

COMPLETING THE PICTURE

How the circular economy
tackles climate change



About this paper

This is a republication of a paper first published in 2019 with the same name, which can be found [here](#). It is reprinted now to make the case at COP26 that the circular economy is a crucial element of the global response to climate change. This argument has as much relevance now as then, and its urgency has only increased in light of the publication of the IPCC's Sixth Assessment Report in August 2021. For this reason we have not felt it necessary to update the analysis or the facts and figures that gave it context at the time of first publication: its conclusions remain valid. We have however changed some of the language used to define the circular economy and its principles, incorporated and defined the term 'regenerative production', made other minor edits to the text, and redesigned the publication.

As in its original incarnation, *Completing the picture* highlights the indispensable role that the circular economy plays in tackling the climate crisis. It aims to demonstrate how applying circular economy principles significantly reduces greenhouse gas emissions. Its analysis on industry and the food system illustrates 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 report *Cities and circular economy for food (2019)*. Its initial findings indicate 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.

Completing the picture can be seen as a sister paper to the recently published *The Nature Imperative: How the circular economy tackles biodiversity loss (2021)*, which sets out the fundamental contribution the circular economy can make to halting and reversing biodiversity loss. It details the role of each circular economy principle and their applicability across sectors by providing deep dives in food, built environment, fashion, and plastics.

To further explore the potential for a circular economy to bring both climate and biodiversity benefits to the food system, the Foundation's recent report, *The big food redesign – regenerating nature with the circular economy (2021)*, explores the opportunity food brands and retailers have to employ circular design approaches to move towards a food system that is nature-positive, reduces greenhouse gas emissions, and benefits farmers, consumers, and business.

Foreword by Ellen MacArthur

As the global economy is gradually getting back on track, we're entering another round of climate negotiations with current emissions pledges still falling short of the objectives laid out in the Paris Agreement. The scope of the discussion has nevertheless evolved, and the message that we sent by releasing the initial version of "Completing the Picture" in 2019 has gained significant momentum: if we want to fix the climate, we have to transform the economy - and not only the way it's powered.

The energy transition naturally remains a central pillar of the pathway to a low-carbon system, yet the material side of the equation is today better understood, as demonstrated by the growing number of governments pledging to accelerate the transition to a circular economy as a tool to combat climate change. UNFCCC figures indeed show that 25% of countries that communicated new or updated Nationally Determined Contributions by July 2021 included the promotion of circular economy measures. This is progress, but a lot remains to be done in order to highlight economic opportunities and to move the solutions space upstream, beyond traditional (yet necessary) material efficiency strategies.

If we are to address the 45% of emissions that arise from the way we make and use products and food, as this paper shows, a systemic approach to redefining value creation has to be adopted. One that relies on the three fundamental principles of eliminating waste, circulating materials and products, and regenerating nature. Translating these into concrete action could start now, and yield significant results while paving the way for innovation. For instance:

Eliminating waste in the food industry alone would reduce annual emissions by 1.4 billion tonnes by 2050ⁱ - that's more than the entire airline industry pre-pandemic

Circulating steel while avoiding its contamination, and getting more value from the steel we use, would avoid 500 Mt of additional primary steel production by 2050. This corresponds to more than 1 billion tonnes of CO₂e emissions per yearⁱⁱ

Regenerating nature through ecosystems-focused agricultural practices not only reduces GHG emissions but also sequesters carbon in soils and plant matter: switching to regenerative food production globally would reduce emissions by 3.9 billion tonnes of CO₂e equivalent per year by 2050ⁱⁱⁱ



As a nature-positive solutions framework, the circular economy brings answers to the interconnected biodiversity and climate emergencies: leading companies are starting to harness the opportunities it offers, and scaling up circular innovations is now a priority. Mobilising finance and raising the ambition level of national commitments are essential steps on the journey, and this report highlights the contribution that a circular regenerative system can make to opening a new era of prosperity, COP25 saw the circular economy topic rise in prominence in the multilateral process, and over the two years that have since passed, the understanding of its relevance to climate has steadily increased. "Completing the Picture" helps us visualise and quantify the opportunities, and provides business leaders as well as policymakers with a shared perspective on how to approach the material side of the economy, to achieve a low-carbon regenerative model of growth.

i Completing the picture

ii Material Economics, *The circular economy - a powerful force for climate mitigation* (2018)

iii Completing the picture

In support of the original 2019 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

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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 net-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 CO₂e 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 production 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 production 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 do it alone. International institutions can put the circular economy squarely on the climate agenda and give it the prominence afforded other important emission 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.

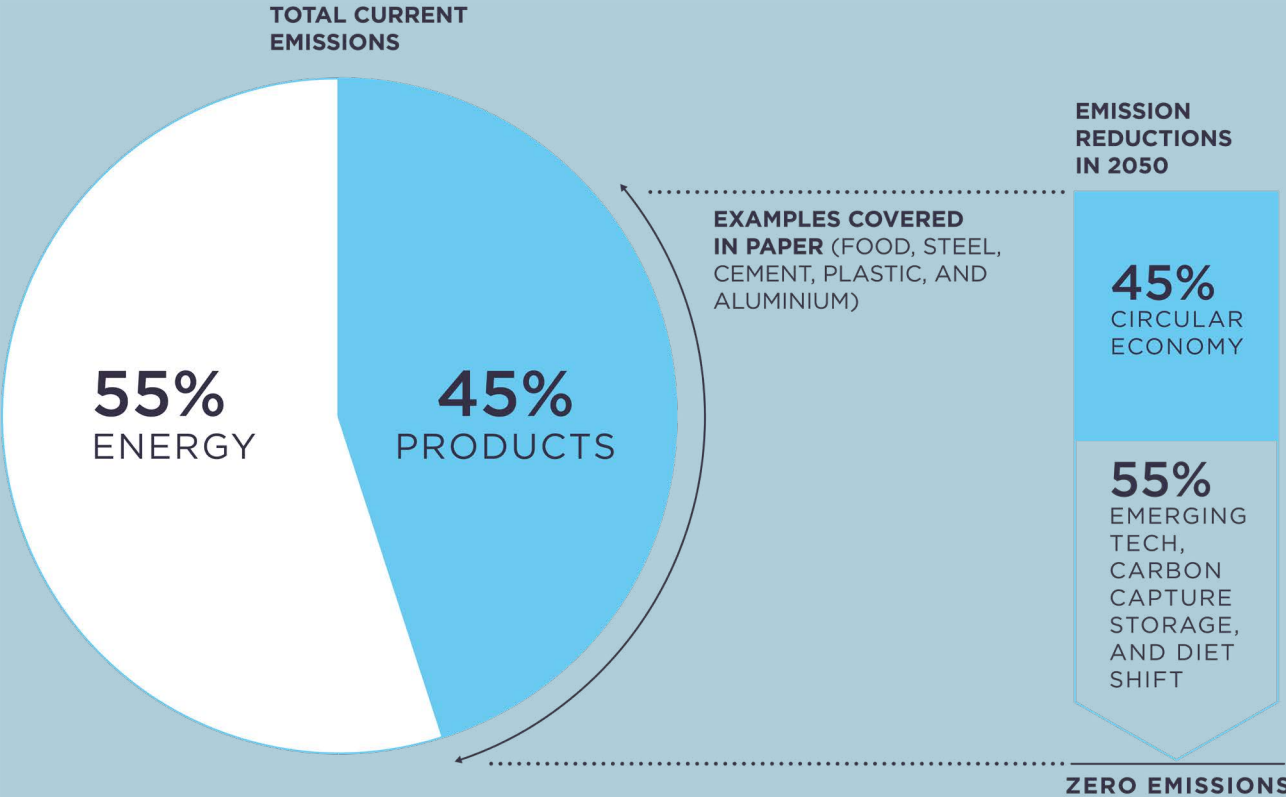
A complete picture of a thriving, net-zero-emissions economy is coming into focus: the mission now is to make it a reality.



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 energy sources 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.



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 CO₂e 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^{iv} 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^v 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

iv About 80% of CO₂e 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)
v The carbon budget is the quantity of GHGs the world can emit while limiting warming to internationally agreed temperature goals.

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 CO₂e 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

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 CO₂e emissions by 2050.⁹ The cost of generating electricity from wind, solar, and of storing electricity from intermittent source are now lower than fossil fuel alternatives in more than two-thirds of the world, with renewable sources projected to supply more than 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

zero-carbon energy systems that are able to convert surplus energy from renewables (into 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,^{vi} 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 (see Figure 1).^{vii,14} A similar finding has been made in a report published by the International Resource Panel (IRP).^{viii,15} Two sectors: industry; and Agriculture, Forestry, and Other Land Use (AFOLU) each contribute around a quarter of global GHG emissions.¹⁶

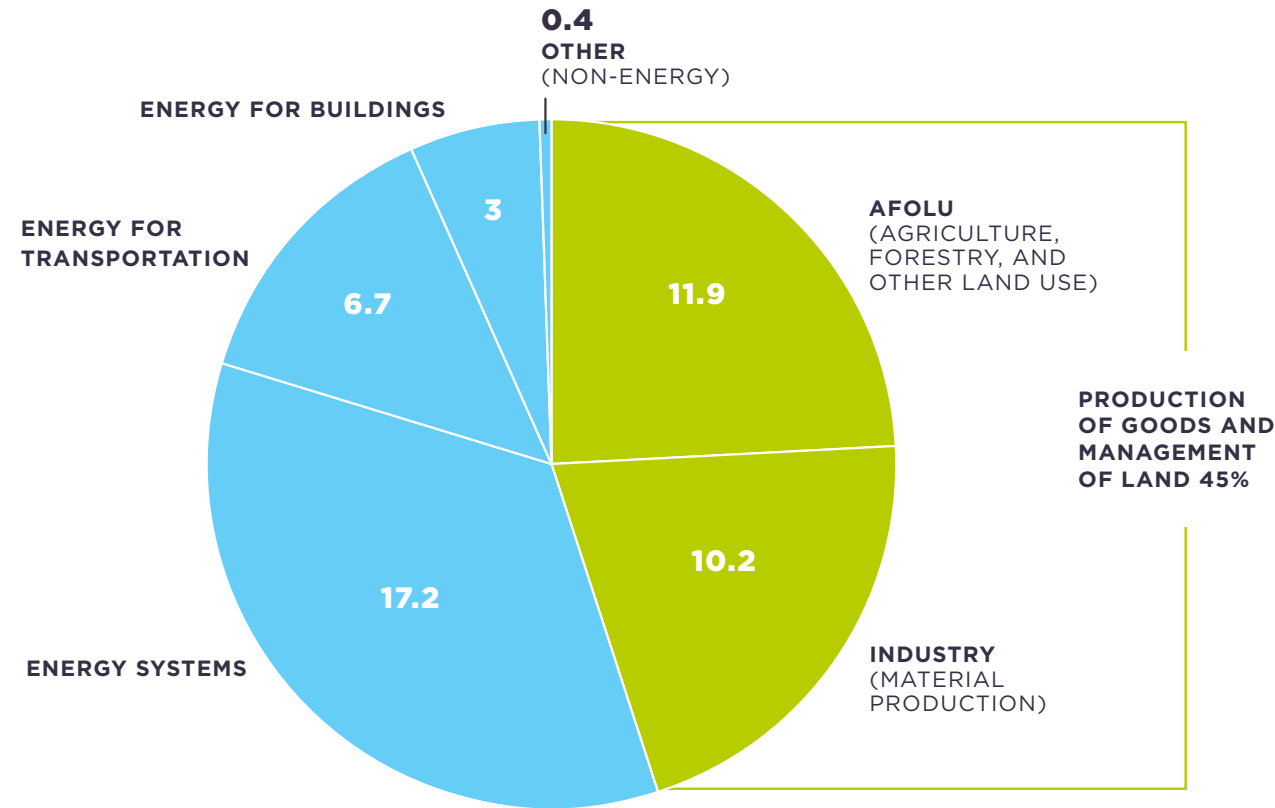
vi Energy systems refers to the production of electricity and heat as well as fuel extraction, refining, processing, and transportation.

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

viii 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)

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

GLOBAL GHG EMISSIONS
BILLION TONNES OF CO₂e PER YEAR, 2010



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

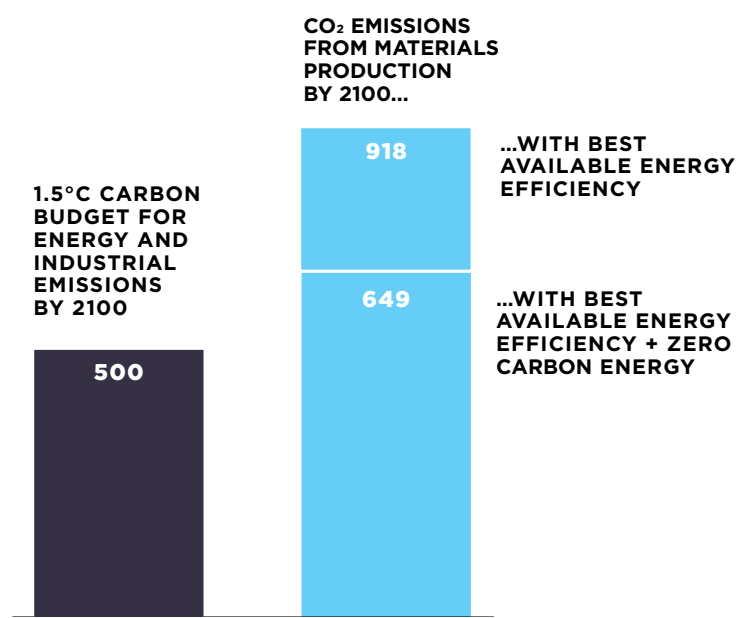
Failing to make such a transformation will make climate targets unachievable. By 2050, the global demand for industrial materials such as steel, cement, aluminium, and plastics is projected to increase by a factor of two to four, while global food demand is projected to increase by 42%.^{ix} This increase 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 CO₂e 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.^x

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

^x This is based on a projected increase in food production of 42% between 2013 and 2050 and takes into account projected improvements to agricultural productivity. Ellen MacArthur Foundation, *Cities and circular economy for food: technical appendix* (2019)

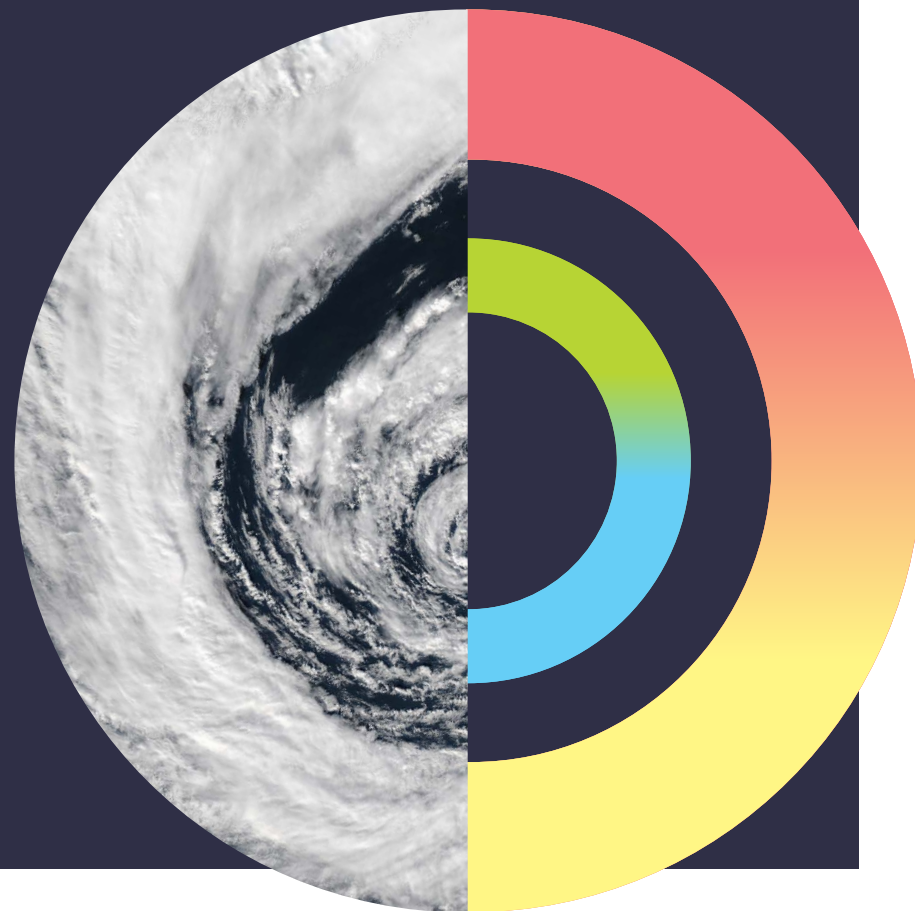
FIGURE 2: MATERIALS PRODUCTION WILL RESULT IN 649 BILLION TONNES OF CO₂e EMISSIONS BY 2100 EVEN UNDER A SCENARIO THAT INCLUDES RENEWABLE ENERGY AND ENERGY EFFICIENCY



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.

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 the soil.

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.^{xi}

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

^{xi} These data come from modelling by the Ellen MacArthur Foundation in reports on circular economy opportunities in Europe, India, and China. These models not only cover circular economy opportunities that reduce material demand, but also those that reduce energy demand and stimulate the use of renewable energy sources. 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)

What is the circular economy

The circular economy is a framework for systems solutions and transformation that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It has three principles, all driven by design:



Eliminate waste and pollution



Circulate products and materials



Regenerate nature

Based increasingly on renewable energy and materials, and accelerated by digital innovation, it is a more resilient economic model that is distributed, diverse, and inclusive. The circular economy is a systems change agenda that presents opportunities to create better growth. Going well beyond addressing the symptoms of today's wasteful and polluting economy, the circular economy represents an opportunity to create value in ways that benefit society, business, and the environment, thereby offering the potential to substantially contribute to the delivery of the Sustainable Development Goals.

These solutions, which can scale-up quickly and are applicable anywhere in the world, reduce the likelihood of future shocks and create greater resilience. The circular economy is underpinned by design, spurring innovation that harnesses digital technologies across a range of opportunities.

ELIMINATE • CIRCULATE • REGENERATE

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:



Eliminate waste and pollution to reduce GHG emissions across the value chain



Circulate products and materials to retain their embodied energy



Regenerate nature 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/ ELIMINATE WASTE AND POLLUTION

The circular economy is a framework for preventing negative impacts of economic activity that lead to the loss of valuable resources and damage to human health and natural systems. GHG emissions is 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 avoiding negative impacts by 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 conserve their embodied energy.

In the case of plastic packaging, if refillable 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 single-use bottles.²⁰ However, many goods contain materials or ingredients that make them, or their by-products, unsafe to reuse as inputs for new cycles. These need to be designed out.

To allow for the increased utilisation and circulation of products, components, and materials 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 requires 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.^{xii} Currently, in construction projects, around 35–45% more steel is used than is strictly necessary.²¹ 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.²² 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. In other words, 24% of food calories produced for human consumption are lost or wasted across the value chain.²³ Making use of measures such as process optimisation, and emerging technologies such as 3D printing can reduce waste generation during production and thereby reducing 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 reducing 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 CO₂e per kg of bio-based polyethylene (PE) produced, compared to 1.8 kg CO₂e per kg of fossil-based PE produced.²⁴

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 regenerated.²⁵ Furthermore, using non-sustainably harvested wood products is more environmentally detrimental than the benefits of using low-carbon materials in buildings.²⁶ 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.²⁷ 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.²⁸

Apart from renewable materials, other low-carbon substitution options can be considered such as 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 CO₂e footprint.²⁹ It is in principle possible to substitute up to 50% of the clinker (binder) needed to make cement with advanced filler materials that emit less CO₂e during production and provide the same performance.³⁰ When it comes to food, selecting ingredients produced regeneratively sequesters carbon in the soil.

2/ CIRCULATE PRODUCTS AND MATERIALS

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

xii 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 not have been necessary. Moynihan, M. J., and Allwood, M., *Utilization of structural steel in buildings in Proceedings: mathematical, physical, and engineering sciences* (2015)

REUSING PRODUCTS AND COMPONENTS

Reuse measures conserve the embodied energy and other valuable resources used to manufacture products and components. The more a product is utilised, the larger the return on the resources embodied in the product such as materials, labour, energy, and capital. By keeping products in use, the GHG emissions associated with new production and end-of-life treatment are reduced while providing the same benefit. As an example, a Splosh shampoo container that can be reused more than 20 times lowers the energy – and the associated GHG emissions – required to produce it by more than 95%.³¹ For garments, doubling the amount of time items are worn has the potential of avoiding 44% of GHG emissions by not letting them go to waste.³² In the case of Renault's Choisy-le-Roi facility for the remanufacturing of spare parts for vehicles, energy savings – totalling as much as 80% – are the result of avoided new production and end-of-life treatment (e.g. incineration).³³

RECIRCULATING MATERIALS

Recirculation refers to the recycling of materials. GHG emissions are reduced from avoiding new virgin material production and end-of-life treatment, such as incineration and landfill. While measures that increase product utilisation contribute the most to retaining the energy embodied in products, recycling still requires much less energy than the production of virgin materials. Steel recycling for example uses 10–15% of the energy required to produce primary steel.³⁴ For plastics, recycling 1 tonne could reduce emissions

by 1.1–3.0 tonnes of CO₂e compared to producing the same tonne of plastics from virgin fossil feedstock.³⁵ Recycling therefore cuts emissions from industrial production processes, which are among the trickiest emissions to address since they rely, for example, on high temperature heat, which cannot be supplied at scale using currently available renewable energy technologies. By contrast, the recycling processes themselves do not suffer from such constraints.

In the food system, recirculating materials means valorising organic materials such as food by-products. The effectiveness of the collection system and the purity of waste streams are strong determinants of the type of new product that can be produced. Purer streams can be transformed into new structural materials, textiles, or new food products. More mixed 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 used to produce the material in the first place. When the renewable materials are composted or returned to the soil in another form they contribute to the regeneration of natural systems.

3/ REGENERATE NATURE

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 PRODUCTION

Regenerative production is an approach to managing agroecosystems that provides food and materials – be it through agriculture, aquaculture, or forestry – in ways that create positive outcomes for nature. These outcomes include, but are not limited to, healthy and stable soils, improved local biodiversity, improved air and water quality, and higher levels of carbon sequestration. They can be achieved through a variety of context-dependent practices and can together help regenerate degraded ecosystems and build resilience on farms and in surrounding landscapes. Farmers and others may draw on several different schools of thought – such as regenerative agriculture, restorative aquaculture, agroecology, agroforestry, and conservation agriculture – to help them apply the most appropriate set of practices to drive regenerative outcomes in the agroecosystems they manage.

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 CO₂e emissions from cement, steel, plastic, and aluminium production by 40% or 3.7 billion tonnes in 2050, thereby achieving almost half of their net-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 global CO₂e emissions.³⁶ 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 accounts for 73% of the emissions from producing these four materials. The main sources of CO₂e involved in producing these materials include high-temperature heat processes and production emissions, and end-of-life emissions.³⁷ These have long been considered hard to abate. High-temperature heat requirements for core processes of melting and forming steel, steam cracking, and clinker production cannot yet be achieved at scale using renewable energy sources. Although electricity

is already used for some processes, such as 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 to current production processes, either as a building block of the material (plastics) or in the process chemistry of their production (cement, steel, and 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 them.

The circular economy offers an opportunity to tackle hard-to-abate emissions and accelerate the transition towards a net-zero carbon economy.

Circular economy approaches shift emissions away from hard-to-abate, costly industrial processes involved in primary materials production towards activities that are much easier to decarbonise such as remanufacturing and recycling, which can often be powered by renewable electricity. Designing products with alternative feedstock materials that are either low-carbon or renewable ensures that substantial emissions are avoided from the outset.

Opportunities to decarbonise industry in the U.S.

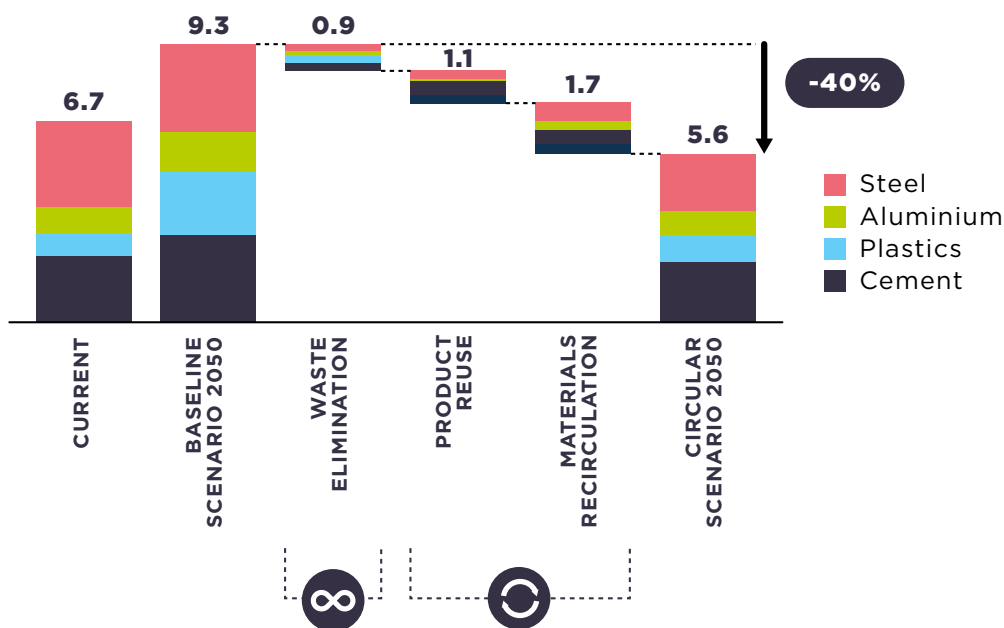
U.S. manufacturing accounts for 25% of the nation's energy consumption at a cost of \$150 billion and for 22% of U.S. greenhouse gas emissions. The REMADE Institute, a public-private partnership established by the U.S. Department of Energy, has estimated that circular economy approaches can achieve a 17% reduction in U.S. manufacturing emissions. These approaches - such as reusing products, remanufacturing components, and recycling materials - work by cutting the amount of virgin materials needed to make products and thereby reducing the amount of energy invested in them. Of the 25 QBTUs of energy consumed by U.S. manufacturing in 2020, REMADE's work in metals, plastics, fibres, and e-waste addresses approximately 7 QBTUs. The circular economy opportunity in these sectors is up to 4.2 QBTUs. Technologies developed by REMADE during its first five years are capable of reducing energy consumption by 1 QBTU and the consumption of virgin materials by millions of tonnes.

Source: Interview with Nabil Nasr, CEO of REMADE institute (1 October, 2021) and the *REMADE 2020 Impact Report*.

Circular economy strategies for reducing emissions in industry

FIGURE 4: A CIRCULAR ECONOMY COULD REDUCE ANNUAL GLOBAL CO₂e EMISSIONS FROM KEY INDUSTRY MATERIALS BY 40% OR 3.7 BILLION TONNES IN 2050

GLOBAL CO₂e EMISSIONS FROM FOUR KEY MATERIALS PRODUCTION
BILLION TONNES OF CO₂e 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).

A circular economy approach could reduce global CO₂e 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, and making productive and efficient use of resources. Both are underpinned by two core circular economy principles:



ELIMINATE WASTE

- Eliminating waste (0.9 billion tonnes CO₂e per year):** Eliminating waste across value chains and in the design of products offers opportunities for avoiding GHG emissions using measures such as material-efficient designs for buildings, industrialised construction processes, and lightweighting 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 CO₂e emissions by 0.9 billion tonnes CO₂ in 2050. For a deep dive on how these circular economy opportunities manifest themselves in the built environment and mobility (passenger cars), see the deep dives at the end of this chapter.



CIRCULATE PRODUCTS AND MATERIALS

- **Reusing products and components (1.1 billion tonnes CO₂e 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 their lifetime through activities such as reuse, refurbishment, and remanufacturing. Keeping products and components in use at their highest value at all times means their embodied energy is preserved for longer, and the need for new production and end-of-life treatment – and the GHG emissions they entail – is reduced.

Modelling this opportunity shows that global emissions could be reduced by 1.1 billion tonnes CO₂e in 2050 by reducing the need for new cement, steel, plastics, and aluminium.

For a deep dive on how these circular economy opportunities manifest themselves in the built environment and mobility (passenger cars), see the deep dives at the end of this chapter.

- **Recirculating material (1.7 billion tonnes CO₂e per year):**^{xiii} The circular economy scenario modelled explores opportunities for new business models that stimulate collection, sorting, and recycling. The scenario envisages an increase in recycling

rates and the quality of both inputs and outputs. It also forecasts an increase in demand for recycled materials giving rise to 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 this 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 degrade 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 to achieve 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 use this in place of new cement. Other alternatives include the use of fly ash, blast furnace slag, and calcined clays.³⁸ For aluminium, less leakage and mixing of different alloys will be crucial. The models for embracing circular economy opportunities of this kind show that global CO₂e emissions could be reduced by 1.7 billion tonnes CO₂e in 2050. This would require secondary production to increase to 48% of total production for steel, 48% for aluminium, and 18% for cement,^{xiv} as well as a mechanical and chemical recycling rates reaching 28% and 21% respectively for plastics.

^{xiii} The 1.7 billion tonnes CO₂/yr also includes the impact of substituting a share of plastics with alternative low CO₂e materials such as bio-based packaging.

^{xiv} Cement is not as easy to recycle, although it is possible to reuse some unreacted cement.

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.³⁹

Innovative industrial processes will be crucial. For example, new low-emission 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 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 storage/use (CCS/U) can play a role in capturing the remaining CO₂e emitted from production, feedstock production, or end-of-life emissions. The captured

carbon can be stored underground permanently or reintroduced as a feedstock in the production of, for example, chemicals for the making of new materials. In a net-zero economy, there would need to be certainty that CCS/U efforts would not later lead to the release of CO₂e emissions and key challenges would have to be overcome, including: obtaining social acceptance, reducing costs, providing suitable transport and storage infrastructure, and achieving the necessary scale.

By reducing the amount of new materials required, i.e. tackling the demand-side, a circular economy makes a substantial move to reduce the size of the costly supply-side challenge of producing zero-carbon steel, aluminium, and plastics and other materials. It therefore plays a similar role to energy efficiency in the renewable energy transition.

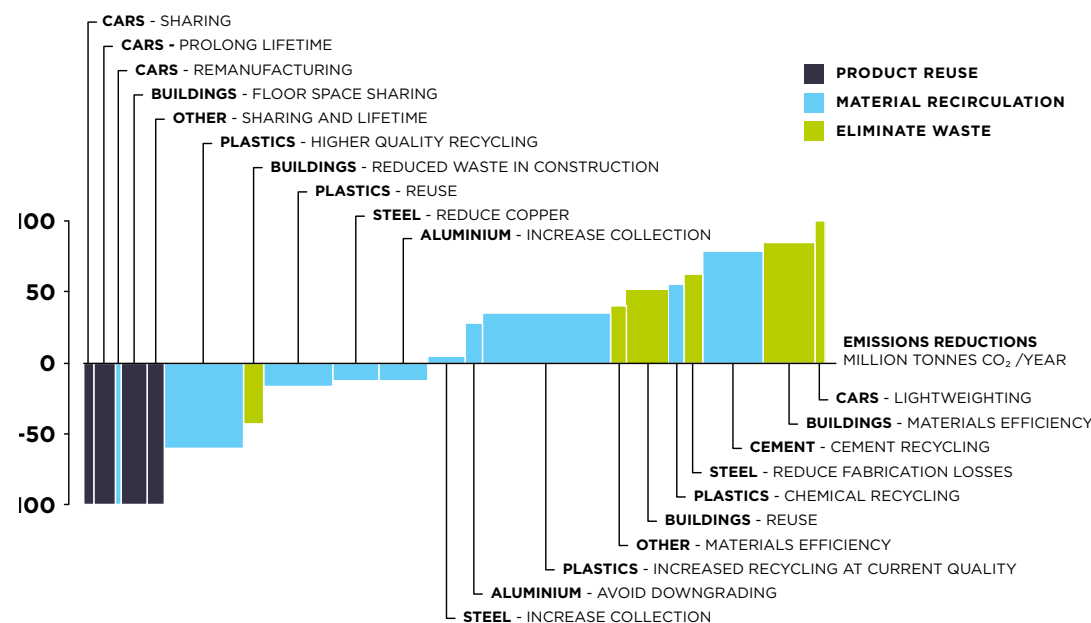
The circular economy approach is cost effective

A circular economy offers cost-effective ways of achieving deep emission cuts. In a circular economy 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.⁴⁰ 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. Like energy efficiency, circular economy solutions are often more cost-effective than emerging emission reduction technologies that are still expensive and untested at scale.

Figure 5 shows a CO₂e abatement cost curve of a number of circular economy opportunities. Some, like sharing business models, durable designs, and high-quality recycling can be cost negative and others fall below USD 50 / t CO₂e. By comparison, many measures required for zero-carbon materials production cost more than USD 100 / t CO₂e.

FIGURE 5: EMISSIONS REDUCTION POTENTIAL FROM CIRCULAR ECONOMY BUSINESS MODELS^{xv}

COST OF EMISSIONS REDUCTIONS EUR / TONNE CO₂e



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

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

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 value chains. For example, a shared and circular mobility system could reduce the cost of travel by as much as 70%.⁴¹ While shared vehicles that are designed to be optimised for intensive use and have long lifetimes may need higher upfront investments, that cost would be spread over a much greater number of kilometres, resulting in much lower costs in the long term due to much more productive use of the materials involved.

When it comes to material efficiency measures, using less material could require alternative feedstock, which may demand higher investment costs. Higher investment costs may for example arise from increased labour inputs, increased inventory, and logistics costs. 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.⁴² 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.

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.

The approach offers system-wide benefits

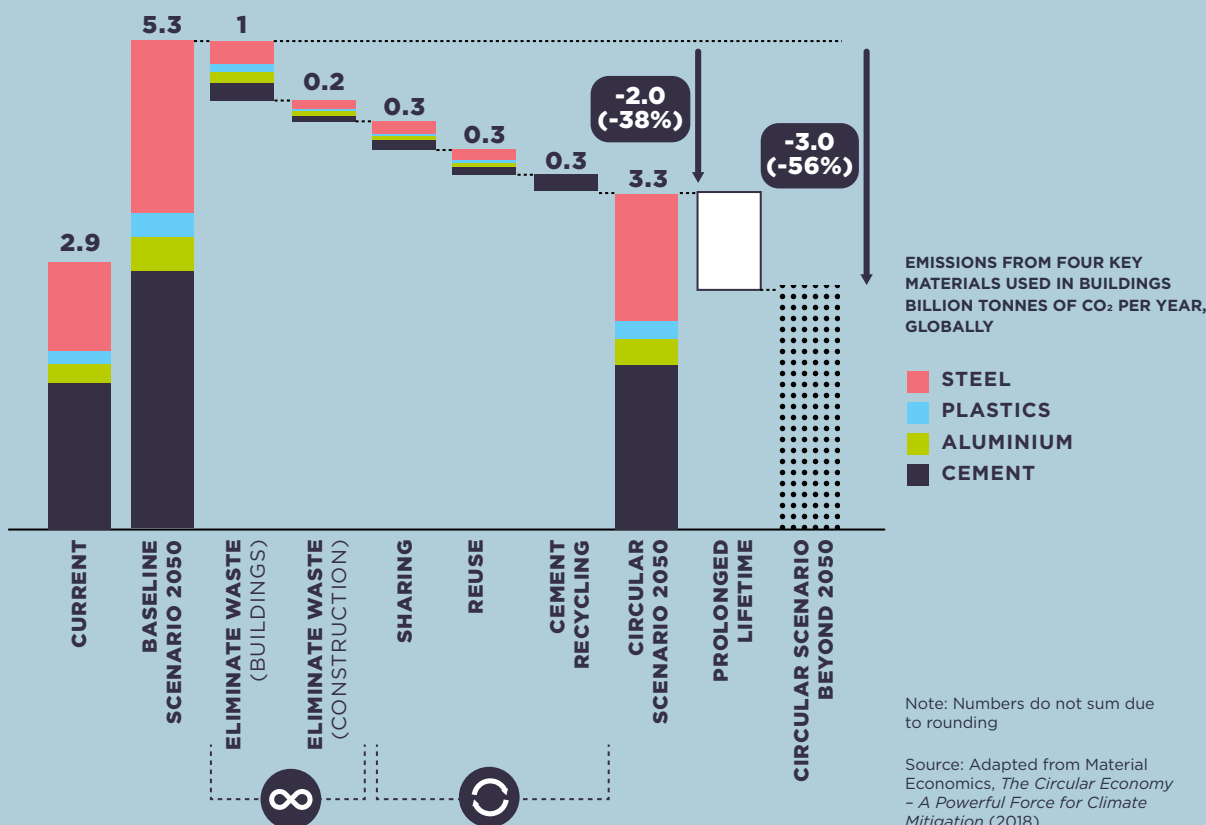
Additional benefits to society are also gained from implementing a circular economy. Beyond significantly reducing GHG emissions, circular economy strategies also present economic opportunities and a wide array of benefits to society and the environment. For people, a circular economy could lower the 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 technologies to address structural waste in supply chains. 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, shared multi-modal systems can reduce travel time and congestion. A sharing economy enabled by digitalisation 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 and 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 other SDGs and can help mitigate trade-offs between them.⁴³ 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, deep-dives on the built environment and mobility illustrate in more detail how 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 CO₂e EMISSIONS BY 38% IN 2050 (OR 56% BEYOND 2050)



The built environment uses almost half the materials extracted globally every year and current projections estimate that by 2060 across the world the equivalent of the city of Paris will be built each week.⁴⁴ 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 2050.⁴⁵ Moreover, a de-densification trend of 2% per year threatens to increase global urban land use in 2050, putting agricultural land and food supplies at risk.⁴⁶ With such trends, by 2050, CO₂e emissions from construction will be responsible for almost half of total new building emissions, compared to 28% today.⁴⁷ 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 climate targets.

A circular scenario for the built environment could reduce global CO₂e emissions from building materials by 38% or 2.0 billion tonnes CO₂e in 2050, due to reduced demand for new 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 shown in Figure 6 contribute to a significant reduction in GHG emissions is described below.^{xvi}



ELIMINATE WASTE

- **Eliminating waste from building designs (1.0 billion tonnes CO₂e per year):** Construction projects often use more materials than needed. For example, it is possible to achieve the same structural strength using only 50–60% of the amount of cement currently used.⁴⁸ 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, using high-strength steel and employing techniques such as post-tensioning could reduce the quantity of steel needed by 30%.⁴⁹
- **Eliminating waste in construction (0.2 billion tonnes CO₂e per year):** Up to 40% of urban solid waste is construction and demolition waste (CDW) and 54% of CDW in Europe is landfilled.⁵⁰ Industrial construction processes such as prefabricated

building elements, off- site construction, and 3D printing have the potential to reduce material demand and waste generation, while offering up to 60% in material cost savings.⁵¹ For example, moving modular construction activities offsite into a controlled environment allows manufacturers to achieve high quality standards and high productivity, while reducing on-site waste generation by up to 90% compared to traditional construction techniques.⁵²



CIRCULATE PRODUCTS AND MATERIALS

- **Sharing business models (0.3 billion tonnes CO₂e 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.⁵³ 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, repurposing buildings, and using them for multi-purposes could by 2036 increase the value of new buildings, double the current 20% building utilisation rate, and save over GBP 600 million a year.⁵⁴

- **Prolonging lifetime (1.0 billion tonnes CO₂e 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 not economically valuable.⁵⁵ 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 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.⁵⁶
- **Reusing building materials (0.3 billion tonnes CO₂e 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.⁵⁷ Designing materials for reuse ensures that they can be reintroduced at their highest value, reducing 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.⁵⁸

xvi The list provides a selection of circular economy solutions that reduce material demand. Those solutions that directly reduce energy demand, such as improving the energy efficiency of buildings, have not been presented as they fall outside the scope of this paper.

- Recycling materials (0.3 billion tonnes CO₂e 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 after use. The use of recycled materials reduces the demand for virgin materials and the processing of recycled aggregates generates 40–70% fewer CO₂e emissions than virgin aggregates.⁵⁹ Designing recyclable materials, increasing recycling volumes, and improving the quality of secondary materials would be essential for such a scenario to be successful. While recycling is already well-established for steel, improvements are needed for 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.

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 circular economy opportunities due to their high concentration of people, resources, capital, data, and talent. 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, organic materials, industrial by-products, building elements, and household recyclables.⁶⁰ This can be enabled by designing compact cities with mixed-use developments,^{xvii} which can reduce urban sprawl. In Europe, for example, such efforts could make more productive use of assets, saving up to 30,000 km² of land by 2050, compared to the current development scenario.⁶¹ Since carbon emissions are closely connected to urban density and structure, compact cities can reduce GHG emissions - by a factor of two or more - by minimising the new construction of roads, sewers, water lines, and other infrastructure.⁶² 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 CO₂e emissions 10 times lower than Atlanta's.⁶³

Moreover, circular economy measures can reduce pollution levels and make cities both healthier and more liveable. Circular economy strategies for cities have the potential to reduce the societal costs of harmful emissions from particulate matter (PM_{2.5} and PM₁₀) by 61%⁶⁴ and reduce household costs by around 15–50% in 2050,⁶⁵ when compared to the current development path.^{xviii}

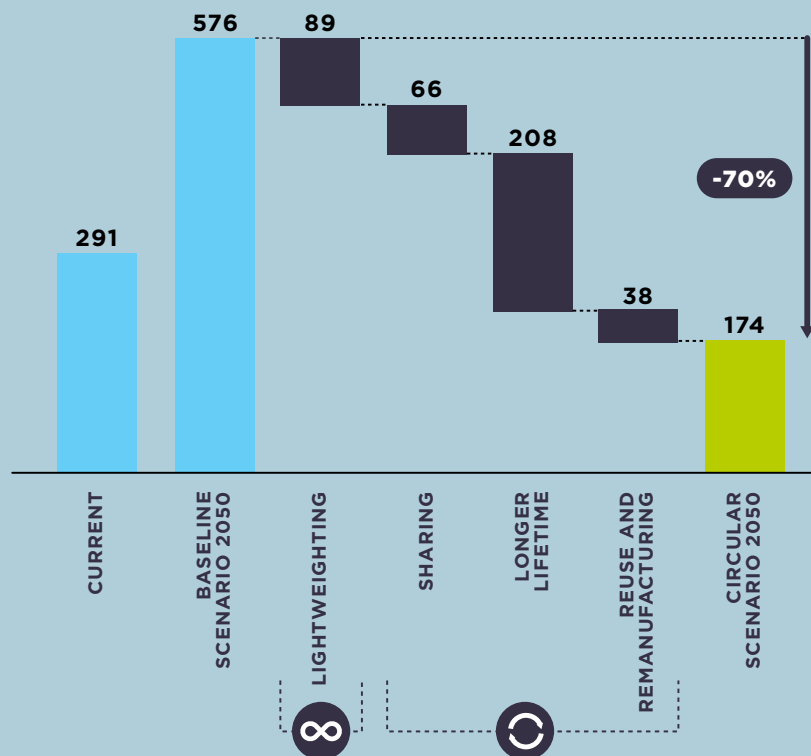
xvii Mixed-use developments refer to the co-location of commercial, residential, and recreational space

xviii These data come from modelling by the Ellen MacArthur Foundation in reports on circular economy opportunities in Europe, India, and China. These models not only cover circular economy opportunities that reduce material demand, but also those that reduce energy demand in the use phase of buildings, such as improving energy efficiency.

Deep dive: the opportunity for mobility

FIGURE 7: A CIRCULAR SCENARIO FOR PASSENGER CARS COULD REDUCE CO₂e

EMISSIONS FROM ALL MATERIALS USED IN PASSENGER CARS
MILLION TONNES OF CO₂e PER YEAR, GLOBALLY



Note: Numbers do not sum due to rounding

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

Road travel accounts for 75% of global emissions from the transport sector and by 2050 the number of cars in the world is set to more than double.⁶⁶

These emissions are currently dominated by the use phase, i.e. the burning of petrol and diesel. However, over time, the increased penetration of hybrid, plug-in hybrid, and electric vehicles will reduce emissions from the use phase of vehicles, though emissions from the manufacture of cars will become the dominant source of life cycle emissions for new cars in only 5-10 years.⁶⁷ How we design, produce, and use electric – and other zero emission – vehicles will matter greatly if we are to meet climate targets.

A circular scenario for passenger cars could reduce global CO₂e emissions by 70% or 0.4 billion tonnes CO₂e in 2050. The modelled scenario depicts a shared multi-modal mobility system in which different modes of transport are on offer that are shared, electrified, autonomous, and interconnected. In such a scenario, passenger cars would increasingly be used 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 lower air pollution. In this system, cost per average passenger-km could drop by as much as 77% in 2050.⁶⁸

How the circular economy opportunities modelled in Figure 7 contribute to a significant reduction in GHG emissions is described below.^{xix}



ELIMINATE WASTE

- **Designing for lightweight vehicles (89 Mt CO₂e 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 reduce fuel consumption.⁶⁹ 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.^{70,xx} Not only does the lower material demand mean a reduction in GHG emissions, but the innovative material itself offers better aerodynamics and a much longer lifespan.



CIRCULATE PRODUCTS AND MATERIALS

- **Sharing business models (66 Mt CO₂e 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.⁷¹ Public and private sharing services can tackle this challenge by increasing the utilisation

of vehicles while also offering convenient access to other forms of transport. Heavy rail transit, such as subways and metros, emit around 76% fewer CO₂e emissions per passenger/km than an average single-occupancy vehicle.⁷² 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 CO₂ 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 service provider and not the individual. In such cases, designing vehicles that are modular and can be easily maintained and repaired helps retain their value. It allows for the direct replacement of broken or outdated components, enabling fleets to last up to 10 times longer.⁷³ 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 CO₂ 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 measures increase the value of the components as well as avoid the production of new ones, thereby saving raw materials and reducing GHG emissions. Other benefits include avoiding the depreciation and obsolescence of vehicles, facilitating maintenance, and supporting the localisation of production which can shorten the supply chain. Renault has applied such measures and managed to reuse 43% of its vehicle carcasses.⁷⁴ Michelin has shown that 85% of worn-out tyres can be reused, and an estimated 60 kg of CO₂ emissions avoided each time a tyre is retreaded.⁷⁵ When it comes to remanufactured automotive engines, on average 73–87% less CO₂ is emitted compared to the traditional manufacturing processes for new engines.⁷⁶

- **Recirculating materials:^{xxi}** 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.⁷⁷ However, recycling is becoming much more common. The European End-of-Life Vehicles Directive has already set a target of 95% recyclability per vehicle.⁷⁸ The challenge is that current recycling processes lead to significant degradation of material quality and therefore value. However, Renault has shown high levels of recyclability are possible by designing 85%

xix The list provides a selection of circular economy solutions that reduce 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.

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

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

of its models to be recyclable. Though this is the case, 48% of carcasses are in fact recycled for the production of new parts, while 43% are first put to better use by being reused.⁷⁹ 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, and ride-shares) and active mobility options (e.g. walking and cycling). The OECD has estimated that when integrating autonomous vehicles with mass-transit, nine out of ten cars in European cities could be, in theory, removed.

Such a shared multi-modal system in Europe 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.⁸⁰

Such a system 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. It would also lead to the freeing up of a significant amount of parking space.⁸¹ Modelling suggests that reducing vehicle ownership in C40 cities could lead to the release of 170 million m² of on-street parking back to the public realm, providing enough space for 2.5 million trees and 25,000 km of cycle lanes.⁸² A circular mobility system further has the potential to reduce congestion costs by 50–60%, and reduce the societal costs of harmful emissions (PM2.5 and nitrogen oxide) by 20–30% compared to the current development path.^{xxii,83}

xxii These data come from modelling by the Ellen MacArthur Foundation in reports on circular economy opportunities in Europe, India, and China. These models not only cover circular economy opportunities that reduce material demand, but also those that reduce energy demand in the use phase of vehicles, 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 CO₂e in 2050. This opportunity is driven by measures that design out waste and keep materials in use, coupled with the expansion of regenerative production.

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, and 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).⁸⁴ Calculating food system emissions is made even more complex because living organisms 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.^{xxiii}

Total food system emissions are expected to increase from 8.4 billion tonnes CO₂e to 11.4 billion tonnes CO₂e 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.⁸⁵ Excess tillage exposing soil organic matter to the air releases locked-in soil carbon to the atmosphere. Overuse of fertilisers releases nitrous oxide, a GHG with a high global warming potential, as well as emissions associated with the production of agricultural input chemicals such as ammonia.^{xxiv}

EXPLORE MORE

To further explore the potential for a circular economy to bring both climate and biodiversity benefits to the food system, the Foundation's recent report, *The big food redesign - regenerating nature with the circular economy* (2021), explores the opportunity food brands and retailers have to employ circular design approaches to move towards a food system that is nature-positive, reduces GHG emissions, and benefits farmers, consumers, and business. Its analysis of example ingredients - wheat, dairy, and potatoes - in the EU and UK shows that circular design for food in concert with regenerative production can reduce farm-level greenhouse gas emissions by an average of 70% and the impact on farm-level biodiversity by an average of 50% in 2030 while achieving higher food production and increased incomes for farmers.

xxiii Other sources of food system emissions not modelled in this paper include: land use change; energy use in farming equipment and fertiliser production; wastewater treatment plants; and deforestation.

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

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 along the supply chain adds up to about 30% of overall production, making food waste a major contributor to food system emissions.⁸⁶

A circular economy could reduce emissions by sequestering carbon in the soil and minimising carbon emissions in the supply chain – by eliminating waste, circulating materials, and regenerating nature. Reducing food waste and valorising organic waste flows from our towns and cities offers business opportunities and helps 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 were 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 industrial emissions produced since the Industrial Revolution.⁸⁷ No other economic sector has this game-changing potential to soak up so much atmospheric carbon.

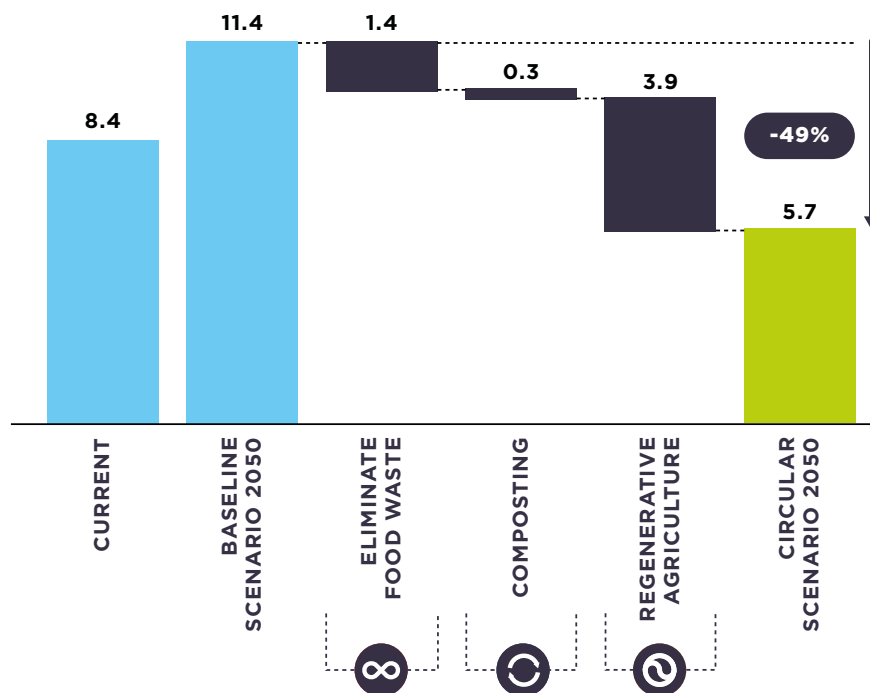


Circular economy strategies for reducing emissions in the food system

Circular economy strategies could reduce emissions by 5.6 billion tonnes CO₂e, corresponding to a 49% reduction in the projected 2050 total food system emissions. Achieving this means shifting to regenerative production 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 CO₂e EMISSIONS BY 49% IN 2050

EMISSIONS FROM THE GLOBAL FOOD SYSTEM
BILLION TONNES OF CO₂e PER YEAR



Note: Numbers do not sum due to rounding

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



ELIMINATE WASTE

Every second around the world approximately six garbage trucks' worth 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 during their production. One example is the use of more plant-based ingredients, which are generally associated with lower production emissions.⁸⁸

For this paper, the only emission benefits in this category that have been modelled are those that derive from reducing food waste.

- **Food waste reduction (1.4 billion tonnes CO₂e 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 demand for different food types, by discounting soon-to-expire products, and by using produce approaching its expiration date in in-store restaurants. Innovative companies can develop new business models: for example, MIWA provides an online service to its customers in the Czech Republic to buy precise amounts of food in reusable packaging, thereby helping 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 interventions, combined with taking 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/CO₂e.



CIRCULATE PRODUCTS AND MATERIALS

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,⁸⁹ with only 2% of this looped back to productive use.⁹⁰ 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 and DueDiLatte), structural material for packaging and furniture (e.g. Ecovative and RiceHouse), or innovative new food products (e.g. Canvas Drinks and 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 generation 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 and in developing countries, energy demand by WWTPs is set to increase by 20% in the next 15 years.⁹¹ A number of forward-thinking utilities have proved that WWTPs can be operated as net energy producers. For example, WWTPs in Aarhus and Odense in Denmark have both demonstrated they can generate twice as much energy as they consume by collecting the biogas released by the anaerobic digestion of sludge.⁹² Further carbon benefits are achieved as the nutrient-rich biosolids left over from this process can be spread over local farmers' fields.

This paper has modelled emission reductions associated with the looping of food by-products and green waste without associated energy generation:

- **Composting of by-products and green waste (0.3 billion tonnes CO₂e):** Composting is mainly an aerobic process generating CO₂e, which has a much lower global warming potential than methane, which organic materials would produce if they are left to decompose in uncontrolled conditions. Besides carbon, compost contains other materials that can nourish and strengthen soils, so that using compost in agriculture 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 found the emissions-reduction potential of this opportunity to be 0.3 Gt CO₂e per year in 2050 based on the high organic material recovery potential (>70%) demonstrated by cities such as San Francisco.



REGENERATE NATURE

Regenerative production represents the greatest opportunity to turn the food system from a major contributor to climate change to a major actor part of the solution to it. The broad definition of regenerative production is growing food in ways that improve soil health, agrobiodiversity, and local ecosystems. How this is done in practice depends on context, scale, and other factors. However, all approaches share a mindset that a farm is part of a larger and mutually supportive ecosystem and acknowledges the critical importance of building soil organic matter.

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).⁹³ Carbon sequestration in the soil is possible on both these types of land, but the specific practices that can be employed to achieve this depend on climate, soil type, slope, and other factors.

On pastureland, the main opportunity is to build levels of organic matter in the soil using livestock and plant growth. Key ways of achieving this are managed grazing (modelled for this paper, see below) or other methods such as silvopasture which integrates tree crops within the grazing area. For cropland, carbon benefits are achieved by minimising soil disturbance and therefore release of carbon from the soil, and by reducing or even eliminating high carbon synthetic inputs such as chemical fertilisers. 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 production on cropland covers an array of schools of thought such as regenerative agriculture, agroecology, agroforestry, and conservation agriculture. For this paper, we have modelled the carbon benefits of using two broad categories.

- **Managed grazing (1.4 billion tonnes CO₂e per year):** This approach uses livestock as a tool for building soil fertility by carefully controlling the 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. These techniques are currently applied on around 80 million hectares of land globally but could be applied on approximately 40% of the world's 3.3 billion hectares of grazing land.⁹⁴ Applying a conservative adoption rate of around half of 40% on the applicable land not already under managed grazing leads to an annual carbon benefit of 1.4 billion tonnes CO₂e in 2050. This estimate represents the sequestration of carbon net of emissions related to enteric fermentation and degradation of manure on pastureland.

use of organic fertilisers. These methods 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 such as chemical fertilisers. The total cropland suited to regenerative agriculture globally is about 800 million hectares,⁹⁵ with about 40 million hectares already being farmed in this way. If regenerative agriculture were to be adopted on 80% of the remaining applicable land, it could lead to an annual carbon benefit of 2.5 billion tonnes CO₂e in 2050.

- **Regenerative cropland (2.5 billion tonnes/ CO₂e per year):** This term refers to a set of techniques on arable land that reduce GHG emissions associated with growing certain crops as well as increasing carbon sequestration in the soil. Regenerative cropland approaches use a number of different methods including minimising soil disturbance (no-till), the use of cover crops, intercropping, and the

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 necessary to reach net-zero, other interventions will be needed such as further improvements in farming methods besides those modelled in this paper, the continuing development and scaling of emerging technologies, and taking measures to encourage behavioural change.

There is a wide range of promising interventions based on emerging technologies, 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 chemical inputs) 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.⁹⁶ The overuse of nitrogen fertilisers is particularly harmful as, it can lead to a release of nitrous oxide – one of the most powerful GHGs – and these emissions increase

exponentially with each excess kilogram of fertiliser.⁹⁷ Reducing fertiliser use also results in a reduction in the industrial emissions associated with their production.

Methane inhibitors are supplements derived from natural sources (e.g. seaweeds, tannins, and oils) or synthetic chemicals that when mixed into feed have been proven to reduce enteric fermentation by up to 30% in ruminant livestock.⁹⁸ 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 technologies⁹⁹ could also play a role in addressing food system emissions. Interventions include 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 helping identify new types of food products that have lower embodied energy. For example, the AI platform of NotCo, a Chile-based start-up, analyses food on a molecular level and produces designs for less carbon-intense food products but with similar textures and flavours.

Improved farming techniques 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.

Behavioural change refers mainly to shifting diets and reducing overconsumption. It is also a key factor in driving food waste reduction for households, institutions, and companies. Behavioural change is widely recognised as being crucial for emissions reduction,¹⁰⁰ but when related to food can be particularly challenging due to the deep social and cultural factors involved. Solutions often involve educational programmes and public health campaigns with results spread over a long time frame. However, food designers can play a crucial role in influencing behaviour by offering a wider range of meals and products that have lower carbon emissions embedded in their production.

The circular economy approach is cost effective

The economic benefits of implementing the circular strategies described above are estimated at USD 700 billion per year by 2050.¹⁰¹

The direct economic opportunity includes valorisation of organic materials and the collection 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 the costs of urban food security programmes.

Numerous other economic benefits could accrue from applying circular economy 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%.¹⁰² Regenerative production 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 107,000.¹⁰³ In northern India, more than 160,000 farmers practice 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, reducing their exposure to debt, and increasing both profits and food security.¹⁰⁴ 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).¹⁰⁵

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 contribute to staying within 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 Great Acceleration^{xxv} 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 currently 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 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)".¹⁰⁶

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 possible 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 production applied to livestock and fish breeding, coupled with improved wastewater treatment, could help alleviate the threat that antimicrobial resistance may pose to millions of people 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 regenerative approach to farming could save 290,000 lives per year by 2050.

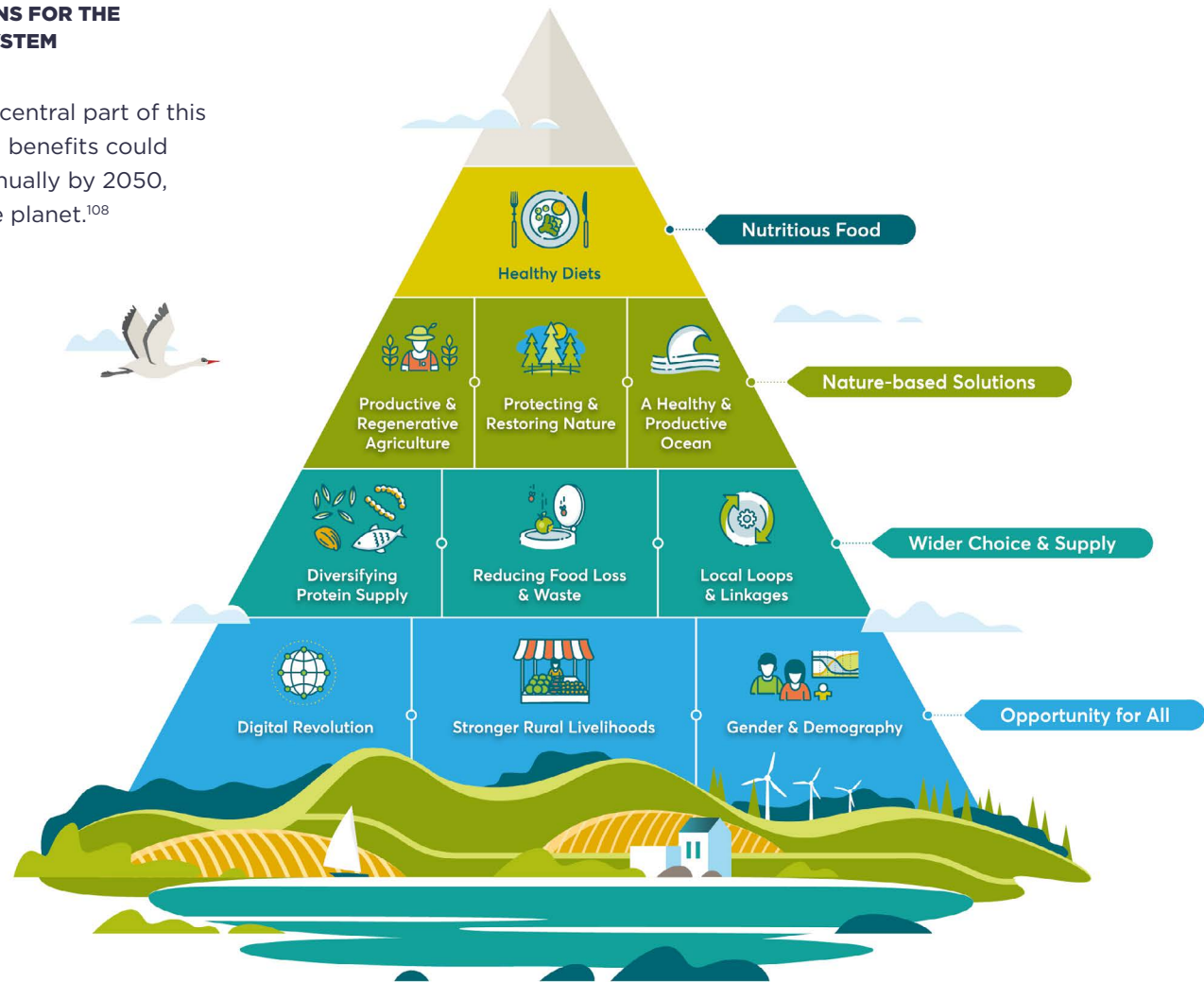
While combating climate change is one of the greatest challenges of our time, enhancing food security and reducing malnutrition for more than 800

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 production and other circular economy 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."¹⁰⁷

^{xxv} 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.¹⁰⁸



Source: FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use* (2019)

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 production 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.



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.¹⁰⁹ 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:¹¹⁰

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.¹¹¹ 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.¹¹² Moreover, considerable concerns exist over the security of supply of so-called 'critical' materials,^{xxvi} 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.¹¹³

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.¹¹⁴ 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".¹¹⁵ These 'transnational climate impacts' are risks that can travel across borders and cascade through the global economy.¹¹⁶ 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.¹¹⁷ Western Digital, which has one-

xxvi 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)

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.¹¹⁸ Total insured losses were estimated to be USD 15–20 billion.¹¹⁹

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.¹²⁰ 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.^{xxvii} 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).¹²¹ The elements 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'¹²² 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.¹²³

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".^{xxviii} 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.¹²⁴ 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.¹²⁵

xxvii 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. Source: Global Commission on Adaptation, *Adapt now: a global call for leadership on climate resilience* (2019)

xxviii 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)

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.¹²⁶

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”.¹²⁷ The European Commission considers recycling a “risk-reducing measure”.¹²⁸ 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.”¹²⁹ 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).¹³⁰

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.¹³¹ 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 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,¹³² 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.¹³³ 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.¹³⁴ 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”.¹³⁵ 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”.¹³⁶

Regenerative production, a core element of a circular economy for food, can increase the resilience of soils. Regenerative production 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 matter in the top 12 inches of soil by 1% makes it able to store an additional 144,000 litres of water per hectare.¹³⁷ Employing regenerative production 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%).¹³⁸ 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).¹³⁹

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 identifies a set of circular economy strategies that can help tackle the climate crisis. Incorporating 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. Such a transition represents opportunities for a range of stakeholders. Only a systems-level approach from these groups will enable us achieve net-zero emissions by 2050, while building greater resilience to the effects of climate change.

EXPLORE MORE

For a fuller discussion of the opportunity policymakers have to create a common direction of travel in policy development for a faster transition to a circular economy, please see the report: [Universal circular economy policy goals – Enabling the transition at scale.](#)

For an exploration of the opportunities for investing, banking, and insurance of the transition to a circular economy, with analysis of the recent rapid growth in circular economy financing and investment, please see the report: [Financing the circular economy – Capturing the opportunity.](#)



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 the effects of climate change is significant but 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 economy as an effective and valid framework to include in countries' NDC. 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 (...)".¹⁴⁰

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".¹⁴¹ The setting of international standards on recyclability, repairability, eco-design, labelling, and the use of materials and chemicals plays a critical enabling role. Such standards could remove barriers hindering the trade in secondary materials and in 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 these flows can be channelled to destinations where there is comparative advantage in sorting and processing.¹⁴²

Mobilise capital towards circular economy investments.

Multilateral 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.¹⁴³ 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 by other multilateral development banks

such as the World Bank, the International Financial Corporation, the 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) into its financial policy framework.¹⁴⁴ The aim is to mobilise finance for sustainable growth and help benchmark projects across the world, especially in 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. It is helpful to fully explore these synergies so that policies are mutually reinforcing.¹⁴⁵

Encourage and support collaboration.

The transition to a circular economy requires collaboration between governments, the investment community, industry organisations, companies, academia, and civil society. International institutions can play a convening role. An example is the World Economic Platform for Accelerating the Circular Economy (PACE), which facilitates global public-private collaborations related to e.g. plastics, electronics, and food to help accelerate action towards a circular economy across Asia, Europe, and Africa.¹⁴⁶

THE ROLE OF POLICYMAKERS

Incentivising, mobilising, and accelerating the transition towards a net-zero emissions circular economy.^{xxix}

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 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”.¹⁴⁷ Strategy plans are being set up such as the Netherlands’ “Government-wide Programme for a Circular Economy”, whose policies when implemented have been estimated to reduce CO₂e emissions by around 13 million tonnes in 2050

(in a conservative scenario).¹⁴⁸ City governments are also increasingly developing net-zero commitments and targets.^{xxx}

Incentivise and accelerate the scaling of new circular solutions.

Public funding can be used to enable and accelerate the scaling of circular business solutions. Circular economy and CO₂e-intensity criteria could be included in public procurement tenders, which could incentivise innovations in circular economy markets 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 2021.¹⁴⁹ 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.

Public-private partnerships and ventures can be used to share and reduce investment risks in circular economy projects. 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.^{xxxi}

Put in place infrastructure and renew assets.

Cities have a particularly important role to play in ensuring the effective recirculation of products and materials 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 replacements, there is also an opportunity to consider designs that are low-carbon, energy efficient, modular, repairable, adaptable, durable, and made with secondary materials. A comprehensive asset database held by local government, such as that developed by the City of Winnipeg,¹⁵⁰ 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 the 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,

xxix 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)

xxx 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)

xxxi “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)

and practices. A price on carbon emissions should be set,^{xxxii} and balancing mechanisms could be introduced for goods imported from regions that do not levy a sufficiently high CO₂e price. 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 for businesses that share, repair, and recycle.¹⁵¹ For example, Sweden has introduced a 50% reduction in VAT for repair activities related to certain products, including apparel, bicycles, and white goods.¹⁵²

Establish enabling regulations.

Regulations can promote the reuse of resources and the reduction of waste. Existing standards should be amended to enable low-emission solutions, e.g. setting a maximum cement content in concrete. Quotas and standards for CO₂e intensity, reusability, recyclability, and repairability of products and materials can enable the scaling of secondary materials and products, while having a positive impact on the durability of some products.¹⁵³ 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.¹⁵⁴

THE ROLE OF BUSINESS

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, cuts 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.¹⁵⁵

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 recycled into a new shoe.¹⁵⁶ Corporates can also help drive circular innovation by using their investment funds or internal dedicated funds to support small innovative companies.¹⁵⁷

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 of the GHG emissions reduction potential that such circular economy opportunities bring. Examples of effective campaigns that aim to stimulate the reuse, recycling, and resource-efficient design of products include Unilever's Get Plastic Wise,¹⁵⁸ Coca-Cola's World Without Waste,¹⁵⁹ and Patagonia's Don't Buy This Jacket.¹⁶⁰

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-

xxxii 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. Source: Mercer, *Climate change scenarios – implications for strategic asset allocation* (2011)

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 brands, retailers, manufacturers, collectors, sorters, academia, 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 be easily recycled, and are made in a way that is better for the environment and the health of garment workers.¹⁶¹

THE ROLE OF INVESTORS

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 creating value through circular economy opportunities (e.g. through product innovations or by developing new markets for secondary materials and refurbished goods). 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; 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.¹⁶² For example, the Intesa Sanpaolo Bank and the European Investment Bank (EIB) are cooperating to provide a EUR 1 billion credit facility to support circular economy projects carried out by mid-cap companies and Italian SMEs.¹⁶³

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.¹⁶⁴ 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.¹⁶⁵

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.¹⁶⁶ 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.¹⁶⁷ Requirements can also be set for portfolio companies’ and businesses’ plans to incorporate sustainability and circularity. For businesses that are not currently bankable, banks can provide advice on alternative sources of funding and support for challenging business models and technological risks.¹⁶⁸ 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.¹⁶⁹ These are intended to help companies deliver on their circular economy strategic plans and identify market trends, innovation, and value realisation opportunities.

THE ROLE OF ACADEMIA

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 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 in 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 of 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 reuse and recycling.

Lead innovation by students.

Initiatives that develop circular economy solutions through students’ commitment, application, and exploration of the topic can help drive 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 large purchasing power and complex supply chains. These organisations can act as lighthouse demonstrators of circular economy. 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, ranking 14th in the 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 be the driving force behind a local shift 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.¹⁷⁰

Appendix

FIGURE 10: THE SCOPE OF THIS PAPER

White circles show areas not covered by the paper.

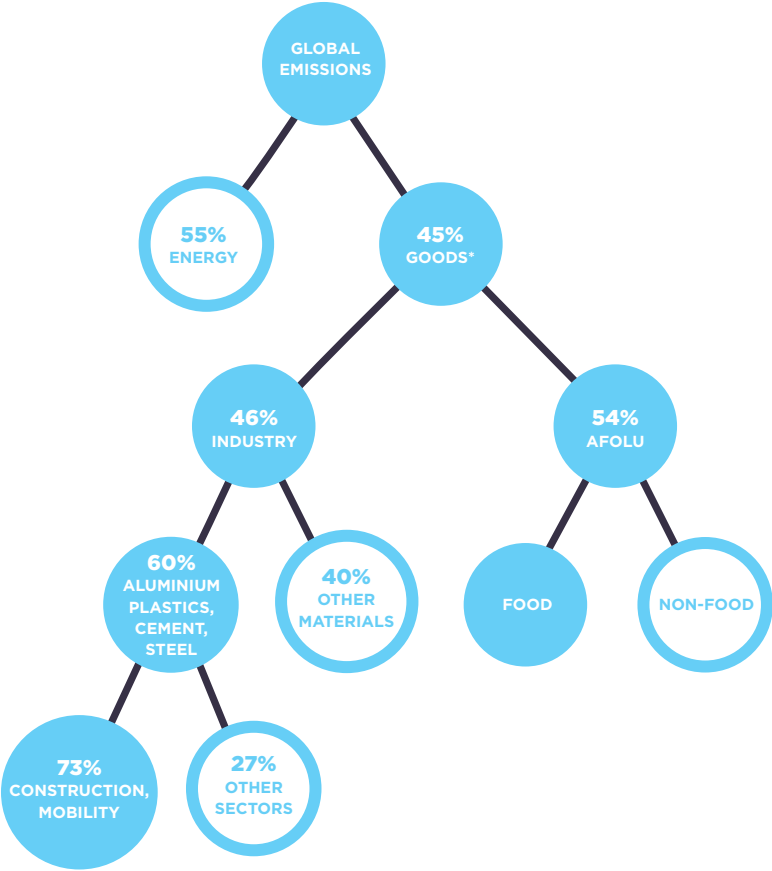
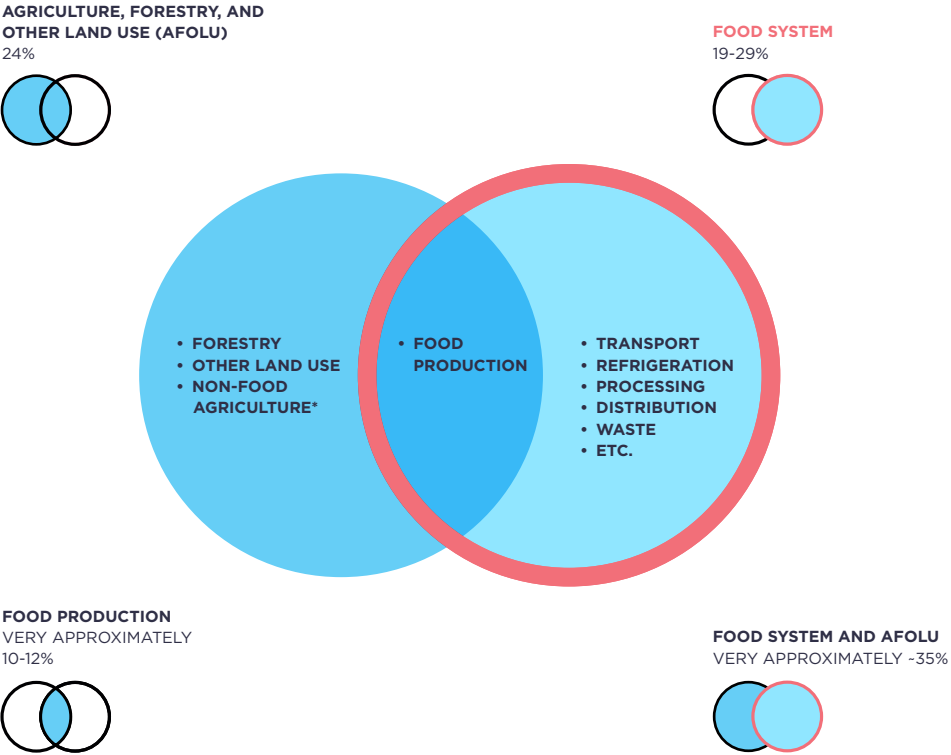


FIGURE 11: THE FOOD SYSTEM SCOPE OF THIS PAPER

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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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.

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MATERIAL
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About the Ellen Macarthur Foundation

The Ellen MacArthur Foundation is an international charity, committed to developing and promoting the idea of the circular economy in order to tackle some of the biggest challenges of our time, such as climate change, biodiversity loss, waste, and pollution. We work with, and inspire, business, academia, policymakers, and institutions to mobilise system solutions at scale, globally. In the circular economy, business models, products, and materials are designed to increase use and reuse, creating an economy in which nothing becomes waste and everything has value. Increasingly based on renewable energy and materials, the circular economy is a resilient, distributed, diverse, and inclusive economic model.

Further information: ellenmacarthurfoundation.org •
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References

- 1 World Economic Forum, *Global Risks 2016*, 11th edition (2016)
- 2 C40, Protecting our capital; Intergovernmental Panel on Climate Change (IPCC), 'Chapter 3: Impacts of 1.5°C of global warming on natural and human systems' in *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (2018)
- 3 United Nations Environment Programme (UNEP), *Emissions gap report 2018*
- 4 UNEP, Emissions gap report 2018; *Energy Transitions Commission, Better energy, greater prosperity: achievable pathways to low-carbon energy systems* (2017)
- 5 The Futures Centre, *The growing middle class*
- 6 International Resource Panel (IRP), *Global resources outlook 2018: natural resources for the future we want*; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (ISPBE), *Summary for policymakers of the global assessment report on biodiversity and ecosystem services* (2019)
- 7 IPCC, *Global warming of 1.5°C: summary for policymakers* (2018)
- 8 UNEP, *Emissions gap report 2018*
- 9 International Renewable Energy Agency (IRENA), *Global energy transformation: a roadmap to 2050* (2018)
- 10 BloombergNEF, *New energy outlook 2019*
- 11 IRENA, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (2019)
- 12 PricewaterhouseCoopers (PwC), *The Low Carbon Economy Index 2019: emissions relapse* (2019)
- 13 International Energy Agency (IEA), *World energy investment 2019: executive summary* (2019); IRENA, *Global energy transformation: a roadmap to 2050* (2018)
- 14 IPCC, *Climate change 2014: mitigation of climate change*, Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014); United States Environmental Protection Agency, Global greenhouse gas emissions data
- 15 IRP and UNEP, *Global resources outlook 2019: natural resources for the future we want*
- 16 IPCC, *Climate change 2014: mitigation of climate change*, Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014); United States Environmental Protection Agency, Global greenhouse gas emissions data
- 17 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 18 Ibid.
- 19 World Benchmark Alliance, *Measuring what matters most: seven systems transformations for benchmarking companies on the SDGs* (2019); United Nations, The Sustainable Development Goals agenda; International Resource Panel, Food systems and natural resources (2016)
- 20 Ibid.
- 21 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 22 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 23 World Resource Institute (WRI), *Creating a sustainable food future: reducing food loss and waste* (June 2013)
- 24 Ellen MacArthur Foundation, *The new plastic economy: rethinking the future of plastics* (2014)
- 25 ClimateTechWiki, *Carbon sink and low-carbon building materials*
- 26 Ibid.
- 27 Drawdown, *Land use: bamboo*
- 28 IRP and UNEP, *The weight of cities: resource requirements of future urbanization* (2018)
- 29 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 30 Favier, A., De Wolf, C., Scrivener, K. L., and Habert, G., *A sustainable future for the European cement and concrete industry* (2018)
- 31 Ellen MacArthur Foundation, *Splosh: how re-thinking the business model for cleaning products can influence design*
- 32 Ellen MacArthur Foundation, *A new textiles economy: redesigning fashion's future* (2017)
- 33 Business Europe, *Renault's remanufacturing of spare parts* (2017)
- 34 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 35 Ellen MacArthur Foundation, *The new plastics economy: rethinking the future of plastics* (2016)
- 36 IPCC, *Climate change 2014: mitigation of climate change*, Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014)
- 37 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 38 Chatham House, *Making concrete change: innovation in lowcarbon cement and concrete* (2018)
- 39 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 40 Ellen MacArthur Foundation, *The new plastics economy: catalysing action* (2017)
- 41 Material Economics, *The circular economy: A powerful force for climate mitigation* (2018)
- 42 Favier, A., De Wolf, C., Scrivener, K. L., and Habert, G., *A sustainable future for the European cement and concrete industry* (2018)
- 43 Global Benchmarking Alliance, *Measuring what matters most: seven systems transformations for benchmarking companies on the SDGs* (2019); United Nations High-Level Political Forum on Sustainable Development, *2018 HLPF Review of SDGs implementation: SDG12 – ensure sustainable consumption and production patterns* (2018)
- 44 UNEP and IEA, *Towards a zero-emission, efficient, and resilient buildings and construction sector, Global Status Report 2017*
- 45 IRP and UNEP, *The weight of cities: resource requirements of future urbanization* (2018)
- 46 Ibid.
- 47 Architecture 2030, *New buildings: embodied carbon*
- 48 Material Economics, *Industrial transformation 2050: pathways to net-zero emissions from EU heavy industry* (2019)
- 49 Ibid.
- 50 World Bank, *What a waste: a global review of solid waste management* (2012); Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 51 Ellen MacArthur Foundation, *A circular economy in Brazil: case study appendix* (2017); Whirlwind Steel, *Impacts of 3D printing on the construction industry* (30 March 2016)
- 52 Waste and Resources Action Programme (WRAP), *Waste reduction potential of offsite volumetric construction*
- 53 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)

- 54 London Waste and Recycling Board, *Towards a circular economy – context and opportunities* (2015)
- 55 Gijsbers, Ir. R., *Towards adaptability in structures to extend the functional lifespan of buildings related to flexibility in future use of space*, TU/e: International Conference on Adaptable Building Structures (2006)
- 56 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 57 Honicet, M., et al., *Data- and stakeholder-management framework for the implementation of BIM-based material passports*, 'Journal of Building Engineering' (2019); Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 58 Circle Economy, Fabric, TNO, and Gemeente Amsterdam, *Circular Amsterdam: a vision and action agenda for the city and metropolitan area* (2016)
- 59 Ellen MacArthur Foundation, *Circular economy in India: rethinking growth for long-term prosperity* (2016)
- 60 Ellen MacArthur Foundation, *Circular economy in cities* (2019)
- 61 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 62 IRP and UNEP, *The weight of cities: resource requirements offshoring urbanization* (2018); Salat, S., Bourdic, L., and Kamiya, M., *Economic foundations for sustainable urbanization: a study on three-pronged approach: planned city extensions, legal framework, and municipal finance* (2017)
- 63 *New Climate Economy, Better growth, better climate: the newclimate economy report* (2014)
- 64 Ellen MacArthur Foundation and Arup, *The circular economy opportunity for urban and industrial innovation in China* (2018)
- 65 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)
- 66 IEA, *CO2e emissions statistics* (2019); World Economic Forum, *The number of cars worldwide is set to double by 2040* (2016)
- 67 Ibid.
- 68 Material Economics, *The circular economy: A powerful force for climate mitigation* (2018)
- 69 The International Council on Clean Transportation, *European Vehicle Market Statistics 2017/2018* (2018)
- 70 Riversimple, *The technology behind the hydrogen car*
- 71 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 72 US Department of Transportation Federal Transit Administration, *Public transportation's role in responding to climate change* (2010)
- 73 Ellen MacArthur Foundation, CE100 Member Open Motors; *OpenMotors*
- 74 Ellen MacArthur Foundation, *The Circular Economy Applied to the Automotive Industry* (2012)
- 75 The Society of Motor Manufacturers and Traders (SMMT), *2018 UK automotive sustainability report* (2018)
- 76 S. S. Yang, et al., *The impact of automotive product remanufacturing on environmental performance*, Elsevier B.V (2015)
- 77 European Commission, *Directive 2000/53/EC of the European Parliament and of the council on end-of-life vehicles* (2000)
- 78 European Automobile Manufacturers Association, *Circular Economy* (2019)
- 79 Ellen MacArthur Foundation, *The circular economy applied to the automotive industry* (2012)
- 80 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015)
- 81 Organisation for Economic Co-operation and Development, *Urban mobility system upgrade: how shared self-driving cars could change city traffic* (2015)
- 82 C40, *The future of urban consumption a 1.5°C world* (2019)
- 83 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)
- 84 IRP, *Food systems and natural resources* (2016)
- 85 WRI, *5 questions about agricultural emissions, answered* (29th July 2019)
- 86 FAO, *Key facts on food loss and waste you should know!*
- 87 Indigo, *Terraton initiative*
- 88 Scarborough, P., et al., *Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK*, *Climatic Change* (2014)
- 89 Ellen MacArthur Foundation, *Urban biocycles* (2017)
- 90 Ellen MacArthur Foundation, *Cities and the circular economy for food* (2019)
- 91 Maktabifard, M., Zaborowska, E., and Makinia, J., *Achieving energy neutrality in wastewater treatment plants through energy savings and enhancing renewable energy production*, 'Reviews in Environmental Science and Bio/Technology' (2018)
- 92 Personal visits to WWTP by author and conversations with technical staff
- 93 Metabolic, *The global food system: an analysis* (March 2017)
- 94 Project Drawdown, *Food – managed grazing* (2019)
- 95 Project Drawdown, *Food – regenerative agriculture* (2019)
- 96 Zhang, W.-F. et al., *New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China*, Proceedings of the National Academy of Sciences of the United States of America (2013)
- 97 ScienceNews, *Fertilizer produces far more greenhouse gas than expected* (9th June 2014)
- 98 Hristov, et al., *An inhibitor persistently decreased enteric methane emission from dairy cows with no negative effect on milk production* (August 2015)
- 99 World Economic Forum, *Innovation with a purpose: the role of technology innovation in accelerating food systems transformation* (January 2018)
- 100 Springmann, M., et al., *Options for keeping the food system within environmental limits*, 'Nature' (2018)
- 101 Ellen MacArthur Foundation, *Food initiative – igniting a food system transformation*
- 102 Winnow
- 103 The New York Times, *Cover crops: a farming revolution with deep roots in the past*, Stephanie Strom (6th February 2016)
- 104 Global International Geosphere-Biosphere Programme Change, *Great acceleration* (2015)
- 105 Zero Waste Europe, *The story of Sardinia, case study #7* (2016)
- 106 IRP, *Food systems and natural resources* (2016)
- 107 Intergovernmental Panel on Climate Change, *Climate change and land* (2019)
- 108 Food and Land Use Coalition, *Growing better: ten critical transitions to transform food and land use* (September 2019)
- 109 Business Social Responsibility, *Nexis Report: Climate + supplychain – the business case for action* (2018)
- 110 Centre for Climate and Energy Solutions, *Weathering the storm: building resilience to climate change* (2013)
- 111 Auburger, A. et al., *Climate change impacts on mining and raw material supply chains*, German Environment Agency (2019)
- 112 Ibid.
- 113 Department for Environment, Food and Rural Affairs, *A review of national resource strategies and research* (2012)

- 114 World Business Council for Business Development, *Building resilience in global supply chains* (2015); Business Social Responsibility, *Why climate resilience and supply chains go hand in hand: how to integrate climate change risks and opportunities into supply chain management* (2018)
- 115 World Business Council for Business Development, *Building resilience in global supply chains* (2015)
- 116 Stockholm Environment Institute, *Introducing the Transnational Climate Impacts Index: indicators of country-level exposure – methodology report* (2016)
- 117 Business for Social Responsibility, *Climate and supply chain management* (2018)
- 118 Ibid.
- 119 Ibid.
- 120 McKinsey, *Why and how utilities should start to manage climate-change risk* (2019)
- 121 Carbon Disclosure Project, *Major risk of rosy opportunity* (2018)
- 122 Arup and Rockefeller Foundation, *City Resilience Index* (2014); Stockholm Resilience Centre, *Applying resilience thinking: seven principles for building resilience in socioecological systems* (2012)
- 123 Business for Social Responsibility and Driving Sustainable Economies, *From agreement to action: mobilising suppliers toward a climate resilient world* (2015)
- 124 World Business Council for Business Development, *Building resilience in global supply chains* (2015)
- 125 Ibid.
- 126 Foresight and Government Office for Science, *Future of manufacturing project: evidence paper 35 – sustainability and manufacturing* (2013)
- 127 All-Party Parliamentary Sustainable Resource Group and All-Party Parliamentary Manufacturing Group, *Triple win: the social, environmental, and economic case for remanufacturing* (2014)
- 128 European Commission, *Critical raw materials*
- 129 IRP and UNEP, *Global outlook 2019: natural resources for the future we want* (2019)
- 130 Energy Storage, *Cycle of life: a circular economy approach to lithium batteries* (27th August 2019)
- 131 Ibid.
- 132 The Economist, *Floods and storms are altering American attitudes to climate change* (May 2019)
- 133 UC Davis Center for Watershed Sciences, *Drought's economic impact on agriculture* (2016)
- 134 European Commission, *Science for environment policy* (10th June 2016)
- 135 Vermeulen, S., Campbell, B., and Ingram, J. *Climate change and food systems, Annual Review of Environment and Resources* (2012)
- 136 IPCC, *Climate change and land* (2019)
- 137 Massy, C., *Call of the Reed Warbler: a new agriculture, a new earth*, Chelsea Green Publishing, White River Junction (2018)
- 138 Natural Resources Defence Council, *How did Farmer Brown bring his dying land back from the brink?* (28th September 2018)
- 139 UNEP, *Andhra Pradesh to become India's first Zero Budget Natural Farming State* (June 2018)
- 140 UN Environment Assembly of UNEP, *Innovative pathways to achieve sustainable consumption and production* (2019)
- 141 World Trade Organization (WTO) and UNEP, *Making trade work for the environment, prosperity and resilience* (2018)
- 142 Organisation for Economic Co-operation and Development and the Resource Efficiency & Circular Economy Project, *International trade and the transition to a circular economy – policy highlights* (2018)
- 143 European Investment Bank, *The EIB in the circular economy*
- 144 European Commission, *Sustainable finance*
- 145 Organisation for Economic Co-operation and Development and the Resource Efficiency & Circular Economy Project, *International trade and the transition to a circular economy – policy highlights* (2018)
- 146 World Economic Forum, *Platform for accelerating the circular economy*
- 147 European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the regions: united in delivering the Energy Union and Climate Action – setting the foundations for a successful clean energy transition* (2019)
- 148 Netherlands Organisation for Applied Scientific Research, *Effecten van het Rijksbrede Programma Circulaire Economieën de Transitieagenda's op de emissie van broeikasgassen* (2018); The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, *A circular economy in the Netherlands by 2050* (2016)
- 149 Ellen MacArthur Foundation, *Toronto: circular economy procurement implementation plan and framework* (2019)
- 150 City of Winnipeg, *2018 City asset management plan* (2018)
- 151 De Groene Zaak, *Governments going circular* (2015)
- 152 World Economic Forum, *Sweden is paying people to fix their belongings instead of throwing them away* (27th October 2016)
- 153 Scottish Government, *Climate change plan: third report on proposals and policies 2018–2032 (RPP3)* (2018)
- 154 The Telegraph, *France to ban unsold clothes and electronics from being destroyed in 'world first'* (4th June 2019)
- 155 Houdini, *Planetary Boundaries Assessment* (2019)
- 156 Quartz, *Adidas's zero-waste sneaker is a simple idea that took years to execute* (2019)
- 157 Oliver Wyman, *Supporting the circular economy transition: the role of the financial sector in the Netherlands* (2017)
- 158 Unilever, *Our five point plastics plan in the UK and Ireland* (2019)
- 159 Coca-Cola, *A world without waste: Coca-Cola announces ambitious sustainable packaging goal* (2018)
- 160 Patagonia, *Don't buy this jacket, black Friday and the New York Times* (2011)
- 161 Ellen MacArthur Foundation, *The jeans redesign: guideline* (2019)
- 162 ING, *Financing the circular economy* (2015)
- 163 Intesa SanPaolo, *From Intesa Sanpaolo and the EIB 1 billion euro for Midcaps and the Circular Economy* (2019)
- 164 ING, *Financing the circular economy* (2015)
- 165 CDC Investment Works – ESG Toolkit, *Resource efficiency and the circular economy* (2018)
- 166 Oliver Wyman, *Supporting the circular economy transition: the role of the financial sector in the Netherlands* (2017)
- 167 ING, *Financing the circular economy* (2015)
- 168 Oliver Wyman, *Supporting the circular economy transition: the role of the financial sector in the Netherlands* (2017)
- 169 *Circular Capital, Our approach.*
- 170 Arizona State University, *Economic Impact Opportunity of Circular Economy in Phoenix*



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