uses for renewable bio-feedstock that feed into the design of new types of food products with lower embodied energy. NotCo, a Chile-based start-up, exemplifies the potential of such an approach: the company's AI platform analyses food on a molecular level, producing designs for less carbon-intense food products but with similar textures and flavours.

Improved farming techniques also offer a wide range of emissions-reducing solutions. Mid-season drainage of rice paddy fields can shift rice growing conditions from anaerobic to aerobic, greatly reducing the methane production associated with global rice cultivation. Improved manure management addresses the significant nitrous oxide and methane emissions arising from decomposing animal urine and faeces. The techniques employed vary according to context, but most aim at the collection of biogas through anaerobic digestion and the use of biosolids to enhance soil fertility. One promising technology has been developed by PrairieFood, which has created a process to convert manure and food waste into biochar (charcoal produced from plant matter). When mixed into topsoil, biochar sequesters carbon, enhances nutrient cycling, and improves soil structure.

Behaviour change refers mainly to shifting diets and reducing overconsumption. It is also a key factor in driving food waste reduction for individuals, institutions, companies, and households. Behaviour change is widely recognised as being crucial for emissions reduction,[104] but it is also particularly challenging, as these behaviours are often deeply entwined in social and cultural issues, requiring educational programmes and public health campaigns with results spread over a longer time frame. Having said that, circular 'food designers' can play a role in influencing behaviour change by offering a wider range of meals and products that have lower carbon emissions embedded in their production.

4.3 THE CIRCULAR ECONOMY APPROACH IS COST EFFECTIVE

The economic benefits of implementing the circular strategies described above are estimated as USD 700 billion per year by 2050.[105] The direct economic opportunity includes valorisation of organic materials and the recovery of USD 26 billion worth of nitrogen and phosphorus that would otherwise have been lost. The bulk of the opportunity lies in designing out food waste, which can ensure surplus edible food and the significant market value it represents is not lost. Through edible food redistribution efforts, cities can keep valuable food from going to landfill and contribute to reducing costs in urban food security programmes.

Numerous other economic benefits could accrue from applying circular thinking to the food system. Winnow's smart weighing scales that generate regular analytics on kitchen waste can reduce food costs in catering companies by 2–8%.[106] Regenerative agriculture can save money through reduced requirements for agricultural inputs. In Indiana, farmer Rodney Rulon spends about USD 100,000 on cover crop seeds on his 6,200 acre arable farm, saving USD 57,000 on fertilisers and increasing profits by USD 107,000.[107] In northern India, more than 160,000 farmers practise zero-budget natural farming, an approach that turns agricultural by-products into a soil-activating, seed-protecting inoculant. As a result, farmers avoid borrowing money to buy expensive synthetic inputs, so reducing exposure to debt and increasing food security and profits.[108] In Italy, cities are realising the benefits of more effective organic waste collection. In Parma, moving from roadside to door-to-door collection reduced annual costs of treating organic waste by EUR 450,000 (USD 510,000).[109]

4.4 THE APPROACH OFFERS SYSTEM-WIDE BENEFITS

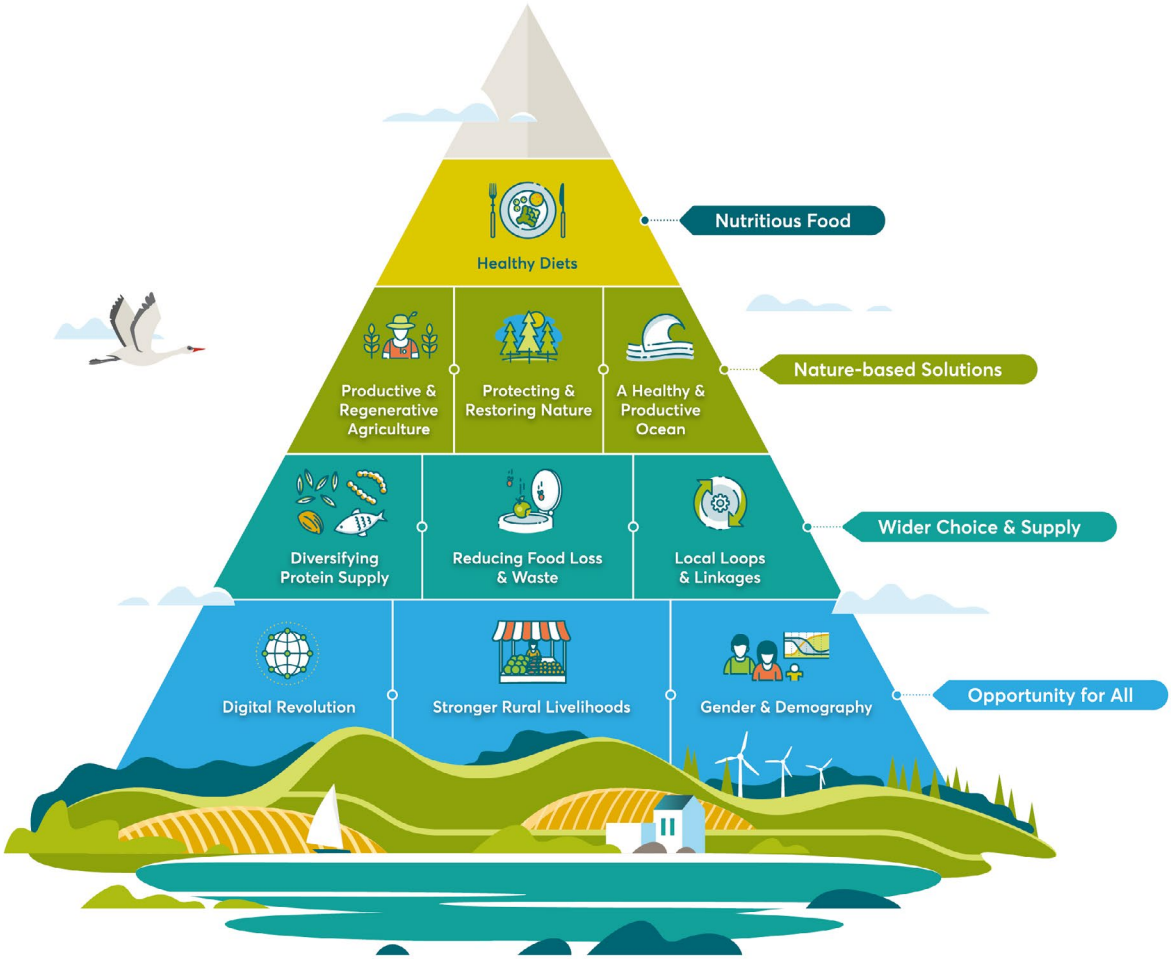
A circular food system can contribute to staying within planetary boundaries and meeting UN SDGs. In a global context, there is great potential for a more circular food system to have a positive impact on many of the 'planetary boundaries'. This concept, developed by the Stockholm Resilience Centre, refers to the nine most critical earth system processes that are being threatened by the recent Great Acceleration[xxii] in human industrial activity. In particular, regenerative food production and better cycling of nutrients could positively impact phosphorus and nitrogen runoff and the conservation of genetic diversity, the two boundaries that are being exceeded to the greatest degree. The numerous other environmental benefits include significant positive impacts on biodiversity, avoided soil degradation, and the conservation of freshwater. Going beyond the environment to include broader societal benefits, a 2016 report by the IRP provides solid evidence that a 'resource-smart' food system is "an imperative for the achievement of at least 12 out of the 17 Sustainable Development Goals (SDGs)".[110]

A more circular food system also offers significant health gains. The reduction of pesticide exposure is the most significant of these benefits with annual savings of USD 550 billion in health costs from pesticide-related illnesses expected by 2050. Another important potential health benefit is a reduction in antimicrobial resistance, which is seen by many scientists as a deeply worrying future public health threat. Regenerative practices applied to livestock and fish breeding, coupled with improved wastewater treatment, could help alleviate the threat that antimicrobial resistance may pose to millions of lives by 2050. Reductions in water contamination, foodborne diseases, and air pollution will all have a positive impact on other health issues. In the case of air pollution, it is estimated that a more regnerative approach to farming could save 290,000 lives per year by 2050.

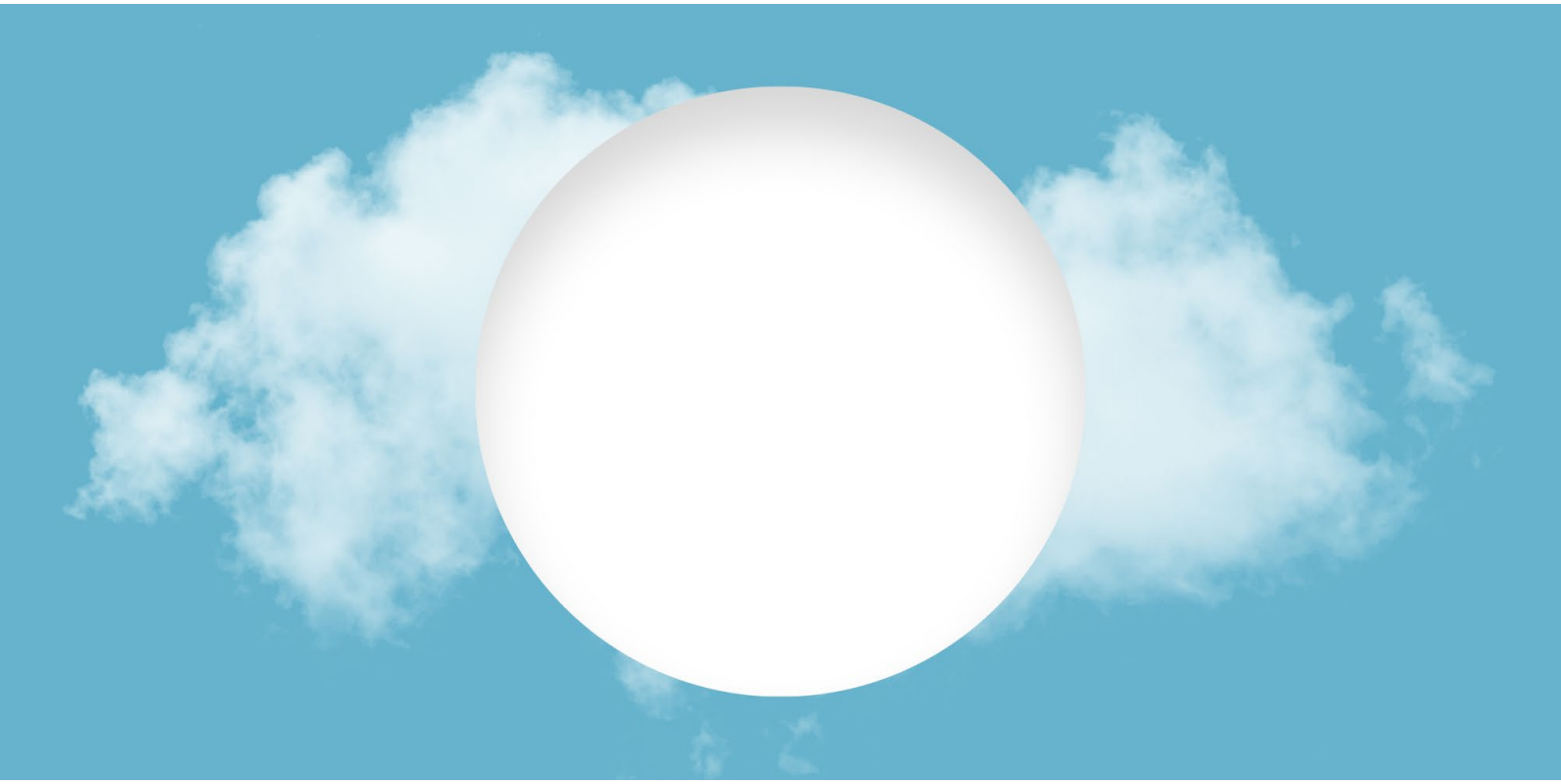
While combating climate change is one of the greatest challenges of our time, enhancing food security and reducing malnutrition for more than 800 million hungry people, as well as improving livelihoods and quality of life for the world's poor, are also critical issues. The positive news is that regenerative agriculture and other circular approaches have the potential to simultaneously address many of these critical issues, as a recent Intergovernmental Panel on Climate Change (IPCC) report on land use acknowledges: "Many land-related responses that contribute to climate change adaptation and mitigation can also combat desertification and land degradation and enhance food security."[111]

xxii Refers to the most recent age of the Anthropocene epoch during which the rate of impact of human activity upon the Earth's natural systems has increased significantly

FIGURE 9: TEN CRITICAL TRANSITIONS FOR THE TRANSFORMATION OF THE FOOD SYSTEM



Circular economy strategies are a central part of this transformation and the associated benefits could be as much as USD 10.5 trillion annually by 2050, improving all aspects of life on the planet.[112]



5

A circular economy could help build resilience to the effects of climate change

As well as being effective in reducing GHG emissions, the circular economy could also contribute to building climate change resilience. There are indications that circular economy business models offer a range of possibilities to distribute risk across supply chains, increasing their flexibility and resilience to climate risks such as extreme weather. The evidence base is relatively strong in the agriculture sector, with findings suggesting there is a positive relationship between regenerative agricultural practices and climate resilience. However, the degree to which a circular economy increases resilience is context-specific since climate risks and vulnerability vary greatly by industry, geography, and socio-economic context. This chapter outlines the opportunity and acknowledges that further research is needed to estimate the size of the potential and identify further tangible examples.

5.1 THE IMPACTS OF CLIMATE CHANGE REPRESENT IMPORTANT RISKS FOR BUSINESS

Climate change causes a wide range of physical risks with serious implications for business and investors. Physical climate risks can be categorised as being either acute or chronic. Acute physical risks are event-driven such as increased severity of extreme weather like droughts, floods, and wildfires, while chronic physical risks arise from long-term climatic shifts such as sustained high temperatures and sea level rise.

These impacts lead to a set of business risks. Climate change is increasingly recognised as a systemic risk to which every large multinational company is exposed.[113] A survey of Standard and Poor's Global 100 companies, an index that measures the performance of businesses that are global in nature, listed the top five climate-related business concerns as follows:[114]

1. Reduction/disruption in production capacity e.g. power outage or shortage of key input.
2. Increased operational costs e.g. higher costs for key supplies or back-up.
3. Inability to do business e.g. damage to facilities or logistics systems.
4. Increased capital costs e.g. plant or equipment upgrades, insurance costs.
5. Reduced demands for goods and services e.g. shifting market preferences.

A lesser-discussed element of point 1. is the risk of weather events disrupting the availability and supply of raw materials. Raw material reserves and production are not evenly spread across the world and regions vary in their vulnerability to climate change risks.[115] For example, over 70% of global bauxite reserves are concentrated in six countries, and of those reserves, around 75% have a relatively high exposure to climate hazards.[116] Moreover, considerable concerns exist over the security of supply of so-called 'critical' materials,[xxiii] with rare earths attracting the greatest attention. What may make these materials critical for the EU is a lack of domestic production and a high risk of supply disruption from external shocks such as increased scarcity, monopoly supply, political instability, and vulnerability to the effects of climate change in key supplying regions.[117]

Structural factors undermine the resilience of businesses to these risks. Today's global economy has developed interconnected, interdependent, and complex supply chains. Businesses increasingly source their materials and components from across the globe, clustering their activities in concentrated geographical areas, reliant on maximum efficiency (e.g. just-in-time production), vulnerable to outdated infrastructure, and challenged by a lack of information exchange and transparency.[118] Not only does this make businesses vulnerable to disruptions, but the complexity of the networks involved makes the prediction of such disruptions very difficult. This can have global repercussions whereby a "disruption caused by a storm or drought at one remote location can bring a whole supply chain to a halt".[119] These 'transnational climate impacts' are risks that can travel across borders and cascade through the global economy.[120] A commonly known example of such a cascade is the severe floods in Thailand in 2011. The floods hit suppliers of the electronics and automotive industries, leading to the disruption of 14,500 businesses worldwide that were heavily reliant on Thai suppliers.[121] Western Digital, which has one-third of the global hard-drive market, couldn't fulfill 45% of its shipments, HP lost USD 2 billion, while Toyota, Honda, and Nissan could not deliver 240,000, 150,000, and 33,000 cars respectively.[122] Total insured losses were estimated to be USD 15–20 billion.[123]

Understanding of the value of climate resilience and how to achieve it is emerging. There is mounting evidence of the benefits and cost effectiveness of investing in resilience compared to inaction.[124] One recent report found that investing USD 1.8 trillion over the next decade in five key climate adaptation strategies would lead to USD 7.1 trillion in total net benefits.[xxiv] Another found that across industries the benefits of increasing resilience outweigh the costs by nearly seven to one (~USD 312 billion of costs versus ~USD 2.1 trillion of potential opportunities).[125] The elements

xxiii The EU defines critical materials as "economically important raw materials and whose supply is associated with a high risk." European Commission, Study on the review of the list of critical materials: criticality assessment (2017)

xxiv The five areas we consider are early warning systems, climate-resilient infrastructure, improved dryland agriculture, mangrove protection, and investments in making water resources more resilient. Global Commission and Adaptation, Adapt now: a global call for leadership on climate resilience (2019)

needed to achieve greater resilience are well-established and include diversity, flexibility, collaboration, integration, and inclusivity. These characteristics are common to climate resilience frameworks such as the Stockholm Resilience Centre's 'seven principles'[126] and the Arup/ Rockefeller City Resilience Framework. However, putting these principles into practice is not straightforward. One survey found that while 72% of suppliers believe climate risks could significantly affect their business operations, revenue, or expenditure, only half are currently managing this risk.[127]

Lithium supply and electric vehicle (EV) batteries. For EVs, raw material supply vulnerability is especially apparent in the production of lithium-ion batteries. While lithium is an abundant element with worldwide reserves, it has been termed a "critical metal".[xxv] Production based on extraction from lithium-rich brines, which is less costly, is concentrated in only a few countries – notably Chile and Australia, which account for 70% of total output.[128] From extraction all the way to vehicle production and distribution, the lithium supply chain is particularly at risk from floods and extreme weather events that may delay or interrupt mining and other operations. Furthermore, while production of lithium is concentrated in the southern hemisphere, manufacturing takes place in the northern hemisphere, and transportation links are at risk of disruption at ports and during shipping. In addition to the risk of being dependent on a few suppliers vulnerable to disruption, the complex nature of the supply network itself also increases vulnerability since multiple raw resource inputs are needed to produce just one battery component.[129]

5.2 CIRCULAR ECONOMY CAN HELP ADDRESS THESE RISKS BY INCREASING RESILIENCE ACROSS SECTORS

Circular economy business models in industry have the potential to increase resilience. In a circular economy, business models are underpinned by designs that enable products to be reused, components remanufactured, and materials recycled. Supplies of materials and components are therefore increasingly decoupled from the consumption of raw materials, which may be vulnerable to climate-related risks. These supplies are instead more diverse and flexible since they draw increasingly on products and materials returned from customers. This has the potential to spread the risks of climate-related disruptions more widely along supply chains, thereby increasing resilience.[130]

The risk-reducing potential of these business models is beginning to be recognised. One of the most important drivers for remanufacturing is acknowledged to be the "rising insecurity of supply and associated cost of raw materials, caused by (amongst other factors) vulnerable global supply chains being increasingly put at risk by natural disasters and geopolitical conflict".[131] The European Commission considers recycling a "risk-reducing measure".[132] Overall, the IRP concludes that "a shift to remanufacturing and recycling of materials could diversify and add high value-added economic activity to extraction focused economies."[133] Some companies are already benefiting. For example, Renault has set up its factory in France to remanufacture and recondition car parts. By doing so, not only is the dependency on overseas resources decreased but by reconfiguring the supply chain, risks are redistributed and reduced. Energy Storage, a company in the UK, has developed a technology that enables lithium-ion batteries for EVs to be repaired, upgraded, and reused when no longer suitable for EVs, extending their use by up to 25 years and reducing reliance on virgin lithium, which has a vulnerable supply chain (see box).[134]

However, context is crucial and will determine the net resilience effect of pursuing these opportunities. Vulnerability to climate impacts, both local and transnational, will differ by region since every country differs in its level of exposure to climate hazards, economic development, reliance on imports/exports of materials and goods, and political context. Organisations therefore need to take a "cross-scale and multidimensional perspective" of climate risk.[135] In practice this means balancing the local reuse of products and materials, and associated reverse logistics, with supplies of raw materials often sourced from further afield to avoid increasing overall vulnerability to climate disruptions. There are other considerations. When putting in place more distributed

xxv A study by Defra used eight criteria to rank 69 elements and minerals in order of their criticality. Two types of criteria were used: 'material risk' criteria and 'supply risk' criteria. The material risk criteria were global consumption levels, substitution potential, global warming potential and total material requirement; the supply risk criteria were scarcity, monopoly supply, political instability in key supplying regions, and vulnerability to the effects of climate change in key supplying regions. Department for Environment Food and Rural Affairs (Defra), A review of national resource strategies and research (2012)

supply chains, operational efficiency must be considered since more complex networks are more costly and difficult to manage.

The food sector has particular vulnerability to climate risks. The physical risks described above will have impacts on agriculture. These have been seen in the June 2019 flooding in the US Midwest that left millions of acres unable to be sown,[136] and in the Californian drought (2011-15), whose direct cost to agriculture in 2014 was estimated at USD 1.5 billion, about 3% of the state's total agricultural value.[137] In addition, there are risks specific to the food system such as increased exposure to pests and diseases, and phenological changes, in which plant and animal life cycles are affected, altering the start and end of growing seasons.[138] These impacts are difficult to predict and will be "widespread, complex, geographically and temporally variable and profoundly influenced by pre-existing social and economic conditions".[139] In the short term, impacts could be both positive and negative as in temperate regions productivity could increase due to slightly higher average temperatures, while in already water-constrained tropical regions yields may decline due to factors including water stress. Two things are certain in the longer term: the degree of uncertainty will increase and, despite some benefits, "negative impacts will dominate".[140]

Regenerative agricultural practices, a core element of a circular economy for food, can increase the resilience of soils. Regenerative agricultural practices such as managed grazing and regenerative cropland have been shown to improve soil health. Healthy soils can better resist erosion caused by wind and floods. Moreover, they have higher capacity to both absorb and store water, increasing their resilience to floods and droughts respectively. The potential is significant: increasing organic content in the top 12 inches of soil by 1% makes it able to store an additional 144,000 litres of water per hectare.[141] Employing regenerative agricultural practices on a 5,000-acre mixed arable and livestock farm in North Dakota led to its soil infiltration rate increasing by 30% (while also at least tripling carbon sequestration rates per acre and increasing yields by 20%).[142] Resilience-building farming approaches are context-dependent. For example, smallholder farmers in locations particularly vulnerable to climate change can increase resilience by adopting conservation agriculture or natural systems of farming. An example is Zero Budget Natural Farming (ZBNF), a low-input technique practised by more than 130,000 farmers in the Indian state of Andhra Pradesh. ZBNF uses fermented farm by-products to activate soil biology which, combined with the application of green manures, increases the water retention capacity of the soil (while also increasing yields and strengthening plants).[143]

In conclusion, the circular economy has exciting potential to increase climate resilience, but further research is needed. Understanding to what extent and in what circumstances a circular economy can contribute to greater resilience to the effects of climate change will require in-depth investigation, as little research – in particular in sectors beyond agriculture – has yet been done on the subject. It is also important to note that not all circular economy opportunities lead to greater resilience: making cities more compact enables more productive use of assets and resources, but it also concentrates risks and so may make cities more vulnerable to climate disruptions. However, the early indications of potential laid out above are encouraging and worthy of further exploration. What is clear is that strategies to increase resilience to the effects of climate change are needed, and if such strategies also reduce emissions and create economic value they are an exciting prospect.

6

Next steps: concerted action is needed

This paper has identified a set of concrete circular economy strategies that can help tackle the climate crisis. Together with a necessary a transition towards renewable energy, the circular economy is a critical step forward in addressing the remaining 45% of global emissions associated with the production of materials and goods. It completes the picture of strategies to address climate change. However, such a transition requires concerted action from multiple stakeholders ranging from policymakers to academia. Only a systems-level approach will enable us to achieve the 1.5˚C target by 2050, while building greater resilience to climate change.

THE ROLE OF INTERNATIONAL INSTITUTIONS

Setting standards, coordinating, and encouraging a transition towards a net-zero emissions circular economy.

- **Put circular economy on the international agenda**
  The potential of circular economy measures to contribute to climate targets and increase resilience to climate change is significant but it is far from recognised in the current climate discourse. The circular economy should have the same status as other recognised key areas of climate action in international processes, such as reforestation, energy efficiency, and renewable energy. This would enable organisations such as the United Nations Framework Convention on Climate Change (UNFCCC) to recognise the circular model as an effective/valid framework for NDCs to help countries accelerate the net-zero carbon transition needed to reach our 2050 climate targets. A step in this direction has been taken with the ratification of the resolution on "Innovative pathways to achieve sustainable consumption and production" at the fourth session of the UN Environment Assembly (UNEA-4) in March 2019. The text "invites Member States to consider approaches and policies for achieving sustainable consumption and production, including but not limited to improving resource efficiency and moving towards a circular economy, when developing relevant national plans and policies (...)".[144]

- **Enable the trade of circular products and materials**
  To support a circular economy, international trade needs to act "as a vehicle for delivering on the environmental and resilience agenda".[145] The setting of international standards on recyclability, repairability, eco-design, labelling, and materials and chemical use plays a critical enabling role. This could remove barriers hindering the trade of secondary materials, and remanufactured and refurbished goods. Technologies that enable a circular economy could benefit from advantages that facilitate their adoption at scale globally. When it comes to the cross-border movement of waste, secondary materials, and second-hand goods, unnecessary trade barriers could be removed so that they can be channelled to destinations where there is comparative advantage in sorting and processing.[146]

- **Mobilise capital towards circular economy investments**
  Impact investors play a key role in providing financial support that can help accelerate a transition towards a net-zero circular economy. For example, over the past five years the European Investment Bank (EIB) has provided EUR 2.1 billion in co-financing for circular projects run by SMEs that have reduced material and energy consumption, offered environmental and climate benefits, and contributed to innovation.[xxvi,147] The lending instruments and services come in the form of risk-bearing instruments, project loans, and financial support for funds as well as technical advisory services. A similar approach could be used within other multilateral development banks such as the World Bank, the International Financial Corporation, Asian Infrastructure Investment Bank, and the African Investment Bank. To further accelerate the transition towards a low-carbon economy, the EU is examining how to integrate sustainability considerations (which include circular economy strategies among others) into its financial policy framework.[148] The aim is to mobilise finance for sustainable growth and help benchmark projects across the world, especially for emerging economies.

- **Coordinate climate policies**
  A circular economy presents solutions to some of the world's most pressing global challenges, meeting multiple policy objectives. It has the potential to tackle climate change, achieve many of the SDGs, and deliver economic prosperity and resilience. To enable this, synergies must be put in place to create mutually reinforcing policies.[149]

- **Encourage and support collaboration**
  The transition to a more circular economy requires collaboration between governments, the investment community, industries, companies, academia, and civic organisations. International institutions can play a convening role in this. An example is the World Economic Platform for Accelerating the Circular Economy (PACE), where global public-private collaborations related to plastics, electronics, food and bioeconomy, business models, and market transformation are put in place to help drive change by accelerating leadership, collaboration, investment, policy reform, and action towards a circular economy across China, ASEAN, Europe, and Africa.[150]

THE ROLE OF POLICYMAKERS

Incentivising, mobilising, and accelerating the transition towards a net-zero emissions circular economy.[xxvii]

- **Integrate the circular economy into climate change strategies**
  Circular economy ambitions can be integrated into supranational, national, and city climate strategies, roadmaps, long-term targets, and plans to help achieve and accelerate the transition towards a resilient and net-zero carbon economy. For example, through the Paris Agreement, countries have been requested to submit their NDCs and report on the efforts being made to reduce emissions and adapt to climate change. These NDCs must be updated every five years. This offers an opportunity for circular economy measures to be integrated as an action plan to help accelerate progress in countries achieving their nationally determined climate targets or even allow for more ambitious targets. Some EU member states are for example integrating circular economy measures in their National Energy and Climate Plans, as "the benefits of the circular economy for decarbonisation are widely acknowledged".[151] Strategy plans are being set up such as the Netherland's "Government-wide Programmme for a Circular Economy", whose policies when implemented have been estimated to reduce

xxvi "The European Investment Bank said that it will stick to its target of investing around USD 100 billion in climate action over the next five years, the largest climate finance contribution of any single multilateral institution, and is already exceeding its own targets for climate finance." EIB, Together on climate.

xxvii For a deeper understanding of the various policy levers that national and local governments have at their disposal to bring about circular economy transitions, please see reports: Ellen MacArthur Foundation, City governments and their role in enabling a circular economy transition: an overview of policy levers (2019); Ellen MacArthur Foundation, Delivering the Circular Economy: a Toolkit for Policymakers (2015)

CO_2e emissions by around 13 million tonnes in 2050 (in a conservative scenario).[152] City governments are also increasingly developing commitments and targets to net-zero carbon transition.[xxviii]

- **Incentivise and accelerate the scaling of new circular solutions**
  Public funding can be used to enable and accelerate the scaling of circular business solutions. Government spending in OECD countries contributed 25–57% of GDP in 2015.[153] Moreover, circular economy and CO_2-intensity criteria could be included in public procurement tenders, which could incentivise circular economy market innovation as well as support research, capacity-building, demonstrations, and early-stage projects. For example, the City of Toronto has established a circular economy procurement implementation plan and framework, initially running a three-year pilot before delivering recommendations in 2021.[154] It is also worth noting that European Green Public Procurement policy criteria include circular economy components.

- **Enable and de-risk investment in the circular economy**
  For circular projects with high potential and risk, public-private partnerships and ventures can be used to share and reduce investment risks. For example, the EU JESSICA Urban Development Funds contain financial contributions from EU member states, cities, and other public and/or private sources that are invested as equity, loans, and guarantees for projects that support sustainable urban development and regeneration in cities.[xxix]

- **Put in place infrastructure and renew assets**
  Cities have a particularly important role to play in ensuring the effective recirculation of materials, products, and nutrients in urban areas. Enabling this will require infrastructure such as asset-sharing infrastructure, waste collection systems, treatment facilities, material banks, and disassembly and recycling centres. When planning for infrastructure renovations and replacement, there is also an opportunity to consider designs that are low-carbon, energy efficient, modular, repairable and adaptable, durable or robust, and made with secondary materials. A comprehensive asset database within local government, such as that developed by the City of Winnipeg,[155] can help provide a clearer picture of the share and type of city assets that are underutilised, underperforming, and deteriorating due to poor maintenance, design, or end-of-use. In combination with material passports and circular economy performance indicators, knowledge of this sort can lead to improved use and maintenance of assets.

- **Use fiscal levers to create enabling conditions and incentivise actions**
  Fiscal policy levers can be used to enable lead markets for circular economy products, services, and practices. A price on carbon emissions should be set,[xxx] and balancing mechanisms could be introduced for goods imported from regions that do not enforce a CO2 price similar to that of the regional context. From a local perspective, fiscal measures can include tax benefits for circular economy products or businesses, tax increases on undesirable waste streams, tax reductions on the use of secondary materials, and tax reductions for businesses that share, repair, and recycle.[156] For example, Sweden has introduced a 50% reduction in VAT for repair activities related to certain products, including apparel, bicycles, and white goods.[157]

- **Establish enabling regulations**
  Regulations can promote the reuse of resources and the reduction of waste. Existing standards should be amended to enable low-emissions solutions e.g. setting a maximum cement content in concrete. Quotas and standards for CO_2 intensity, reusability, recyclability, and repairability of products and materials can enable the scaling of secondary material and products, while having a positive impact on the

xxviii A recent study by CDP has shown that of the 596 countries ranked on their actions to cut emissions and set climate strategies, 7% received a top score (e.g. Paris, Cape Town, and San Francisco), with five cities already having 100% renewable energy targets (e.g. Paris, San Francisco, and Canberra). CDP 43 cities score an A grade in new cities climate change ranking (2019)

xxix "Joint European Support for Sustainable Investment in City Areas (JESSICA)" is an initiative of the European Commission developed in cooperation with the European Investment Bank and the Council of Europe Development Bank; European Investment Bank, The EIB in the circular economy (2018); European Commission, JESSICA: joint European support for sustainable investment in city areas; University College London, JESSICA urban development funds – impact funds: a concept for urban policy delivery (14th June 2011)

xxx Policy measures could increase the cost of carbon emissions by as much as USD 8 trillion cumulatively, by 2030. The future cost of carbon emissions increases the longer the policy delay and the less well-anticipated and coordinated the policy action is. Mercer, Climate change scenarios – implications for strategic asset allocation (2011)

durability of some products.[158] For example, as part of its upcoming circular economy law, France is working on a repairability index and looking to ban the destruction of unsold goods.[159]

Innovating, inspiring, and demonstrating the opportunities of a net-zero emissions circular economy.

- **Integrate circular economy into strategy**
  The circular economy's potential to generate value can be included in company strategy and governance. This could come in the form of mission statements, commitments, targets, and plans. With climate and circular economy strategies in place, tools and metrics will be required to measure progress. For example, companies can measure how circularity reduces GHG emissions, cut costs, enhances customer relationships, differentiates the company from the competition, and stimulates innovation. For example, outdoor sportswear company Houdini aims to have its products and supply chains 100% circular by 2030. Part of its strategy is to publish an annual *Planetary Boundaries assessment* report highlighting the impact of the company's operations and its progress towards an impact-positive status.[160]

- **Pilot, innovate, and invest**
  Through pilots, incubators, and demonstration projects, circular business solutions can be tested, and a better understanding can be gained of the benefits they generate for business, society, and the environment. For example, it is through years of testing a completely new design and process that Adidas made a breakthrough innovation with Futurecraft. Loop, the world's first 100% recyclable performance running shoe made from a single material that can be upcycled into a new shoe.[161] Corporates can also help drive circular innovation by using their investment funds or internal dedicated funds to support small innovative companies.[162]

- **Corporate communication and public awareness campaigns**
  Public buy-in from customers can be created through corporate communication and public awareness campaigns. The aim of such campaigns would be to establish trust in secondary products and materials and inform users about them, to help users accept and appreciate access-over-ownership models, and increase public awareness around the GHG emissions reduction potential that such circular economy opportunities bring. Effective campaign examples that aim to stimulate the reuse, recycling, and resource-efficient design of products include, among many others, Unilever's Get Plastic Wise,[163] Coca-Cola's World Without Waste,[164] and Patagonia's Don't Buy This Jacket.[165]

- **Stimulate collaboration**
  Tackling climate change is too complex to be approached with isolated efforts. When it comes to complex materials streams like plastics, textiles, or food, the whole value chain needs to cooperate and align around a common vision. High levels of commitment, and incentives and actions at pre-competitive level are needed from those with a stake in the way materials cycle in the economy. For example, the Jeans Redesign – created by the Ellen MacArthur Foundation's Make Fashion Circular initiative – brought together more than 40 denim experts from academia, brands, retailers, manufacturers, collectors, sorters, and NGOs, to co-develop guidelines for what 'good' looks like for jeans. The Jeans Redesign Guidelines set out minimum requirements on garment durability, material health, recyclability, and traceability. Based on the principles of the circular economy, the guidelines will work to ensure jeans last longer, can easily be recycled, and are made in a way that is better for the environment and the health of garment workers.[166]

Supporting, funding, and scaling the opportunities of a net-zero emissions circular economy.

- **Mobilise capital towards circular economy investments**
  Investors can play an essential role in directing more assets and capital to businesses that are capturing higher values in circular supply chains (e.g. through product innovation, upscaling efforts, and developing markets for secondary materials and refurbished goods), thereby offering the opportunity to significantly reduce GHG emissions and generating greater resilience to climate change. Strategies that could increase the financeability of circular business models include: taking end-of-life value of products into account for a financial business case; determining the residual value of used products in second-hand markets; offering multiple forms of capital such as bank finance, venture capital, capital market financing and impact investing; cash-flow optimisation and shortening the pay-back period to manage the risk of circular business model contracts (e.g. by charging higher fees in the first years of pay-per-use models); and offering contract opportunities in place of hold over assets for service-based business models.[167] For example, the Intesa Sanpaolo Bank and the European Investment Bank (EIB) are cooperating together to provide a EUR 1 billion credit facility to support circular economy projects carried out by mid-cap companies and Italian SMEs.[168]

- **Recognise and assess the de-risking benefits of circular economy investments**
  Risk and pricing models assess the price volatility of materials, credit risk, asset valuation, and management of products and assets in circular business models.[169] Adjusting these risk and pricing models to take into account circular economy considerations can help investors to demonstrate that a circular economy is an effective strategy to reduce levels of climate risk and other systemic risk – including volatility driven by climate change – in their investment portfolios, and generate a portfolio of businesses that have implemented circular economy strategies. Moreover, circular business models may enhance Environmental, Social, and Governance (ESG) performance.[170]

- **Provide financial advice**
  Banks that gain expertise in valuing goods for reuse and refurbishment can support businesses seeking specialist investment advice on how to best mitigate risk or improve the financeability of their projects.[171] This will require engaging with SMEs to overcome the current knowledge gap on circular business models and risks. With circular business model expertise, investor support can be provided by reviewing circular projects, identifying weaknesses and improvement opportunities, and advising on financial incentives for circular business models.[172] Requirements can also be set for portfolio companies' and businesses' plans to incorporate sustainability and circularity. For businesses that are not currently bankable, the banks can provide advice on alternative sources of funding and support in challenging business models and technological risks.[173] For example, Circularity Capital offers equity funding to SMEs that innovate in the field of the circular economy and also provides services such as strategic support, specialist operational support, capability building, and business market development.[174] These are intended to help companies deliver on their circular economy strategic plans, and identify market trends, innovation and value realisation opportunities.

Teaching, researching, and demonstrating the opportunities of a net-zero emissions circular economy.

- **Teach for a circular economy**
  Embedding circular economy principles into teaching across all ages of learning supports a mindset shift that will enable future leaders and young professionals to gain circular economy insights, skills, and capabilities which they can take forward within their careers. This supports the skills and knowledge change required to move towards a low-carbon economy. For example, TU Delft in the Netherlands has developed a MOOC – 'Circular Economy for a Sustainable Built Environment' – which is accessible to both students and professionals, and the University of Exeter offers a number of learning opportunities through its Centre for Circular Economy, including the Grand Challenge to address climate change.

- **Stimulate research on the circular economy**
  As an engine for innovation, applied research can provide the critical insights and knowledge required to initiate industry and policy shifts. Stimulating academic research on circular economics, where many crucial topics remain unexplored or at an early stage of study, will be vital to developing understanding and knowledge to support industry to act differently and tackle climate change. The Rochester Institute of Technology has, in partnership with industry, established the REMADE Institute, which will enable early stage applied research and the development of technologies that could dramatically reduce the embodied energy and carbon emissions associated with industrial-scale materials production and processing. Through CircEL, University College London has an exciting cross-faculty, cross-discipline initiative, aiming to use the university's expertise to improve the design of buildings and products with a view to reusing, recycling, and returning materials back to the economy.

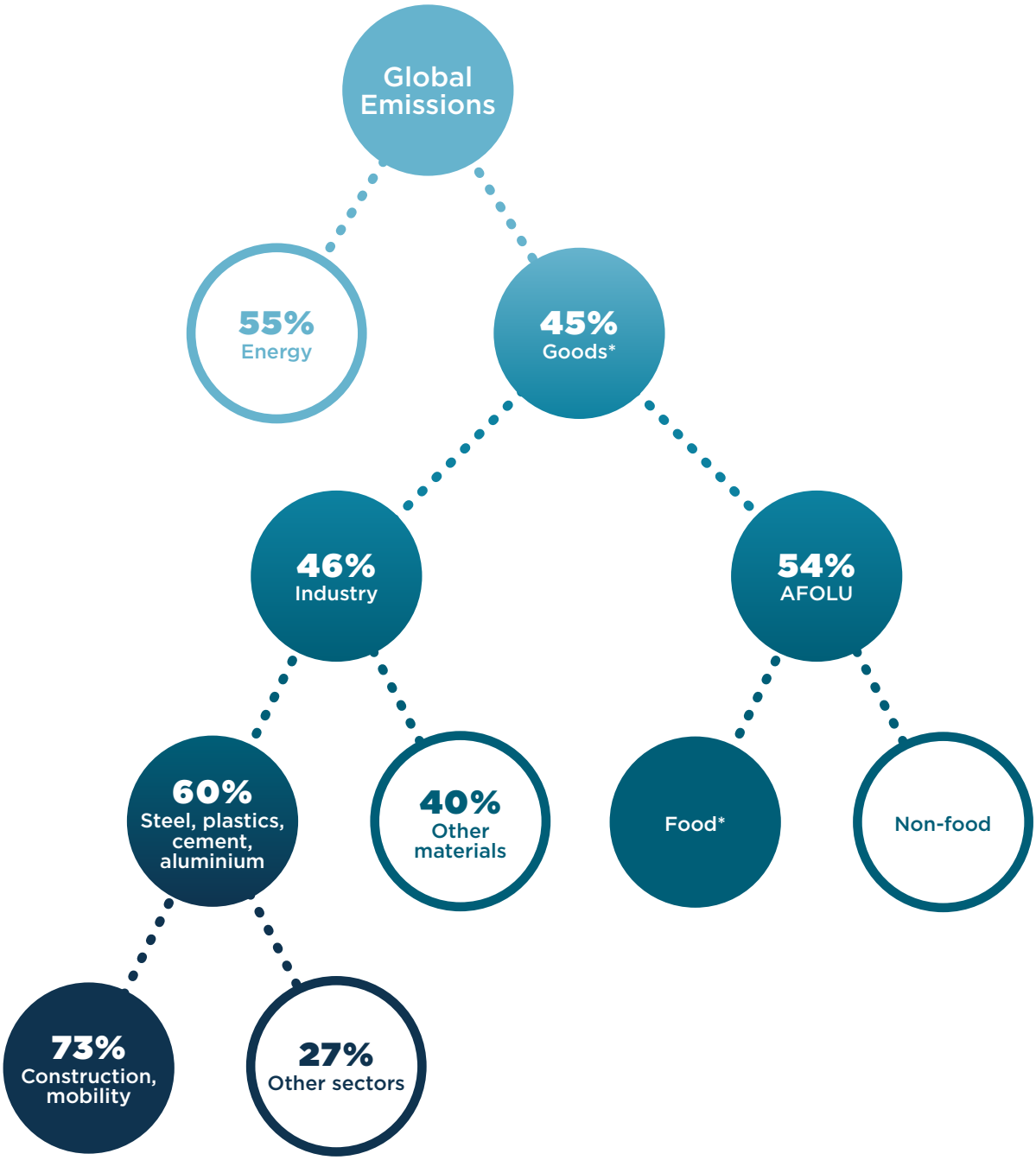
- **Lead innovation by students**
  Initiatives which drive circular solutions through students' commitment, application, and exploration of the topic can be the drivers for the transition to a circular economy. Georgia Tech University launched a Carbon Reduction Challenge to encourage students to spend a summer working with industry to develop new ideas and technologies to reduce the carbon footprint of the organisation they were working with.

- **Manage estates**
  University campuses are usually large estates which have great purchasing power and complex supply chains. These organisations can act as lighthouse demonstrators of circular economy practices across their estate operations and as local leaders. Many universities have ambitious plans for more sustainable campuses and have emissions reduction targets. For example, Bradford University aims to reduce carbon emissions by 50% by 2020 and in 2018 had already made a 30% reduction; itis ranked 14th in the UI GreenMetric World University Rankings.

- **Lead and influence local change**
  Universities often have significant local influence and act as leaders and agents for change. Working in conjunction with their municipalities (or regional/national funders), universities can provide the driving force for a collective movement to a circular economy, addressing a number of climate challenges en route. For example, Arizona State University collaborates with local partners in the Greater Phoenix area and with the City of Phoenix to research, develop, and implement circular economy solutions that benefit regional communities and improve the environment.[175]

Appendix

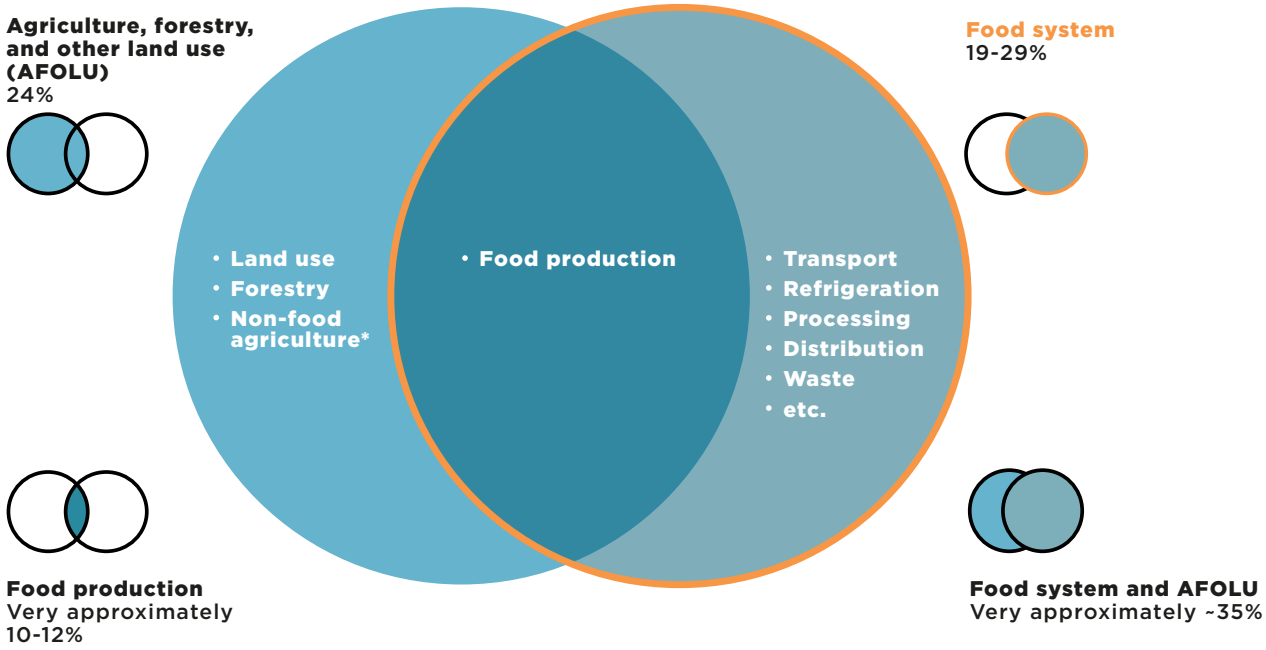
FIGURE 10: AN ILLUSTRATION OF THE SCOPE OF THIS PAPER
White circles show areas not covered by the paper



*The focus of this paper is on the "food system" which includes: food production, food logistics (processing, distribution, storage), and direct food waste emissions. Figure 11 shows the relationship between emissions from the food system and those from the AFOLU sector.

FIGURE 11: FOOD SYSTEM SCOPE OF THIS PAPER

% of global emissions, 2010



Global food system emissions are interlinked with those generated by the AFOLU sector, the overlap being defined as food production. Emissions from the 'food system' are defined in this paper as comprising: food production, food logistics (processing, distribution, storage) and direct food waste emissions.
*Non-food agriculture includes e.g. cotton.

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