SITRA STUDIES 205

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TACKLING ROOT CAUSES

– Halting biodiversity loss through the circular economy

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Tackling root causes
Halting biodiversity loss through the circular economy

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Foreword

Biodiversity matters – and not just for the millions of plants, animals and other species besides humans. It also underpins our economy, society and ultimately our survival as a species. Hence, biodiversity loss even eclipses climate change in terms of the gravity of the threat we are faced with. Yet, biodiversity loss has continued at an alarming rate, and we face imminent disruption and eventually collapse unless swift action is taken.

The good news is that we already today have many of the tools needed to halt the decline – we just have not started applying these at scale. While conservation and restoration efforts will continue to play a central role, the circular economy is a key addition to the toolbox – a tool without which the repair work our planet needs could not be completed.

Faced with a sixth mass extinction, this is not just a once-in-a-lifetime but a once-in-an-aeon opportunity, and the time for action is now. For the first time, biodiversity has seriously grabbed the attention of policymakers and businesses in the run-up to the first part of the COP 15 biodiversity negotiations in Kunming. Following the limited progress of the Aichi Targets, set in 2010 under the UN Convention on Biological Diversity, the successor framework – postponed to 2022 – heralds unprecedented momentum.

The beginning of the 2020s has also seen two tragedies afflict the world. First, Covid-19 ended millions of lives and disrupted billions of livelihoods and the economy at large. As the pandemic had started to recede in parts of the world, Russia invaded Ukraine, resulting in more suffering and lives lost. The supply of key resources – from energy to metals, grains and other commodities – that had already started to become more expensive, was hit by another shock, affecting those with little to spare disproportionately. We were not prepared. We were not resilient – the impacts exacerbated by a fossil-dependent, wasteful and unfair linear economic system. We made that system. We can also transform it.

The circular economy has emerged as a vision of a more resilient economy, which both redefines and unlocks new growth by giving us more from what we have. This makes us less dependent on problematic resources and fragile supply chains, while mitigating climate change and reducing our pressure on nature. The circular economy has gained traction as a solution pathway at the highest levels of decision-making, including in the European Union and across dozens of countries which today have national circular economy road maps and strategies in place.

The circular economy allows us to tackle some of the leading root causes of resource overconsumption, climate change and biodiversity loss all at once, by rethinking how we produce, consume and manage materials, which reduces resource extraction and tackles the main pressures which drive biodiversity loss today, including changes in land use, climate change and pollution. Yet policymakers and businesses have thus far addressed biodiversity and the circular economy discretely rather than jointly.

Hitherto, the potential the circular economy can play in tackling biodiversity loss has partly rested on assumptions, while the scale and shape of this opportunity has largely remained unknown. This study is a first-of-its-kind effort to analyse and quantify the role the circular economy can play in halting and reversing global biodiversity loss. It focuses on the four sectors that are responsible for driving the largest share of biodiversity loss, and within each sector, identifies the most effective interventions as well as their economic opportunities.

The study is based on a thorough scoping phase, an extensive literature review, state-of-the-art modelling and consultations with more than 160 experts outside of Sitra and Vivid

Economics. We would like to thank all the experts who contributed to the study by sharing their thoughts, ideas and insights during the course of the study, not least the members of the study's advisory board: Akanksha Khatri (World Economic Forum), Alberto Arroyo Schnell (International Union for Conservation of Nature), Enni Ruokamo (Finnish Environment Institute), Eva Dalenstam (European Commission), James Vause (UN Environment Programme World Conservation Monitoring Centre), Janne Kotiaho (Finnish Nature Panel), Jocelyn Blériot (Ellen MacArthur Foundation), Kaisa Pietilä (Finnish Environment Institute), Mark van Oorschot (Netherlands Environmental Assessment Agency), Patrick Schröder (Chatham House), Soukeyna Gueye (Ellen MacArthur Foundation), as well as the other coordination group members of the European Circular Economy Stakeholder Platform (ECESP) (IUCN, EMF, INEC and Sitra) which have worked together to increase the understanding of how the circular economy can serve as a tool for addressing biodiversity loss. We would also like to thank Tim Forslund and the whole Circular economy team at Sitra for co-ordinating the project and providing your valuable input to the work.

We hope that this study, presented close to the second round of COP 15, will help catalyse biodiversity action for the next decade and beyond – on a larger scale, at a global level and in more effective ways – among policymakers, businesses and throughout society at large.

Helsinki, May 2022

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Executive summary

Rationale for this study: biodiversity loss is a major threat to us all demanding transformative change

Species are dying out at a rate not seen since the last mass extinction 66 million years ago. The future of our ecosystems, societies and economies is at risk. Yet, action is alarmingly insufficient both in scale and scope, and there is only a narrow window of opportunity to change course. In short, we need transformative change, and we need to tackle the root causes of biodiversity loss across our extractive and polluting linear consumption and production systems. At present, these create too much stuff, too inefficiently and at too high a cost for the planet.

A transition to a circular economy can on its own halt global biodiversity loss

The circular economy redefines how we produce, consume and manage materials and products. It gives us more value from what we have and leaves room for nature. A transition to a circular economy offers a wide range of environmental benefits and economic opportunities for governments, business and consumers. However, no prior work has quantitatively modelled the potential impact a transition to a circular economy could have on halting global biodiversity loss. This work sets out to fill this crucial gap.

This study emphasises how the circular economy can halt and partly reverse biodiversity loss by 2035, through policy- and business-led interventions in the food and agriculture, buildings and construction, fibres and textiles, and forest (i.e., forestry and the forest industry) sectors. These interventions are focused on regenerative production principles, as well as on business models that extend product lifetimes, increase use rates and cut waste to reduce our extraction of resources and in turn tackle the key drivers of biodiversity loss: land-use change, climate change, pollution, direct exploitation and invasive alien species.

Methodology

This study developed a comprehensive modelling approach to assess how much biodiversity loss can be halted in a circular economy scenario by 2050. MAgPIE, a state-of-the-art land-use model, is used to study the effects of a circular transition. The modelling approach allows for the examination of how individual circular interventions across four sectors affect key drivers of biodiversity loss – zooming in on land-use change – and consequently biodiversity intactness. The assumptions and key results underlying this modelled transition are summarised in figure 1.

Figure 1. The circular economy halts and reverses biodiversity loss and helps mitigate climate change by 2050
Note: The circular lever changes result in drivers of impacts measured as land-use change, either as forests or agricultural land, regardless of in which sector the lever change occurs. For example, the changes to the 280 million hectares of natural forests accrue from reductions in demand for textiles, food and building material, as well as timber.
Source: Vivid Economics

	CIRCULAR LEVER CHANGES	DRIVERS OF IMPACTS
FOOD AND AGRICULTURE	• **Meat** consumption falls by **50%** and **dairy** consumption falls by **67%** • **Food waste** per capita falls by **50%** • **Regenerative** principles are applied on **60%** of croplands and **18%** of pasturelands	**Agricultural land** area falls by **640 million hectares**
FIBRES AND TEXTILES	• **Use rate of clothing** increases by **50%** • **Recycling** of clothing increases to **75%** • **Regenerative** principles are used on **60%** of the land used for cotton cultivation	**Cotton cultivation** area falls by **24 million hectares**
BUILDINGS AND CONSTRUCTION	• **Construction timber** efficiency savings reduce demand by **50%** • **Urban density** increases by **51%**	**14 million hectares** are spared from **urban area** development
FORESTS	• **Paper use** falls by **55%** • **Recycling** reduces new pulp demand by **48%** • **Regenerative** principles are applied in **20%** of secondary forests and in **all** other managed forests	**280 million hectares** of **natural forest** is spared

IMPACTS

Biodiversity loss is halted and biodiversity recovers to 2000 levels by 2035

By 2050, **1 Gt of CO_2** is sequestered a year through land use change

Methane emissions from agriculture fall by almost **90%**

Results: the circular economy can turn the tide on biodiversity loss

A rapid transition to a circular economy could halt global biodiversity loss and start the process of biodiversity recovery, assuming no other action is taken globally, with biodiversity recovering to its 2000 levels by 2035. By 2050, this could lead to the amount of agricultural land being 640 million hectares lower than under business as usual – an area roughly one and a half times the size of the European Union – with 280 million hectares of forest habitats saved. Beyond merely halting biodiversity loss, this transition could contribute 28% of the required action to meet the highly ambitious biodiversity recovery goals set out by Leclère and other leading scientists.

The focus is on the four sectors that have the largest potential for halting biodiversity loss through circular economy solutions. The set of potential solutions or "levers" in each sector were given values entailing significant shifts, but which are technically feasible. These values were selected using a mixture of existing policy targets set by governments worldwide and academic and industrial research on the effectiveness of specific circular economy solutions.

Food and agriculture: Reductions in pollution and food loss and waste across the supply chain increase the efficiency of production to reduce input requirements, particularly for proteins, while regenerative agriculture effects positive biodiversity impacts.

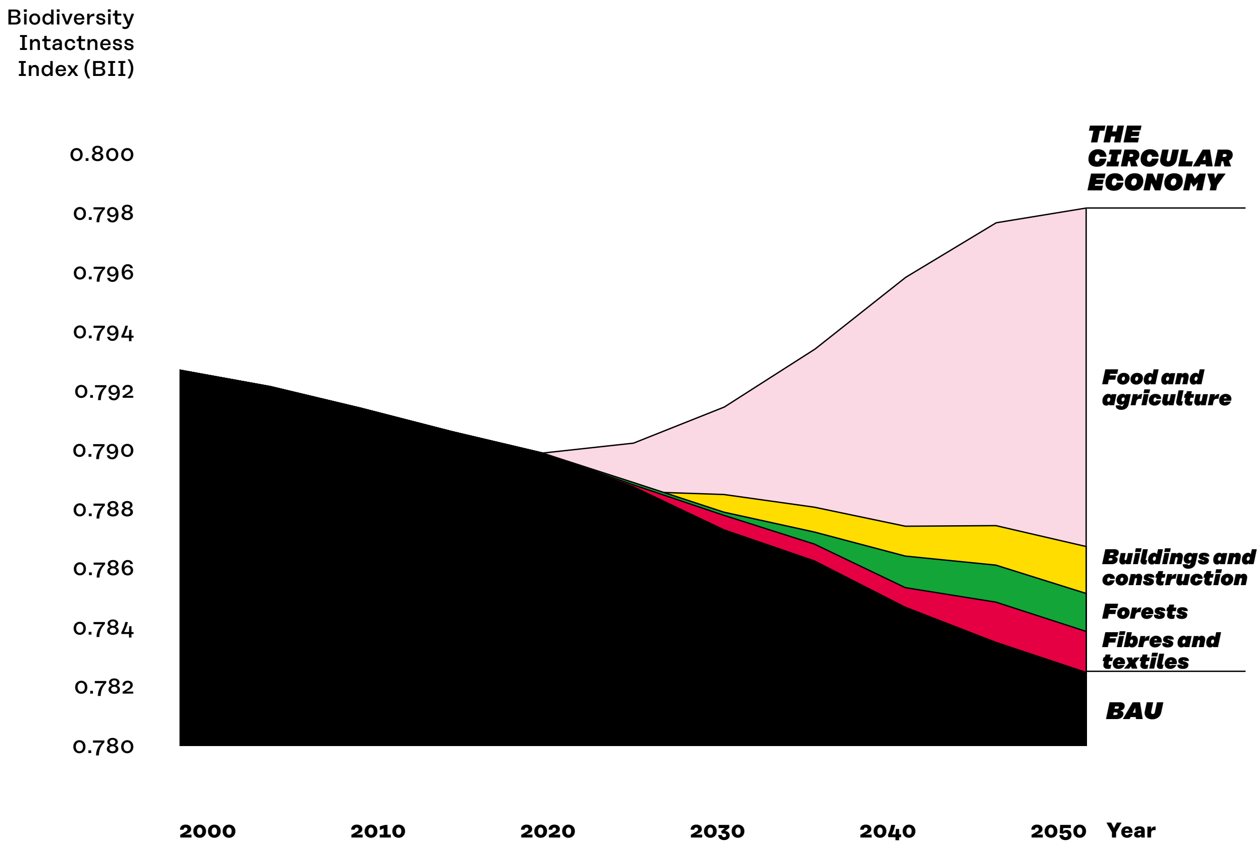
Forests: Improvements in product lifetimes and the reuse of products and materials lower the demand for timber. New wood is sourced from forests that are managed according to regenerative principles to improve biodiversity outcomes.

Buildings and construction: Fewer materials and less urban space are used by extending building lifetimes, optimising active use, reducing material use and reusing and recycling materials. More renewable materials are used in construction.

Fibres and textiles: Demand for new materials is reduced by increasing the durability, use rates, reuse and recycling of clothing, while regenerative methods of cultivation are increasingly used.

A shift to a circular food and agriculture sector makes the greatest contribution to biodiversity recovery.

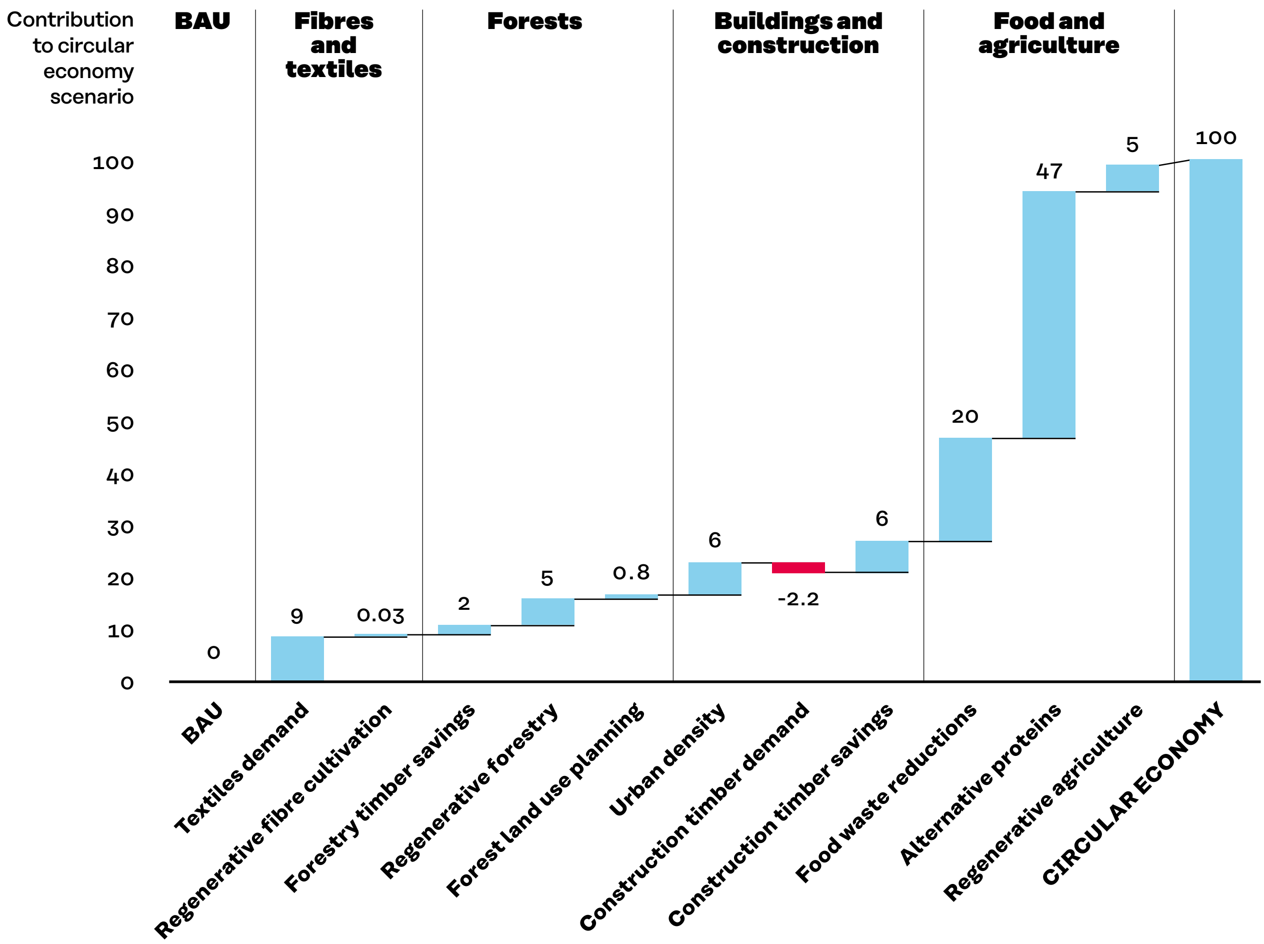
Figure 2. The food and agriculture sector makes the greatest contribution to biodiversity recovery
Source: Vivid Economics



A shift to a circular food and agriculture sector makes the greatest contribution to biodiversity recovery, constituting 73% of total contribution to the circular economy scenario in this study. Buildings and construction, fibres and textiles, and forests contribute 10%, 9% and 8%, respectively.

The food and agriculture sector presents both an opportunity and a key challenge to policymakers: without reforming the food and agriculture sector, biodiversity decline can be reduced but not altogether halted. These results reflect the footprint of global agriculture, which currently uses approximately half of the world's habitable land.

Figure 3. Alternative proteins and food waste reductions make the greatest contributions to overall biodiversity recovery in the circular economy
Note: Figures express the percentage of total change in the Biodiversity Intactness Index (BII) in 2050 that occurs when moving from business as usual to the circular economy.
Source: Vivid Economics



The opportunities and impacts of the circular economy differ regionally due to different patterns of production, consumption, international trade and varying drivers of biodiversity loss regionally. The largest per capita potential for shifting to alternative proteins and making better use of textiles is in the northern hemisphere, whereas the greatest changes in agricultural land area, and subsequent improvements in biodiversity, take place mostly in regions such as Latin America, Sub-Saharan Africa and India. In contrast, interventions in the forest and building sectors mostly improve biodiversity within the regions these actions take place.

The circular economy can tackle multiple crises at once. Besides making it possible for biodiversity to recover, the circular economy can help to mitigate climate change, not least by substantially reducing land-use emissions. Mitigating climate change in turn provides additional benefits for biodiversity, as climate change is one of the five main drivers of biodiversity loss, and likely to be the largest in future. The modelling shows that this transition could shift land-use change from a source of atmospheric CO_2 to a temporary sink. In the EU alone, this would be enough to meet the European Commission's revised proposal of net removal of 310 Mt CO_2 per year from land use, land-use change and the forest sectors by 2030. Methane emissions from agriculture could fall by almost 90%, driven by shifts away from livestock-intensive agricultural production. This underscores the important synergies between circular policies to address both biodiversity and climate crises.

The transition could help build economic resilience by reducing the dependence on virgin raw materials, volatile markets and fragile supply chains. Moreover, it leads to significant increases in economic activity and jobs across the four sectors. The transition to alternative proteins could provide annual global benefits of US$170 billion by 2030, rising to US$500 billion by 2050, provided the investments required are not stalled. This could support around three million new jobs annually. There are also significant efficiency gains from savings that accrue to producers, retailers or consumers from reduced resource consumption resulting from efficiency gains. Efficiency gains in construction timber recycling, reducing food loss and waste and cotton recycling, for example, could each provide annual savings to businesses of between US$0.6 and 1.5 billion per year.

The way forward

This analysis presents the first set of results on the potential for the circular transition to halt and reverse biodiversity loss. As with any initial analysis, it is subject to limitations that can be improved upon to further develop the understanding of the circular economy's potential to drive meaningful changes in global biodiversity loss. In particular, the study does not cover marine and freshwater ecosystems as it focuses on the sectors that drive most biodiversity loss through land-use change, and more research into other drivers and ecosystems could reveal an even larger circular potential. The study is also meant as an illustration of what a plausible transition scenario in line with current policy goals and circular economy opportunities could look like, without making predictions about future technological trends.

Policymakers play a central role in staking out the path forward, enabling new technologies and business models, addressing price differentials based on biodiversity impacts and setting the rules of the game for business and industry. In particular, they can do this by making more explicit the role of the circular economy as a tool for halting biodiversity loss across central policy areas, prioritising circular economy policies that have significant overlaps between climate and biodiversity benefits, and using circular principles to reduce land use from biomass production, not least from key commodities such as meat and dairy. Finally, attention is needed to measure and address biodiversity impacts beyond countries' own borders, at a global level.

Business and industry. To lead the way in the transition, business and industry have many opportunities to transform production and unlock more value from existing resources in areas central to biodiversity loss. These can be identified and addressed by first measuring and reporting biodiversity risks and impacts and then by setting science-based targets. To save resources and prioritise the most effective action, firms should identify overlaps between biodiversity and climate impacts and action and where possible reduce the land-use footprint from biomass production, especially from food. Finally, to deliver on the set targets, firms should apply a hierarchical approach to identify the most relevant circular solutions and put them into practice to reach the set goals.

Tiivistelmä

Miksi selvitys tehtiin: luontokadon pysäyttäminen ei onnistu nykymenolla

Luonnon monimuotoisuus katoaa hälyttävää vauhtia kaikkialla maailmassa – myös Suomessa. Tilanne on vakava, sillä terveytemme, taloutemme ja hyvinvointimme ovat täysin riippuvaisia luonnosta.

Luontokatoa on yritetty pysäyttää, mutta kansalliset, kansainväliset ja yritysten toimet ovat olleet riittämättömiä. Luonnon monimuotoisuutta ei ole turvattu riittävästi globaalilla tasolla, vaikka olemme kaikki riippuvaisia paitsi oman maamme myös muiden valtioiden luonnon monimuotoisuudesta ja vaikutamme kulutuksemme kautta luontokatoon muuallakin päin maailmaa. Luontokadon pysäyttäminen maapallolla on kuitenkin mahdollista. Se vaatii laajamittaista muutosta ja ongelmien juurisyiden ratkaisemista. Käytännössä meidän on uudistettava nykyinen talousjärjestelmä, joka on tehoton, tuottaa valtavasti jätettä ja perustuu hupenevien luonnonvarojen käyttöön.

Kiertotalous on talousmalli, jossa olemassa olevien tuotteiden ja materiaalien arvoa hyödynnetään mahdollisimman pitkään. Kun resurssit ovat tehokkaassa käytössä mahdollisimman pitkään, vähenee tarve ottaa käyttöön uusia luonnonvaroja ja luonnolle jää enemmän tilaa.

Siirtymä kiertotalouteen tarjoaa taloudellisia mahdollisuuksia valtioille, yrityksille ja kansalaisille, ja edistää samalla ekologista kestävyyttä. Kiertotaloudella voidaan myös merkittävästi vähentää ilmastopäästöjä. Aiemmin on jo tunnistettu, että kiertotalous voi vähentää luontoon kohdistuvia paineita, mutta sen potentiaalia maailmanlaajuisen luontokadon ratkaisemisessa ei ole tähän mennessä mallinnettu kvantitatiivisesti. Tämän tietovajeen täyttäminen on selvityksemme tärkein tavoite.

Tämän selvityksen mukaan kiertotalous voi pysäyttää luontokadon maailmanlaajuisesti ja palauttaa luonnon monimuotoisuuden vuoden 2000 tasolle vuoteen 2035 mennessä. Skenaarion toteutuminen vaatii kuitenkin merkittävää muutosta nykyisiin toimintatapoihin ja mittavia kiertotaloustoimia sekä päättäjiltä että yrityksiltä.

Miten selvitys tehtiin?

Selvityksessä keskitytään neljään sektoriin, joilla on suurimmat vaikutukset maalla tapahtuvaan luontokatoon ja joissa kiertotalousratkaisuilla on myös merkittävä potentiaali sen pysäyttämiseen. Tarkasteltavat sektorit ovat ruoka ja maatalous, rakennukset ja rakentaminen, kuidut ja tekstiilit sekä metsäsektori.

Kiertotaloustoimenpiteiden luontovaikutusten mallintamiseksi selvityksessä rakennettiin kaksi skenaariota: Business as Usual -skenaario (BAU), jossa jatketaan nykyisillä tuotanto- ja kulutustavoilla sekä kiertotalousskenaario, jossa kiertotalouden mukaiset tuotanto- ja kulutustavat vähentävät merkittävästi jätettä ja saastumista, lisäävät tuotteiden käyttöasteita ja pidentävät niiden käyttöikää sekä vähentävät tarvetta ottaa käyttöön uusia luonnonvaroja. Näitä skenaarioita verrattiin Leclère ym. (2020) laatimaan Integrated Action Portfolio -skenaarioon (IAP), jossa luontokato pysäytetään ja luonnon monimuotoisuus toipuu merkittävästi.

Kiertotalousskenaariota varten tunnistettiin tarkastelluilta neljältä sektorilta kiertotaloustoimenpiteitä, joiden vaikutuksia luonnon monimuotoisuuteen mallinnettiin tarkastelemalla niiden mahdollistamia maankäytön muutoksia. Kullekin kiertotaloustoimenpiteelle määriteltiin tutkimuskirjallisuuden perusteella oletusarvot, jotta kiertotalousskenaarioita pystyttiin vertaamaan BAU-skenaarioon.

Mallinnetut sektorikohtaiset kiertotaloustoimenpiteet ja niiden mahdollistamat maankäytön muutokset vuoteen 2050 mennessä on esitelty alla.

Ruoka- ja maataloussektorin kiertotalousskenaariossa lihankulutus puolittuu ja maitotuotteiden kulutus laskee 67 prosenttia. Ruokahävikki henkilöä kohti puolittuu, ja 60 prosentilla maatalouden viljelymaasta sekä 18 prosentilla laidunmaasta siirrytään uudistavaan viljelyyn. Kiertotalousskenaariossa 640 miljoonaa hehtaaria maatalousmaata vapautuu muuhun käyttöön verrattuna BAU-skenaarioon, jossa nykyinen kehitys jatkuu. Maataloudelta vapautuva alue vastaa kooltaan 1,5 kertaa Euroopan unionin pinta-alaa.

Rakennusten ja rakentamisen kiertotalousskenaariossa puutavaran kysyntä puolittuu ja kaupunkien väestötiheys kasvaa 51 prosentilla. Rakennusten ja rakentamisen kiertotalousskenaariossa kaupungit vievät 14 miljoonaa hehtaaria vähemmän tilaa kuin BAU-skenaariossa.

Kuitujen ja tekstiilien kiertotalousskenaariossa vaatteiden käyttöikä kasvaa 50 prosenttia ja tekstiilien kierrätysaste nousee 75 prosenttiin. Uudistavan maatalouden periaatteita otetaan käyttöön 60 prosenttia puuvillan viljelymaasta. Kuitujen ja tekstiilien kiertotalousskenaariossa 24 miljoonaa hehtaaria puuvillan viljelyalaa vapautuu muuhun käyttöön BAU-skenaarioon verrattuna.

Metsäsektorin kiertotalousskenaariossa paperin käyttö laskee 55 prosenttia ja sellun kysyntä paperin tuotantoon laskee 48 prosenttia. Uudistavan metsätalouden periaatteita käytetään 20 prosentissa kerran päätehakattuja talousmetsiä sekä kaikissa muissa talousmetsissä. Metsäsektorin kiertotalousskenaariossa 280 hehtaaria metsäelinympäristöjä välttyy hakkuilta verrattuna BAU-skenaarioon.

Menetelmät: maailmanlaajuinen maankäytön malli

Selvityksessä tehtiin kattava mallinnus, jonka avulla arvioitiin, voidaanko luontokadon suunta kääntää kiertotaloustoimenpiteillä vuoteen 2050 mennessä.

Kiertotaloustoimenpiteiden mahdollistamat maankäytön muutokset mallinnettiin maailmanlaajuisen maankäytön mallin, MAgPIEn (Model of Agricultural Production and its Impact on the Environment), avulla. Mallilla lasketaan maankäytön allokointi sekä BAU- että kiertotalousskenaariossa. Malli ottaa huomioon muun muassa oletetut väestön, BKT:n ja ruoan kulutuksen kasvun, maataloushyödykkeiden kysynnän ja tuotantokustannukset sekä alueelliset rajoitteet, kuten sadon, maan ja veden. Parametrien perusteella selvityksessä on mallinnettu BAU- ja kiertotalousskenaarioiden todennäköiset maankäytön muutokset, joista on johdettu kiertotaloustoimenpiteiden alueelliset vaikutukset luonnon monimuotoisuuteen.

Kiertotaloustoimenpiteiden vaikutusta luonnon monimuotoisuuteen mitataan Biodiversity Intactness Indeksillä (BII), joka kuvaa tietyn maantieteellisen alueen keskimääräistä luonnonvaraisten lajien runsautta viitepopulaatioon verrattuna.

Selvityksessä käytetyt oletukset ja mallinnuksen keskeiset tulokset on esitelty kuvassa 1.

Kuva 1. Kiertotaloustoimet pysäyttävät luontokadon ja auttavat hillitsemään ilmastonmuutosta vuoteen 2050 mennessä
Huom! Kiertotaloustoimenpiteet johtavat maankäytön muutoksiin, mitattuna joko metsä- tai maatalousmaana, huolimatta siitä, millä sektorilla toimenpiteitä tehdään. Esimerkiksi siihen, että 280 miljoonaa hehtaaria metsää säästyy hakkuilta, vaikuttavat puunkäytön ohella myös elintarvikkeiden, tekstiilien ja rakennusmateriaalien kysynnän väheneminen.
Lähde: Vivid Economics

KIERTOTALOUSTOIMENPITEET		MAANKÄYTÖN MUUTOKSET
RUOKA JA MAATALOUS	• **Lihan** kulutus **puolittuu** ja **maitotuotteiden** kulutus laskee **67 %** • **Ruokahävikki** henkilöä kohti **puolittuu** • **Uudistavan** viljelyn periaatteet otetaan käyttöön **60 %:lla** viljelymaasta ja **18 %:lla** laidunmaasta	**640 miljoonaa hehtaaria maatalousmaata** vapautuu muuhun käyttöön
KUIDUT JA TEKSTIILIT	• **Vaatteiden käyttöikä** kasvaa **50 %** • Tekstiilien **kierrätysaste** nousee **75 %:iin** • **Uudistavan viljelyn periaatteet** otetaan käyttöön **60 %:lla** puuvillan viljelymaasta	**24 miljoonaa hehtaaria puuvillan viljelyalaa** vapautuu muuhun käyttöön
RAKENNUKSET JA RAKENTAMINEN	• **Puutavaran** kysyntä puolittuu • **Kaupunkien asukastiheys** kasvaa **51 %**	**Kaupungit** vievät **14 miljoonaa hehtaaria** vähemmän tilaa
METSÄSEKTORI	• **Paperin käyttö** laskee **55 %** • **Kierrätys** laskee sellun kysyntää paperin tuotantoon **48 %** • **Uudistavan metsätalouden periaatteet** otetaan käyttöön **20 %:ssa** kerran päätehakatuista talousmetsistä sekä **kaikissa** muissa talousmetsissä	**280 miljoonaa hehtaaria metsää** säästyy hakkuilta

VAIKUTUKSET

Luontokato pysähtyy ja luonnon monimuotoisuus elpyy vuoden 2000 tasolle vuoteen 2035 mennessä

Maankäytön muutokset sitovat **1 Gt hiilidioksidia vuodessa** vuoteen 2050 mennessä

Maatalouden **metaanipäästöt** vähenevät lähes **90 %**

Tulokset: Luontokadon suunta voidaan kääntää kiertotalousratkaisuilla

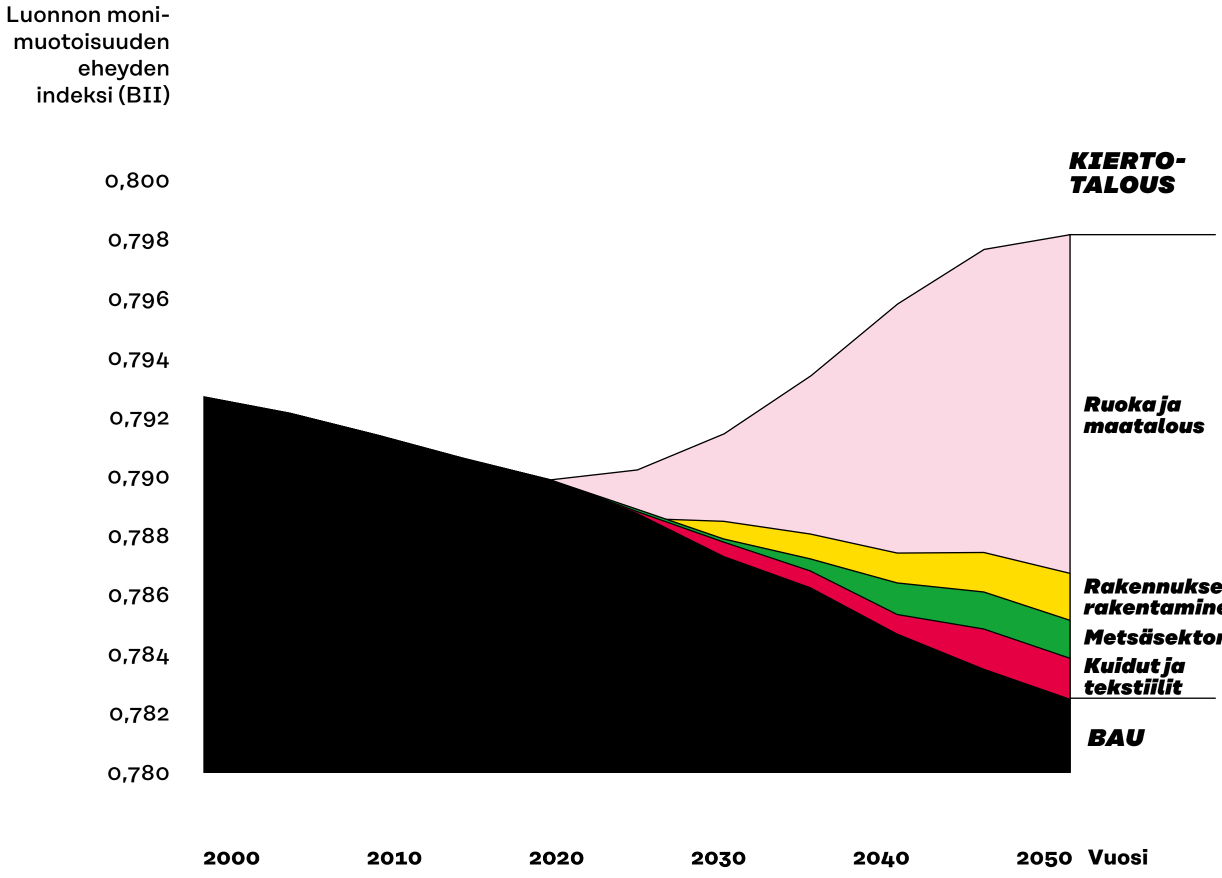
Selvityksen mukaan siirtymä kiertotalouteen ruoka- ja maataloussektorilla, rakennussektorilla, tekstiilisektorilla ja metsäsektorilla voisi pysäyttää maailmanlaajuisen luontokadon, vaikka mitään muita toimenpiteitä ei tehtäisi. Esimerkiksi suojelu- ja ennallistamistoimia ei ole huomioitu mallinnuksessa.

Luontokadon pysäyttämisen lisäksi kiertotaloussiirtymä voisi kattaa 28 prosenttia tarvittavista toimista, jotta saavutetaan sama luonnon monimuotoisuuden BII-taso kuin Integrated Action Portfolio (IAP)-skenaariossa. Leclère ym. (2020) ovat määritelleet IAP-skenaariossa kunnianhimoiset tarvittavat toimet luonnon monimuotoisuuden palauttamiseksi vuoteen 2050 mennessä.

Ruoka- ja maataloussektorin kiertotalousratkaisuilla on suurin ratkaisupotentiaali

Merkittävin kiertotalouden ratkaisupotentiaali luonnon monimuotoisuuden kääntämiseksi elpymisuralle on ruoka- ja maataloussektorilla. Sen osuus kiertotalousskenaariossa tapahtuvasta luonnon monimuotoisuuden elpymisestä on peräti 73 prosenttia. Kaikista selvityksessä mallinnetuista kiertotaloustoimenpiteistä vaihtoehtoisten proteiinien käytöllä on merkittävin rooli luontokadon pysäyttämisessä. Rakennussektorin ja rakentamisen osuus on 10 prosenttia, kuitujen ja tekstiilien 9 prosenttia ja metsäsektorin 8 prosenttia.

Kuva 2. Ruoka- ja maataloussektorin kiertotaloustoimenpiteet edistävät luonnon monimuotoisuuden elpymistä eniten
Lähde: Vivid Economics



Merkittävin kiertotalouden ratkaisupotentiaali luonnon monimuotoisuuden kääntämiseksi elpymisuralle on ruoka- ja maataloussektorilla.

Ruoka- ja maataloussektorin rooli on merkittävä, koska tällä hetkellä noin puolet asuinkelpoisesta maa-alasta on maatalouden käytössä. Ruoka- ja maataloussektorin kehittäminen kiertotalouden mukaiseksi on valtava mahdollisuus. Muutos on kestävän tulevaisuuden kannalta myös välttämätön. Ilman muutoksia ruoka- ja maataloussektorilla luontokatoa voidaan hidastaa, muttei pysäyttää.

Sektorikohtaiset tulokset

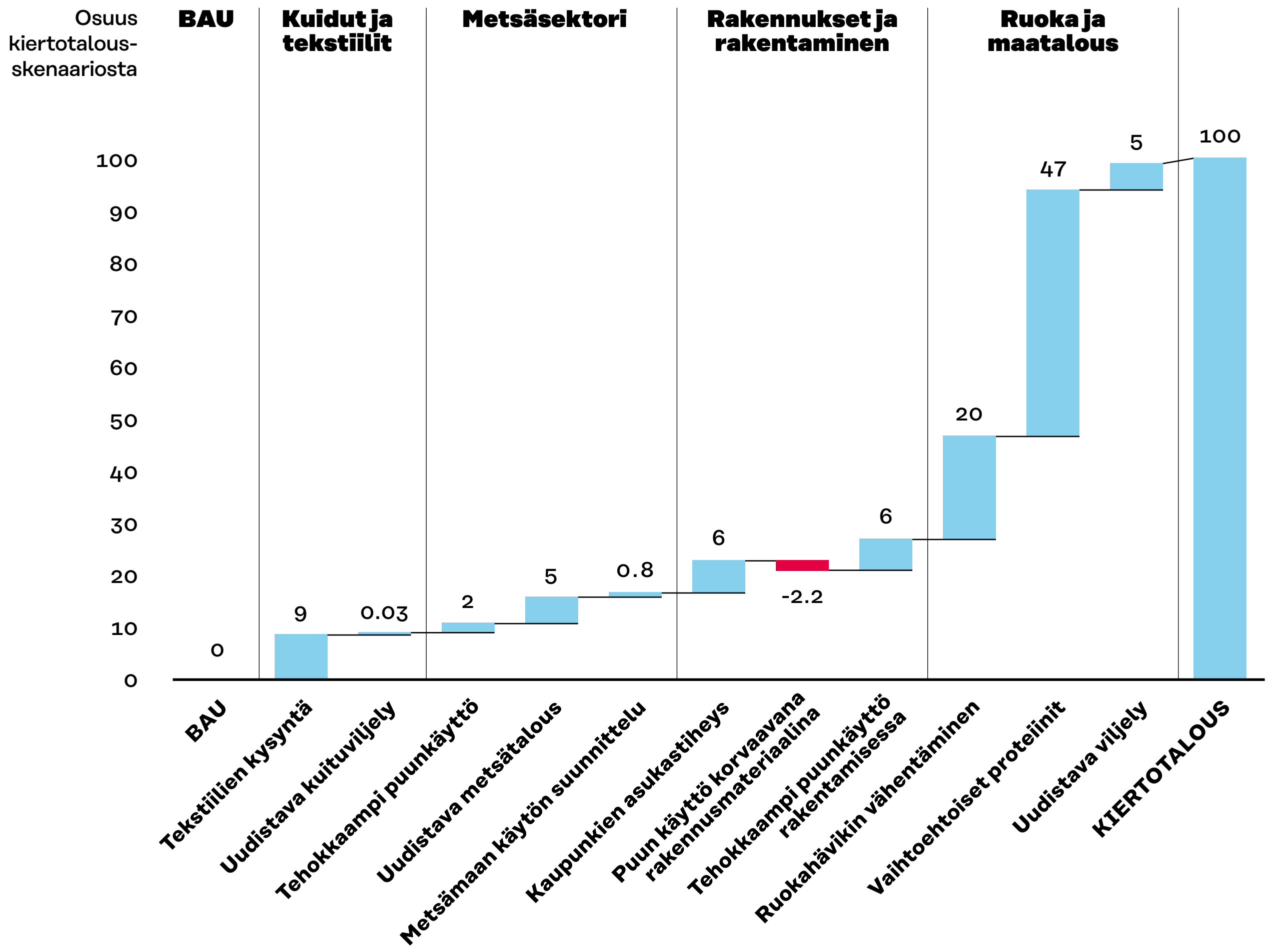
Maatalous- ja ruokasektorilla vaikuttavimpia kiertotaloustoimenpiteitä luontokadon pysäyttämiseksi ovat vaihtoehtoisiin proteiineihin siirtyminen, ruokahävikin vähentäminen ruokaketjun eri vaiheissa sekä uudistava viljely. Uudistava viljely tarjoaa laajan valikoiman menetelmiä, kuten suorakylvön, viljelykierron ja monilajisen viljelyn, täsmäviljelyn sekä luonnonmukaisen viljelyn. Näillä menetelmällä kohennetaan maaperän typenottoa, hiilensidontakykyä ja veden pidätyskykyä, mikä vaikuttaa positiivisesti myös luonnon monimuotoisuuteen.

Rakennusten ja rakentamisen sektorilla neitseellisen puutavaran kysynnän vähentämisellä ja kaupunkien asukastiheyden kasvattamisella on suurin positiivinen vaikutus luonnon monimuotoisuuteen. Rakennusten käytön optimointi, pidemmät elinkaaret sekä puumateriaalien uudelleenkäyttö ja kierrätys vähentävät puuntuotannon maankäytön tarvetta. Sen sijaan rakennuspuun kysynnän kasvulla on negatiivinen vaikutus luonnon monimuotoisuuteen.

Tekstiili- ja kuitusektorin kiertotaloustoimenpiteistä kysynnän vähentämisellä on suurin vaikutus luonnon monimuotoisuuteen. Kiertotaloustoimenpiteet laskevat näiden tuotteiden ja materiaalien kysyntää lisäämällä tekstiilien kestävyyttä sekä käyttöasteita, uudelleenkäyttöä ja kierrätystä. Myös kuitukasvien kuten puuvillan tuotannossa käytettävillä uudistavan viljelyn periaatteilla on positiivinen vaikutus luonnon monimuotoisuuteen.

Metsäsektorin kiertotaloustoimenpiteistä uudistava metsätalous on avainasemassa metsäluonnon monimuotoisuuden elpymisessä ja vahvistamisessa. Uudistava metsätalous yhdistää laajan valikoiman sovellettavia menetelmiä, kuten laho-, kelo- ja vanhojen puiden jätön, puuston eri ikärakenteita sekä luontaisten puulajien ja sekapuuston käytön. Lisäksi kiertotaloustoimenpiteet, kuten puutuotteiden elinkaaren pidentäminen ja uudelleenkäyttö, vähentävät puuraaka-aineen ottoa ja neitseellisen puun kysyntää. Ne tukevat luonnon monimuotoisuutta säästämällä metsiä hakkuilta.

Kuva 3. Vaihtoehtoisten proteiinien käyttö ja ruokahävikin vähentäminen ovat luonnon monimuotoisuuden kannalta merkittävimmät kiertotaloustoimet
Huom! Luvut kuvaavat luonnon monimuotoisuuden eheyden indeksin (BII) prosentuaalista muutosta, joka tapahtuu siirryttäessä kiertotalousskenaarioon vuoteen 2050 mennessä.
Lähde: Vivid Economics



Kiertotaloustoimet ja niiden vaikutukset eroavat toisistaan alueellisesti

Kiertotalouden tuomat mahdollisuudet ja vaikutukset eroavat alueittain, sillä tuotannon, kulutuksen ja kansainvälisen kaupan rakenteet ovat hyvin erilaisia eri puolilla maailmaa, samoin kuin luontoon kohdistuvat paineet.

Pohjoisella pallonpuoliskolla merkittävimmät positiiviset vaikutukset globaaliin luonnon monimuotoisuuteen saadaan aikaan siirtymällä kestävämpään kulutukseen, erityisesti vaihtoehtoisiin proteiineihin ja kiertotalouden mukaiseen tekstiilien käyttöön. Pohjoisen pallonpuoliskon kulutuksen muutos näkyisi ennen kaikkea maatalouden käyttöön tarvittavan maan vähenemisenä ja vähentyvinä maankäytön paineina latinalaisessa Amerikassa, Saharan eteläpuolisessa Afrikassa ja Intiassa.

Toisin kuin ruoka- ja maatalous sekä tekstiili- ja kuitusektoreilla, kiertotaloustoimet metsä- ja rakennussektorilla vaikuttavat pääasiassa paikallisesti: positiivinen luontovaikutus tapahtuu niillä alueilla, joilla toimia tehdään.

Kiertotaloudella voidaan samanaikaisesti pysäyttää luontokatoa ja hillitä ilmastokriisiä

Monet luontokatoa pysäyttävät kiertotaloustoimet vähentävät myös kasvihuonekaasupäästöjä. Kiertotalouden mahdollistama luonnon monimuotoisuuden vahvistuminen voi auttaa hillitsemään myös ilmaston kuumenemista esimerkiksi vähentämällä maankäytön päästöjä. Ilmaston kuumenemisen hillitseminen hyödyttää myös luontoa, sillä ilmastonmuutos on yksi viidestä hallitustenvälisen luontopaneeli IPBESin määrittelemistä luontokadon tärkeimmistä ajureista. Tulevaisuudessa ilmastonmuutoksen arvioidaan nousevan kaikkein merkittävimmäksi luontokadon aiheuttajaksi.

Selvityksen mallinnus osoittaa, että siirtymä kiertotalouteen voi vähentää maankäyttöä ja maankäytön kasvihuonekaasupäästöjä merkittävästi, ja jopa muuttaa maankäytön kasvihuonekaasupäästöjen lähteestä nieluksi. Pelkästään maankäytön muutoksen aiheuttama hiilinielun kasvu Euroopan unionin alueella riittäisi saavuttamaan komission ehdotuksen LULUCF-asetuksen vuosittaisesta 310 Mt CO_2 nettopoistuman tavoitteesta vuoteen 2030 mennessä. LULUCF-asetus määrittelee laskentasäännöt EU:n maankäytön, maankäytön muutoksen sekä metsätalouden nieluille ja päästöille.

Esimerkiksi ruoka- ja maataloussektorilla kiertotalouteen siirtyminen vähentäisi maatalouden metaanipäästöjä lähes 90 prosenttia vuoteen 2050 mennessä. Tulos havainnollistaa kiertotaloustoimien potentiaalia tarjota ratkaisuja sekä ilmastokriisiin että luontokatoon.

Kiertotalous lisää resilienssiä, luo työpaikkoja ja tuo kustannussäästöjä

Siirtymä kiertotalouteen lisää talouden resilienssiä vähentämällä riippuvuutta raaka-aineista, epävakaista markkinoista ja monimutkaisista toimitusketjuista.

Kiertotalouteen siirtyminen tarjoaa myös liiketoimintamahdollisuuksia ja luo työpaikkoja kaikilla tarkastelluilla sektoreilla. Siirtyminen vaihtoehtoisiin proteiineihin voisi vuosittain luoda maailmantalouteen 170 miljardin dollarin arvonlisän vuoteen 2030 mennessä ja peräti 500 miljardin arvonlisän vuoteen 2050 mennessä. Skenaariossa oletetaan, että tarvittavat investoinnit toteutuvat. Muutos voisi synnyttää globaalisti kolme miljoonaa uutta työpaikkaa vuosittain.

Kiertotalous tuo myös säästöjä tuottajille, jälleenmyyjille ja kuluttajille, kun resursseja käytetään tehokkaammin. Esimerkiksi puutavaran ja puuvillan kierrätys sekä ruokahävikin vähentäminen voivat jokainen tuoda yrityksille vuosittain kustannussäästöt, joiden suuruus on jopa 0,6–1,5 miljardia dollaria.

Miten eteenpäin?

Selvityksessä on tarkasteltu neljän sektorin kiertotaloustoimien potentiaalia pysäyttää maailmanlaajuista luontokatoa ja kääntää luonnon monimuotoisuus elpymisuralle. Kyseessä on ensimmäinen kerta, kun kiertotalouden ratkaisupotentiaalia mallinnetaan vastaavalla tavalla. Analyysilla on rajoitteensa, ja sitä voidaan täydentää, kun ymmärrys kiertotalouden eri keinoista vaikuttaa luonnon monimuotoisuuteen kehittyy.

Selvityksen ulkopuolelle on rajattu merien ja makeiden vesien ekosysteemit. Sektorit on valittu arvioimalla niiden maankäytön muutosten aiheuttamaa luontokatoa. On mahdollista, että jos analyysiin otetaan mukaan maankäytön ohella muita luontokadon ajureita ja ekosysteemejä, näyttäytyy kiertotalouden ratkaisupotentiaali vieläkin suurempana. Selvityksen tavoitteena oli esitellä mahdollinen ja saavutettavissa oleva kiertotalousskenaario. Kiertotalousskenaarion oletusarvot pitävät sisällään merkittäviä muutoksia nykyisiin toimintatapoihin, mutta ovat toteutettavissa nykyteknologioilla.

Päättäjät voivat ohjata kehitystä kestävämpään suuntaan nostamalla kiertotalouden keskeisempään rooliin luontokadon ratkaisijana. Lisäksi päättäjien kannattaa priorisoida erityisesti kiertotaloustoimia, jotka hillitsevät samanaikaisesti sekä luontokatoa että ilmastonmuutosta. Tarkastelluista kiertotaloustoimista etenkin vaihtoehtoisiin proteiineihin siirtyminen ja ruokahävikin vähentäminen edistävät myös merkittävästi ilmastonmuutoksen hillintää. Lisäksi kiertotaloudella voidaan vähentää maankäyttöä erityisesti biomassan tuotannosta.

Luonnon monimuotoisuutta voi parantaa vain ratkaisemalla sen haasteita globaalisti. Kiertotalousratkaisut voivat pysäyttää arvokkaan luonnon häviämistä myös toisella puolella maailmaa, missä menetämme nopeasti erityisen lajirikkaita alueita. Kiertotalousratkaisuilla Suomessa ja Euroopassa voidaan hillitä arvokkaimpien alueiden luontoon kohdistuvia paineita esimerkiksi vähentämällä liha- ja maitotuotteiden tai tekstiilien kysyntää.

Yritysten ja toimialojen kannattaa tarttua kiertotalouden mahdollisuuksiin ja vauhdittaa siirtymää hyödyntämällä olemassa olevia resursseja tehokkaammin. Yritys voi aloittaa tunnistamalla ja raportoimalla luontoriskinsä ja vaikutuksensa, minkä jälkeen se voi asettaa tieteeseen perustuvia tavoitteita luontotyölle ja hyödyntää kiertotaloustoimia näiden tavoitteiden saavuttamisessa. Resurssien säästämiseksi ja tehokkaimpien toimien priorisoimiseksi yritysten kannattaa tunnistaa toimia, joiden avulla voidaan sekä vähentää päästöjä että pysäyttää luontokatoa. Yritysten tulisi myös pyrkiä vähentämään biomassan tuotannosta syntyviä maankäytön paineita, erityisesti ruoantuotannossa.

Päättäjät voivat ohjata kehitystä kestävämpään suuntaan nostamalla kiertotalouden keskeisempään rooliin luontokadon ratkaisijana.

Sammanfattning

Varför studien gjordes: det är inte möjligt att stoppa förlusten av biologisk mångfald med dagens metoder

Den biologiska mångfalden minskar i en alarmerande takt överallt i världen och så även i Finland. Situationen är allvarlig eftersom hela mänsklighetens hälsa, ekonomi och välbefinnande är beroende av naturen.

På många håll har man börjat vidta åtgärder för att stoppa förlusten av biologisk mångfald, men hittills har varken de nationella, internationella eller företagsinitierade åtgärderna varit tillräckliga. Därtill har arbetet i för liten utsträckning utgått från att värna den biologiska mångfalden på global nivå, trots att vi i stor utsträckning både är beroende av och genom vår konsumtion också påverkar den biologiska mångfalden i andra länder. Det är ändå möjligt att stoppa den globala förlusten av biologisk mångfald. Det kräver en omfattande förändring och åtgärder som riktas mot grundorsakerna. Dagens ekonomiska system bygger på att nya naturresurser ständigt tas i bruk. Systemet är ineffektivt och ger upphov till stora mängder avfall. Därför måste det reformeras.

Den cirkulära ekonomin är en ekonomisk modell där befintliga resurser utnyttjas i så hög grad som möjligt. När värdet i produkter och material som redan är i användning utnyttjas så effektivt och länge som möjligt, minskar behovet att utvinna nya naturresurser, vilket frigör ett större livsutrymme för naturen.

Omställningen till en cirkulär ekonomi erbjuder både regeringar, företag och medborgare ekonomiska möjligheter samtidigt som ekologisk hållbarhet främjas. Inte minst är det möjligt att samtidigt avsevärt minska klimatutsläppen med cirkulära lösningar. Dock har inga tidigare modellberäkningar kvantitativt fastställt den cirkulära ekonomins potential att minska den globala förlusten av biologisk mångfald. Det främsta målet med den här studien är att fylla den kunskapsluckan.

Enligt studien kan den cirkulära ekonomin redan till 2035 stoppa förlusten av biologisk mångfald och därtill möjliggöra en återhämtning till den nivå av biologisk mångfald som fanns år 2000. Scenariot kräver betydande förändringar jämfört med nuvarande praxis och att både beslutsfattare och företag i större skala genomför cirkulära åtgärder.

Hur utfördes studien?

Studiens tyngdpunkt ligger på de fyra sektor som i sig har störst påverkan på den biologiska mångfalden på land och där cirkulära lösningar också kan spela en betydande roll för att minska förlusten av biologisk mångfald. De fyra sektorerna är jordbruk och livsmedel, byggnation och fastigheter, fibrer och textilier, och skogssektorn.

För att modellera den cirkulära ekonomins effekter på den biologiska mångfalden utformades två scenarier: Business as Usual (BAU), som även fortsättningsvis domineras av de nuvarande produktions- och konsumtionsmönstren, samt scenariot för den cirkulära ekonomin, där produktions- och konsumtionsmönstren bidrar till att avfallet och föroreningarna minskar betydligt, samtidigt som både produkters nyttjandegrad och livslängd förlängs avsevärt och behovet att utvinna nya naturresurser minskar.

I det cirkulära scenariot identifierades cirkulära åtgärder inom de fyra sektorerna. Åtgärdernas inverkan på den biologiska mångfalden uppskattades genom att modellberäkna de förändringar i markanvändningen som de möjliggjorde. För varje cirkulär åtgärd angavs standardvärden baserade på den mest etablerade akademiska litteraturen för att möjliggöra en jämförelse mellan de två scenarierna.

Nedan anges för var och en av de fyra sektorerna de modellberäknade cirkulära värdena och de förändringar i markanvändningen som de möjliggör till 2050.

Jordbruk och livsmedel. Köttkonsumtionen halveras och konsumtionen av mejeriprodukter minskar med 67%. Matsvinnet per person halveras och regenerativa principer tillämpas på 60% av jordbruksmarken och 18% av betesmarken. Jämfört med BAU-scenariot frigörs 640 miljoner hektar jordbruksmark för annan användning – motsvarande en och en halv gånger EU:s yta.

Byggnation och fastigheter. Efterfrågan på timmer minskar med 50% och befolkningstätheten i städerna ökar med 51%. Städer tar upp 14 miljoner hektar mindre yta än i BAU-scenariot.

Fibrer och textilier. Kläders livslängd ökar med 50% och återvinningsgraden för textilier ökar till 75%. Metoder för regenerativt jordbruk införs på 60% av den mark där bomull odlas. Bomullsodlingar motsvarande 24 miljoner hektar frigörs för annan användning jämfört med BAU-scenariot.

Skogssektorn. Pappersanvändningen minskar med 55% och efterfrågan på massa för papperstillverkning minskar med 48%. Metoder i linje med ett regenerativt skogsbruks tillämpas i 20% av sekundärskogar och i all annan, brukad skogsmark. 280 hektar skogshabitat undgår avverkning jämfört med BAU-scenariot.

Som en del av studien utfördes en omfattande modelleringsprocess för att uppskatta i vilken utsträckning det är möjligt att minska förlusten av biologisk mångfald i det cirkulära scenariot fram till år 2050.

De förändringar i markanvändningen som den cirkulära ekonomin möjliggör uppskattas med hjälp av den globala modellen för markanvändning MAgPIE (Model of Agricultural Production and its Impact on the Environment). Med hjälp av modellen beräknades allokeringen av landanvändning för både det cirkulära och BAU-scenariot. Modellen tar ett antal faktorer i beaktande, bland annat den förväntade befolkningsökningen, BNP-tillväxten, livsmedelskonsumtionen och efterfrågan på jordbruksprodukter, produktionskostnader, samt regionala förhållanden som sätter gränser för både land- och vattenanvändningen och möjliga skördenivåer. Parametrarna används i modelleringen av de sannolika förändringarna i markanvändning för de två scenarierna. De förändringarna kan därefter kopplas till lokala effekter på den biologiska mångfalden som följer av de cirkulära åtgärderna.

Effekten på den biologiska mångfalden mäts genom Biodiversity Intactness Index (BII), som beskriver den genomsnittliga förekomsten av vilda arter i ett givet geografiskt område jämfört med dess referenspopulation.

De antaganden som använts i studien och de viktigaste resultaten av modelleringen presenteras i bild 1.

Bild 1. Cirkulära åtgärder kan stoppa och vända förlusten av biologisk mångfald till 2050
Obs! De cirkulära åtgärderna möjliggör förändringar i landanvändning, antingen som skogs- eller jordbruksmark, oavsett i vilken sektor åtgärderna utförs. Exempelvis avverkas 280 miljoner hektar mindre skog som en följd av minskad efterfrågan på timmer, men också på textilier, livsmedel och byggmaterial.
Källa: Vivid Economics

	CIRKULÄRA ÅTGÄRDER	FÖRÄNDRINGAR I LANDANVÄNDNING
LIVSMEDEL OCH JORDBRUK	• Konsumtionen av **köttprodukter** minskar med **50%** och av **mejeriprodukter** med **67%** • **Matsvinnet** per person **halveras** • **Regenerativa** jordbruksprinciper tillämpas på **60%** av åkermarken och **18%** av betesmarken	**640 miljoner hektar jordbruksmark** frigörs för annat bruk
FIBRER OCH TEXTILIER	• **Kläders nyttjandegrad** ökar med **50%** • **Klädåtervinningen** ökar till **75%** • **Regenerativa principer** används på **60%** av bomullsodlingarna	**Bomullsodlingar** upptar **24 miljoner hektar** mindre mark
BYGGNATION OCH FASTIGHETER	• Effektivitetsvinster inom träbyggnation minskar **efterfrågan på timmer** med **50%** • **Förtätningen inom städer** ökar med **51%**	**14 miljoner hektar** mindre mark bebyggs
SKOGSSEKTORN	• **Pappersanvändningen** minskar med **55%** • **Återvinningen** minskar efterfrågan på pappersmassa med **48%** • **Regenerativa principer** tillämpas i **20%** av sekundärskogar och i **all** övrig brukad skog	**280 miljoner hektar** mindre skog avverkas

EFFEKTER

Förlusten av biologisk mångfald stoppas och en återhämtning till samma nivå som år 2000 nås till 2035

Till 2050 ökar koldioxidinlagringen från förändringar i markanvändningen till **1 Gt CO_2** om året

Metanutsläppen från jordbruket minskar med nästan **90%**

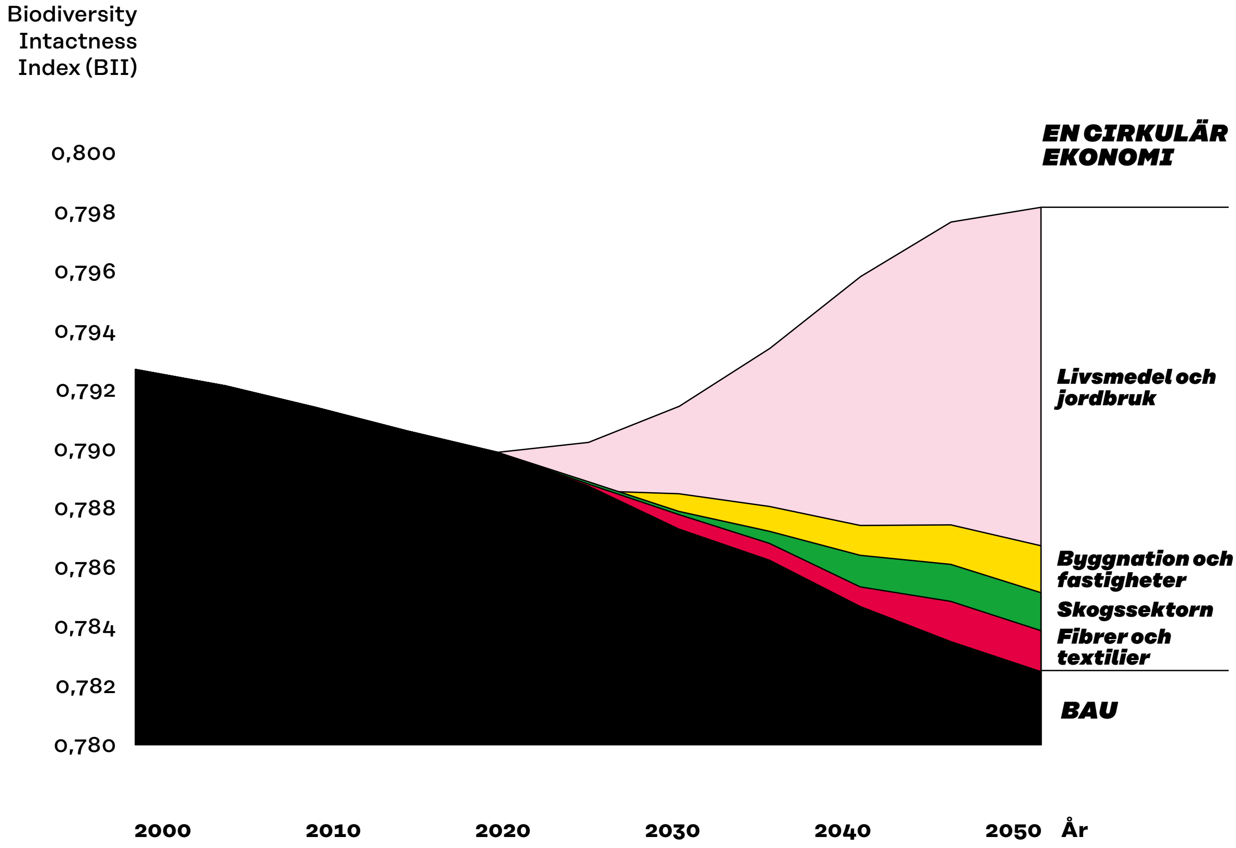
Resultat: Det är möjligt att vända den biologiska mångfaldens negativa utveckling

Enligt studien skulle en snabb omställning till en cirkulär ekonomi kunna stoppa den globala förlusten av biologisk mångfald senast år 2035, även om inga andra åtgärder vidtas. Till exempel beaktas inte åtgärder för skydd och återställande av natur i det cirkulära scenariot. Förutom att stoppa förlusten av biologisk mångfald skulle omställningen till en cirkulär ekonomi kunna bidra med 28% av de insatser som krävs för att uppnå samma nivå av biologisk mångfald, mätt i BII, som i scenariot Integrated Action Portfolio (IAP). Leclère et al. (2020) har i IAP-scenariot identifierat de steg som krävs för att uppnå högt ställda mål för den biologiska mångfaldens återhämtning till 2050.

Livsmedels- och jordbrukssektorns cirkulära åtgärder har störst potentiell inverkan

Den cirkulära ekonomins största potential att minska och vända förlusten av biologisk mångfald återfinns inom livsmedels- och jordbrukssektorn. Sektorns bidrag till det cirkulära scenariot uppgår till så mycket som 73%, och av alla cirkulära åtgärder som modellerats i studien har alternativa proteinkällor störst potential att minska förlusten av biologisk mångfald. Byggnations- och fastighetssektorn står för ytterligare 10%, medan fiber- och textilsektorn och skogssektorn utgör 9% respektive 8% av det cirkulära scenariot.

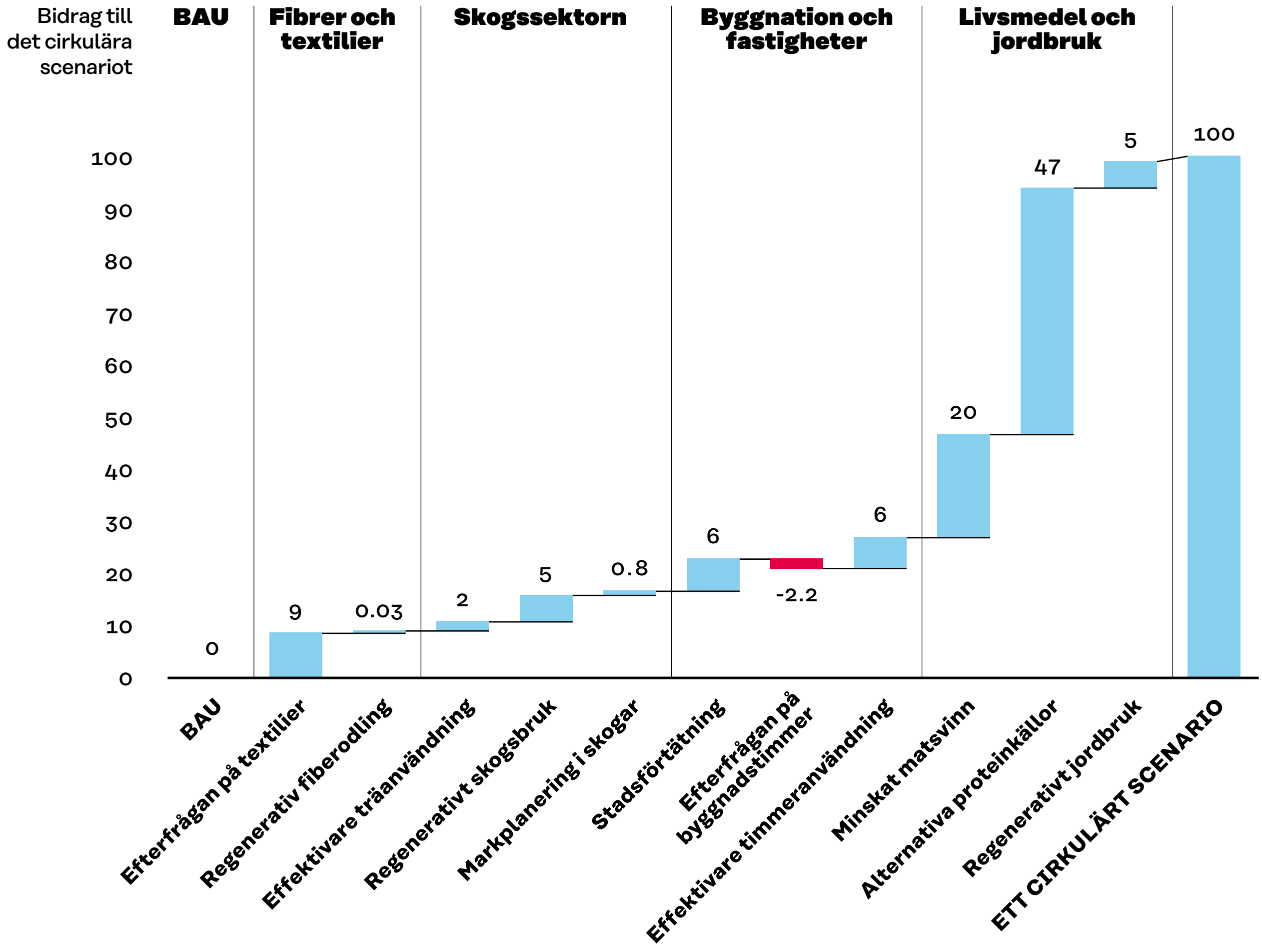
Bild 2. Livsmedels- och jordbrukssektorn bidrar mest till den biologiska mångfaldens återhämtning
Källa: Vivid Economics



Den cirkulära ekonomins största potential att minska och vända förlusten av biologisk mångfald återfinns inom livsmedels- och jordbrukssektorn.

Livsmedels- och jordbrukssektorns centrala roll beror till stor del på att omkring hälften av jordens beboeliga yta för närvarande används för jordbruk. En livsmedels- och jordbrukssektor i linje med den cirkulära ekonomin utgör en enorm möjlighet. Utan åtgärder för att reformera livsmedels- och jordbrukssektorn kan förlusten av biologisk mångfald bromsas men inte helt och hållet stoppas.

Bild 3. Alternativa proteinkällor och minskat matsvinn bidrar mest till den biologiska mångfaldens återhämtning i ett cirkulärt scenario
Obs! Talen markerar den procentuella förändringen i Biodiversity Intactness Index (BII) som sker vid en övergång till ett cirkulärt scenario år 2050.
Källa: Vivid Economics



Sektorspecifika resultat

Livsmedel och jordbruk. De cirkulära åtgärder inom livsmedels- och jordbrukssektorn som mest effektivt kan minska förlusten av biologisk mångfald består i att främja ett skifte till alternativa proteinkällor, att minska matsvinnet i olika led i värdekedjan, samt att ställa om till ett regenerativt jordbruk. Det regenerativa jordbruket kombinerar ett stort urval metoder, till exempel plöjningsfri odling, parallell odling av flera arter, användning av växtföljder, biokol, precisionsodling, ekologisk odling och agroekologi. De här metoderna bidrar till att förbättra markens förmåga att ta upp och binda kol, vatten och kväve och samtidigt ha en positiv inverkan på den biologiska mångfalden.

Byggnation och fastigheter. Minskad efterfrågan på jungfrulig träråvara och ökad förtätning i städerna har störst positiv effekt på den biologiska mångfalden. Längre livscykler för byggnader, en högre nyttjandegrad, samt ökad återanvändning och återvinning av trämaterial minskar behovet av träråvara och i förlängningen markanvändning. Å andra sidan har den ökade efterfrågan på träbyggnation samtidigt en delvis motverkande, negativ inverkan på den biologiska mångfalden.

Fibrer och textilier. Minskad efterfrågan på textilier och fibrer har störst inverkan på den biologiska mångfalden. Cirkulära åtgärder minskar efterfrågan på dessa produkter och material genom att öka textiliernas hållbarhet, nyttjandegrad, återanvändning och återvinning. De metoder för regenerativ odling som används vid produktion av fiberväxter så som bomull har också en positiv inverkan på den biologiska mångfalden.

Skogssektorn. Genom sina positiva effekter på skogars biologiska mångfald spelar det regenerativa skogsbruket en nyckelroll. Ett sådant skogsbruk kombinerar ett brett spektrum av metoder, såsom att lämna kvar äldre och murkna träd och död ved, samt att öka inslagen av lövträd, inhemska trädarter och olika åldersstrukturer. Cirkulära åtgärder minskar även behovet av jungfrulig träråvara genom längre livscykler och återanvändning av träprodukter, vilket möjliggör en minskad avverkning och därigenom gynnar den biologiska mångfalden.

De cirkulära åtgärderna och deras effekter skiljer sig åt regionalt

Såväl möjligheterna som effekterna som följer av den cirkulära ekonomin varierar från region till region, eftersom produktionsprocesser, konsumtionsmönster och handeln på många sätt skiljer sig åt runt om i världen. På samma sätt varierar trycket på naturen runt om i världen.

På norra halvklotet uppnås de mest betydande positiva effekterna på den biologiska mångfalden genom ett skifte till mer hållbar konsumtion, särskilt i fråga om alternativa proteiner och cirkulära principer i textilsektorn. Förändrade konsumtionsmönster på norra halvklotet skulle främst återspeglas i ett minskat tryck på naturen från jordbrukets markanvändning i Latinamerika, Afrika söder om Sahara och Indien. Till skillnad från textilier och fibrer och livsmedels- och jordbrukssektorn har cirkulära åtgärder inom skogs- samt byggnations- och fastighetssektorn en huvudsakligen lokal påverkan på naturen, i anslutning till där verksamheten äger rum.

Den cirkulära ekonomin kan samtidigt bekämpa förlusten av biologisk mångfald och klimatkrisen

Många cirkulära lösningar som minskar förlusten av biologisk mångfald kan samtidigt bidra till att stoppa klimatkrisen. Den cirkulära ekonomin minskar förlusten av biologisk mångfald, vilket i sin tur bromsar klimatuppvärmningen, till exempel genom att utsläppen från markanvändningen blir mindre. När den globala uppvärmningen bromsas upp påverkas naturen i sin tur positivt eftersom klimatförändringen är ett av de fem viktigaste trycken på naturen, det vill säga de faktorer som driver förlusten av biologisk mångfald. Den globala uppvärmningen väntas bli den främsta orsaken till förlusten av den biologiska mångfalden i framtiden.

Modelleringen i anslutning till studien visar att omställningen till en cirkulär ekonomi kan omvandla förändringarna i markanvändningen från en utsläppskälla av växthusgaser till en tillfällig kolsänka. Enbart i Europeiska unionen skulle förändringen räcka till för att tillgodose kommissionens förslag om ett årligt nettoupptag om 310 miljoner ton koldioxid senast 2030 enligt LULUCF-förordningen. I LULUCF-förordningen fastställs beräkningsreglerna för EU:s sänkor och utsläpp i fråga om markanvändning, förändrad markanvändning och skogsbruk.

I det cirkulära scenariot skulle metanutsläppen från jordbruket minska med upp till 90 procent. Resultatet betonar den cirkulära ekonomins potential att erbjuda lösningar på både klimatkrisen och förlusten av den biologiska mångfalden.

Den cirkulära ekonomin ökar resiliensen, skapar nya arbetstillfällen och medför kostnadsbesparingar

Omställningen en till en cirkulär ekonomi kommer att öka ekonomins resiliens genom att minska beroendet av råvaror, volatila marknader och komplexa leveranskedjor.

Omställningen till en cirkulär ekonomi erbjuder affärsmöjligheter och skapar arbetstillfällen inom de sektorer som undersöktes. Övergången till alternativa proteiner skulle årligen kunna generera 170 miljarder dollar i den globala ekonomin fram till 2030 och hela 500 miljarder dollar fram till 2050. I scenariot förutsätts att ett antal nödvändiga investeringar kommer att genomföras. Omställningen skulle även kunna skapa 3 miljoner nya arbetstillfällen per år.

Den cirkulära ekonomin erbjuder också besparingar för producenter, återförsäljare och konsumenter då resurser används mer effektivt. Exempelvis kan återvinning av virke och bomull och minskningar av livsmedelssvinnet ge företag årliga kostnadsbesparingar på mellan 0,6 och 1,5 miljarder dollar.

Vad är nästa steg?

I studien undersöks vilken potential åtgärder i linje med en cirkulär ekonomi inom fyra sektorer har för att minska den globala förlusten av biologisk mångfald och vända utvecklingen mot en återhämtning. Det här är första gången som den cirkulära ekonomins potential som en del av lösningen modellberäknas. Analysen har ett antal begränsningar och den kan kompletteras i takt med att vår kunskap om den cirkulära ekonomins olika möjligheterna att positivt påverka den biologiska mångfalden utvecklas.

Akvatiska ekosystem ingår inte i studien, då sektorerna har valts ut genom att uppskatta den minskning av biologisk mångfald som markanvändningen i de olika sektorerna orsakar. Ifall analysen kompletteras med ytterligare ekosystem och faktorer, utöver markanvändning, som driver minskningen av den biologiska mångfalden torde en än större potential för cirkulära åtgärder kunna påvisas. Målet med studien var att presentera ett möjligt scenario för cirkulär ekonomi som också är realistiskt att uppnå. I det cirkulära scenariot förutsätts genomgripande förändringar jämfört med nuvarande praxis, men som likväl är genomförbara med dagens teknologinivå.

Politiska beslutsfattare kan styra utvecklingen i en mer hållbar riktning genom att ge den cirkulära ekonomin en mer central roll i arbetet med att minska förlusten av biologisk mångfald. Därtill kan cirkulära åtgärder som både kan minska klimatutsläppen och förlusten av biologisk mångfald ges särskild vikt. Markanvändningen är en central faktor för att minska trycket på naturen, och cirkulära principer spelar en särskilt viktig roll genom att frigöra mark som används för produktion av biomassa. Den biologiska mångfalden kan bara räddas ifall utmaningen angrips med ett globalt perspektiv som utgångspunkt. Den cirkulära ekonomin utgör ett viktigt bidrag för att stoppa förlusten av värdefull naturen även på andra sidan jorden, där vi i dag i snabb takt förlorar särskilt artrika områden. Cirkulära åtgärder i Finland och Europa kan dämpa trycket på naturen i dessa områden, till exempel genom att minska efterfrågan på kött- och mejeriprodukter eller textilier.

Företag och industrier kan dra fördel av den cirkulära ekonomins möjligheter och påskynda omställningen genom en mer effektiv användning av befintliga resurser. Företag kan börja med att identifiera och rapportera naturrelaterade risker och påverkan på den biologiska mångfalden. Därefter kan vetenskapligt baserade mål sättas upp för naturarbetet, och cirkulära lösningar kan utnyttjas för att uppnå dessa mål. För att spara resurser och prioritera de mest effektiva åtgärderna kan företag med fördel identifiera åtgärder som både gynnar klimatet och den biologiska mångfalden. Företag bör också aktivt arbeta för att minska markanvändningen som biomassa- och särskilt livsmedelsproduktionen tar i anspråk.

Politiska beslutsfattare kan styra utvecklingen i en mer hållbar riktning genom att ge den cirkulära ekonomin en mer central roll i arbetet med att minska förlusten av biologisk mångfald.

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1 The loss of global biodiversity

1.1 Introduction to biodiversity: there is no well-being without it

What is biodiversity?

Biodiversity refers to the diversity and abundance of life on Earth. The Convention on Biological Diversity (CBD) defines biodiversity as: “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (CBD 2006). The terms “biodiversity” and “nature” are often used interchangeably, although they differ in that biodiversity refers to a characteristic of life, its diversity, rather than to the life itself, which can be called nature or wildlife.

Biodiversity loss is the decline in any of the components of biodiversity, including its genetic, species and ecosystems aspects. This study estimates biodiversity loss using the Biodiversity Intactness Index (BII), which considers the diversity of species only (Scholes and Biggs 2005), although changes in genetic and ecosystem diversity are likely to be in keeping with changes in species diversity. This study measures biodiversity at the global and regional scale, which precludes deeper interrogation of which species decline or increase in abundance. This is important because some species, termed keystone species, are considered more important for ecosystem function than others, but no distinction between these is made in this analysis.

Why is biodiversity important

Biodiversity is a precondition for the continued existence of humans. It underpins our life support system and it supports human activities and well-being, while possessing its own intrinsic value. The many reasons for protecting biodiversity can broadly be placed into three categories: utilitarian, cultural and intrinsic reasons. Utilitarian reasons refer to biodiversity’s role in supporting human activities through ecosystem services, such as providing clean water and air, or supporting crop diversity and pollination (Sukhdev et al. 2014). In fact, US$44 trillion, more than half of global GDP, is moderately or highly dependent on biodiversity and ecosystem services (WEF 2020a). Biodiversity underlies the resilience of these ecosystem services, as diverse habitats are better able to respond to change and disturbance (Dasgupta 2021). Biodiversity also has cultural and social value that varies between people and cultures. These capture the wide array of cultural, religious and spiritual values held about biodiversity (Dasgupta 2021, WWF 2020a). Biodiversity also has intrinsic value; it has value regardless of its usefulness to humans (Soulé 1985). This intrinsic value is a central motivation for protecting biodiversity, although it cannot easily be quantified.

Because of its wide-ranging value, protection of biodiversity has far-reaching implications for human and non-human life. Human activities and well-being can be enhanced and protected by ensuring biodiversity continues to provide its range of ecosystem, social and cultural services. Biodiversity enhancement and recovery can improve the provision of these services where they have been lost as a result of human activities.

How is it measured?

Quantifying biodiversity is needed to identify biodiversity hotspots in need of protection and the key drivers of biodiversity loss.

Measuring biodiversity accurately involves bridging the gap between precise theoretical measurements and less precise practical measurements of biodiversity. In other words, the gap reflects the difference between the conceptual definition of biodiversity, on which researchers generally agree, and the variety of proxy data available in practice. Table 1 below summarises some of the most important practical indices of biodiversity.

Robust measurement of biodiversity is now of critical importance from a policy perspective, given the 2030 global biodiversity targets of the Fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 15). Robust measurements are also central to ensuring that targets set by businesses can deliver effective biodiversity outcomes. To guide the process of setting such targets, the Science Based Targets Network has set out to develop science-based targets for nature. Clear and accessible targets are needed to reach agreements and co-ordinate efforts between a diverse range of actors.

1.2 Global trends in biodiversity loss

A sixth mass extinction?

Global biodiversity is in decline and is projected to continue to decline in the absence of efforts to reduce pressures from human activities.

Species extinction is currently estimated to be occurring at up to 1,000 times the "natural" background rate (Pimm et al. 1996). This has led scientists to suggest that we are in the midst of a mass extinction event (Ceballos et al. 2017), a phenomenon that has not occurred since the Chicxulub asteroid is believed to have wiped out the dinosaurs 66 million years ago (Chiarenza et al. 2020).

Table 1. Practical indices of biodiversity

Sources: Vivid Economics, based on Scholes and Biggs (2005); WCS (2005); IUCN (2020); EPI (2020); WWF (2020a); Swiss Re Institute (2020).

Name	Description	Metric
Biodiversity Intactness Index	Assesses how much of an area's natural biodiversity remains intact	The most authoritative source for BII data draws on the Natural History Museum's PREDICTS database
Global Human Footprint Index	Measures how much a biome has been altered by human activity	Rates human impact on biomes on a scale from 0 to 100 based on satellite imagery
Living Planet Index	Measures global biodiversity based on population trends of vertebrate species	Measures population trends in the 20,811 monitored populations of 4,392 vertebrate species
Red List Index	Tracks the extinction risk of groups of species over time	Assessment of 134,425 species and evaluation of their extinction risk
Species Habitat Index	Measures the proportion of suitable habitats that remain intact for a country's species	Ranks countries with a score from 0 to 100 based on the availability of intact habitats
Swiss Re Biodiversity and Ecosystem Services (BES) Index	Classifies and ranks worldwide ecosystems based on resource availability and habitat intactness	Aggregates data on nature-regulating services and resource availability at a resolution of 1 km^2 across the globe

The abundance of species has been declining at an accelerating rate since the 1970s, across all habitat types. Past and projected future biodiversity trends are summarised in Figure 4 for different habitat types. Populations of species have declined by almost 50% since the 1900s, with a 70% decline in vertebrate species populations since the 1970s. 40% of terrestrial animals are currently threatened with extinction. Many species have already been lost, and if we are to avert cataclysmic outcomes, immediate and significant interventions from policy-makers and businesses are paramount.

The uneven loss of biodiversity across the world

The loss of biodiversity has not taken place uniformly across the world. A major increase in the rate of biodiversity loss took place between the mid-19th and mid-20th centuries due to the expansion of agriculture and industry in Europe and North America. Since the second half of the 20th century, global biodiversity loss has increased at an accelerating pace, but the location of this loss has increasingly shifted away from Europe and North America, where biodiversity had largely been depleted during industrialisation, and moved to Africa, Asia and South America (Dasgupta 2021, WWF 2020a).

Over the last 50 years, biodiversity in the world's most biodiverse areas of Africa, Asia and Latin America[1] has decreased at a rate more than double that of Europe and North America.This is due to a range of factors, which include that these biodiverse regions have some of the highest natural levels of biodiversity, with a high number of endemic species, lower previous depletion of biodiversity than in Europe and North America and rapid recent industrialisation.

The positive trends in biodiversity in Europe and North America in part result from patterns of global trade that cause impacts in different regions.

Figure 4. Global biodiversity loss is occurring because of high extinction rates across all habitat types

Sources: Vivid Economics, based on FAO (2020a); FAO and UNEP (2020); IPBES (2019); WWF (2020a); Our World in Data (2021)

TERRESTRIAL

40% of animal species are threatened with extinction, including:

26% of mammals
40% of amphibians
14% of birds
10% of insects

FRESHWATER

30% of freshwater species are threatened with extinction

84% decline in average freshwater populations since the 1970s

35% of wetlands have been lost since the 1970s, with 85% lost since the 1700s

MARINE

35% of marine species are facing extinction, including:

30% of fishes and marine vertebrates
30% of aquatic mammals

50% of coral area has been lost since the 1850s

1 Latin America is a region in MAgPIE that includes South, Central and parts of North America. This includes Mexico and the Caribbean.

For example, estimates suggest that 33% of negative biodiversity impacts in Central and South America and 26% of impacts in Africa were driven by consumption in other parts of the world (Marques et al. 2019). This implies that measures taken to reduce biodiversity loss in one region can either increase biodiversity loss or have benefits for biodiversity in other regions too. Understanding these spatial dynamics of biodiversity loss is important for co-ordinating policy interventions.

Biodiversity recovery is occurring in parts of the world and will be a vital tool for preventing further global losses. Human-led restoration and natural regeneration of ecosystems can restore them to more biodiverse states. In severely altered ecosystems, human-led restoration may be necessary, but otherwise the removal of pressures on biodiversity can be enough to allow it to recover naturally. This is often called rewilding. Successes in biodiversity recovery in heavily modified landscapes include the recovery of wolf populations in Europe and North America or the increases in biodiversity in sites such as Oostvaardersplassen in the Netherlands and Knepp Castle Estate in England (Rewilding Europe 2022, Rewilding Britain 2022).

1.3 The drivers of biodiversity loss

Direct drivers of biodiversity loss

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identifies five main drivers for understanding the causes of biodiversity loss. The drivers are defined as key pressures applied by human activity on biodiversity, some of which result in immediate cases of extinction, while others drive biodiversity loss over longer timescales. These pressures are known as direct drivers of biodiversity loss. However, behind many of these direct drivers there are indirect drivers of biodiversity loss, such as economic growth, demographic changes and technology advances

Table 2. IPBES categorises five direct drivers of biodiversity loss

Sources: BCG (2021a); IPBES (2019); Morice et al. (2012); WWF (2020a)

Name	Description	Example
Changes in land and sea use	The conversion, degradation and modification of natural habitats from intactness to agricultural or industrial usage	An additional 100 million hectares of land is expected to be converted to agriculture globally by 2050
Direct exploitation of natural resources	The unsustainable extraction of resources from ecosystems before they can naturally regenerate	33% of fish populations are subject to direct exploitation
Climate change	The large-scale and long-term shift from the usual regional and global weather patterns and average temperatures	Average air temperatures have increased by 1.1 °C since the 1850s
Pollution	The contamination of ecosystems caused by the introduction of harmful substances	The contamination of waterways with pollutants rich in nutrients drives eutrophication, 78% of which is caused by agriculture
Spread of invasive alien species	The introduction of organisms in habitats where they are not native, which destabilises the local ecosystems	Recordings of exotic species have increased by 40% since 1980, mainly caused by trade, human mobility, habitat degradation and climate change

(IPBES 2019). The direct drivers are outlined in Table 2 below, with several examples.

The main drivers of biodiversity loss are changes in land and sea use and direct exploitation, followed by climate change, pollution and the spread of invasive alien species (IPBES 2019). Forecasts show that climate change, which is currently driving 11-16% of biodiversity loss, might become the main driver in the future (WEF 2020a, BCG 2021a, WWF 2020a). Since 1970, the pressure of each driver on biodiversity loss has accelerated (IPBES 2019). Understanding the root causes that drive biodiversity loss allows us to start to identify and co-ordinate solutions more effectively.

How sectors in the economy drive biodiversity loss

Today, land-use change is by far the largest driver of biodiversity loss on land. It is mostly driven by food and agriculture, infrastructure and industry. Agriculture uses 50% of habitable land globally, of which 77% is used to farm livestock for meat and dairy consumption or to grow crops for livestock consumption. Almost half of the forest area lost in the tropics has been converted to agriculture, chiefly for beef, palm oil and soybean production. Infrastructure may account for a small share of total land, but the world's urban land area increased by two thirds between 2000 and 2012 (WEF 2020a). Moreover, roads and other infrastructure can also threaten species by fragmenting their habitats. Lastly, changes in land and sea use also result from industry, as natural resources are extracted and processed (IPBES 2019, BCG 2021a, IRP 2019).

Direct exploitation of natural resources is primarily driven by damaging food and agriculture, forestry and fisheries practices. Damaging food practices include overharvesting, overhunting, overgrazing and poaching species at risk of extinction. Agriculture is also estimated to be responsible for 70% of freshwater withdrawals. Forestry is subject to unsustainable practices, as increasing demand for wood encourages overlogging (IPBES 2019, WWF 2020a, BCG 2021a). The global fishing industry mostly operates on an extractive model, where fishing rates exceed stock regeneration rates. It has been estimated that industrial fishing is practised in more than 55% of the ocean and that 33% of fish populations are overexploited (FAO 2020a, IPBES 2019).

Climate change impacts are caused by the release of greenhouse gas emissions. Global average temperatures reached 1 °C above pre-industrial levels in 2017 (IPCC 2018). As temperatures become warmer, entire habitats are transformed through, for example, ice melts, desertification and ocean acidification. Every 1 °C increase in temperature is correlated with a 5% average decrease in marine animal biomass (Lotze et al. 2019). These conditions might alter habitats to the point that they become unsuitable to their native species. Habitats also change because of the increasing frequency of extreme events such as droughts, wildfires, floods and storms. Extreme events might alter habitats and affect the survival of species that fail to adapt, decreasing genetic diversity across animals, plants and other organisms (IPBES 2019, WWF 2020a).

Pollution impacts are mostly driven by water and soil pollution from agriculture and industry, and by air pollution. Water pollution drives biodiversity loss in marine and freshwater habitats through phenomena such as eutrophication, 78% of which is caused by agriculture. Industrial agriculture relies on heavy use of fertilisers and pesticides, which then wash into waterways during rains. Another notable type of water pollution is plastic pollution, as estimates suggest 11 million tonnes of plastic enter the oceans every year (BCG 2021a). Air and soil pollution are also harmful to animal and plant health and development (IPBES 2019). For

Biodiversity loss is expected to accelerate in the future without global intervention.

example, excess nitrogen can adversely affect fungi and orchid species (Denholm et al. 2017).

The arrival of non-native animals, plants and other organisms into new habitats is caused by a variety of factors such as trade, tourism and crop cultivation in agriculture (BCG 2021a). Many non-native species do not cause biodiversity loss; indeed, species migration is a natural phenomenon. However, non-native species can outcompete or predate on native species. They may also become responsible for the introduction and spread of novel diseases to new environments (WWF 2020a, Swiss Re Institute 2020).

Future trends in biodiversity loss

Biodiversity loss is expected to accelerate in the future without global intervention. Additional land and sea-use change is expected to take place in response to population and income increases. Average temperatures and the frequency of extreme weather events are also predicted to increase, driving habitat degradation and species extinctions (WWF 2020a). As nature deteriorates, its productivity also declines, meaning diminishing returns from nature's contributions to people as biodiversity loss accelerates, which might encourage further and more aggressive exploitation (Dasgupta 2021). Thus, the sooner action is taken, the easier and cheaper it will be to make the transition.

Patterns of biodiversity loss will also change, as they will increasingly be driven by the effects of climate change. Average increases in air temperatures of between 1.4 and 2 °C are expected, even with the phasing out of fossil fuels by 2050 (IPBES 2019). As a result, climate change is expected to become the primary driver of global biodiversity loss, exceeding the pressure of changes in land and sea use by 2070. Together, changes in climate and land and sea use could lead to a loss of on average 38% of species from vertebrate communities by 2070 (Newbold 2018). For this reason, both land use and climate change are parameters used when selecting the most relevant sectors in this study.

Box 1. State of marine biodiversity

Marine biodiversity has been drastically reduced by five main drivers. Almost half of coral cover has been lost since the 1850s and 35% of marine species are currently facing extinction. The main drivers are as follows (IPBES 2019).

1. Direct exploitation (30%): overfishing is the main driver of biodiversity loss with the global expansion of fisheries leading to 34% of fish stocks being overexploited, up from 9% in 1978 (Ritchie et al. 2018).
2. Land and sea use change (25%): coastal infrastructure development including marinas and aquaculture lead to the destruction of marine habitats.
3. Climate change (15%): ocean warming, acidification and oxygen depletion have significantly impacted biodiversity; coral reefs have been particularly affected by "coral bleaching" events.
4. Marine pollution (15%): Various forms of pollution, from chemicals to plastics, cause pressures on marine biodiversity. Eutrophication, a result of excess nutrients, drives some of the most detrimental impacts on biodiversity, such as those manifested as coastal dead zones.
5. Invasive alien species (10%): increased trade, travel, habitat degradation and climate change have increased the prevalence of these species, often with devastating impacts; for example, the jellyfish-like sea walnut has contributed to the collapse of local fisheries in the Black Sea (Global Invasive Species Index 2022).

Marine biodiversity loss could lead to irreversible damage. The drivers will be exacerbated by population growth and wasteful, extractive practices. By 2050, there may be more plastic by weight in the sea than fish (WEF 2016). In particular, climate impacts will worsen, triggering severe ecosystem impacts, especially in coral reefs (IPCC 2019). Marine ecosystems provide vital services, supporting over three billion people, and they play a crucial role in the provision of food and drugs, tourism, carbon sequestration and climate adaptation. Fisheries employ 200 million people worldwide and the value of marine resources is estimated at $3 trillion (UN 2022, Global Ocean Commission 2014).

Policy initiatives have halted marine biodiversity loss. Examples include the Coral Triangle Initiative to promote more sustainable fishing in one of the planet's most biodiverse marine areas, and no-fishing zones in Mozambique which increased the number of species by three to four times within four years by letting stocks regenerate (WWF 2015). In fact, by protecting just 5% of key biodiverse marine areas, the future catch could increase by 20% (Cabral et al. 2020). While the urgency to act is clear, the scale of action required is insufficient, and the management approaches needed to mitigate this crisis are less well understood than for terrestrial biodiversity.

A shift toward a more systemic management of our oceans is crucial. Norway has developed an integrated ocean management plan to address overfishing, habitat damage and pollution (Norwegian Ministry of Climate and Environment 2017). As demonstrated by the plan, the drivers of biodiversity loss need to be addressed jointly. They also need to be addressed at the source. Many of the pressures driving biodiversity loss in the world's oceans arise on land, with some 80% of all marine pollution caused by human activities on land (COBSEA 2022). The role that a circular economy could play for oceans, for example by applying regenerative principles in fishing, reducing waste and giving us more value from marine resources, remains relatively unexplored.

1.4 Assessing the impacts of biodiversity loss

More than half of global GDP is moderately or highly dependent on biodiversity and ecosystem services. The Boston Consulting Group (BCG) (2021a) estimates that the world economy may be losing more than US$5 trillion in ecosystem services every year because of biodiversity decline, while Mission Économie de la Biodiversité (MEB) (2019) estimates that activities harmful to biodiversity such as land degradation are responsible for a 10% loss of GDP every year. According to the World Bank (2021a), land-use change alone will be responsible for a global loss in real GDP of between $90 and $225 billion in 2030. Some regions are particularly dependent on ecosystem services. For example, 63% of the Asia-Pacific region's GDP is at risk from biodiversity loss (WEF 2021).

The construction, agriculture, and food and drink sectors are most dependent on biodiversity (Swiss Re Institute 2020, WEF 2020a). 35% of our food depends on pollination, representing a major risk to human health and well-being (Klein et al. 2007). As resources become scarcer, the cost of food and other raw materials may increase by 8% by 2050. The burden of price increases is felt most in lower-income countries (De Palma et al. 2021). Biodiversity loss also increases the risks of zoonotic disease outbreaks, in particular as habitat degradation increases potential contact between humans and animals, a risk made more salient by the Covid-19 pandemic (Keesing and Ostfeld 2021).

These risks and dependencies are not accounted for in linear business models: less than 1% of companies have business models that are compliant with the Sustainable Development Goal (SDG) 14 (Life below water) and SDG 15 (Life on land) (S&P Global Market Intelligence 2022). The circular economy offers businesses new value creation opportunities by preventing biodiversity loss and supporting its recovery. The following section will examine in greater detail what the circular economy is and why it is important when addressing biodiversity loss.

2 The role of the circular economy

2.1 Why does the circular economy matter for biodiversity loss?

Biodiversity loss is occurring at an unprecedented rate globally, yet solutions to this crisis are far from the scale required to halt it. The question posed by this crisis is whether and how an economic system that has delivered prosperity to many at the expense of biodiversity can act in conjunction with nature, rather than against it.

Changing course requires transformative changes in today's economy, which is both extractive, polluting and wasteful. Agriculture and aquaculture threaten nearly two thirds of species at risk of extinction, yet over one third of all food produced is wasted (IUCN 2016, FAO 2011). Similarly, customers lose US$460 billion worth of value every year by discarding clothes that they could continue to wear, suggesting that vast improvements are possible across sectors (Ellen MacArthur Foundation 2017a). However, transformation at scale requires a fundamental rethink in the way products and materials are produced, consumed and managed, moving away from the current model that creates too much, too inefficiently and at too high a cost for the planet.

In this context, a circular economy offers possibilities to address the fundamental drivers of biodiversity loss at source. In Europe, policies at local, regional, national and supranational levels, including the European Union's Circular Economy Action Plan, have introduced the circular economy as a potential solution. Recent work by the Ellen MacArthur Foundation (2021a) sets out the conceptual basis for the ways in which the circular economy could tackle biodiversity loss. Yet the potential impact that a transition to a circular economy would have on halting global biodiversity loss remains poorly understood in quantitative terms.

2.2 What is the circular economy?

In recent years, the circular economy concept has gained traction and wider application due to increased interest in the impact of resource use on the environment, in particular among policymakers and businesses. The interest has been accelerated by its emergence as a solutions framework and tool for addressing multiple challenges and goals across sectors, not least climate change. Material Economics linked the circular economy to climate mitigation in quantitative terms in a 2018 study supported by the Ellen MacArthur Foundation and the Finnish Innovation Fund Sitra, among others (Sitra 2018), and again in 2019 (Ellen MacArthur Foundation 2019).

Despite the increasing interest in the circular economy, there does not exist a single, widely accepted definition of it. However, there are clear overlaps between conceptions of the main principles, which emphasise a shift from linear use of materials to circular flows by maximising both the value and utility of resources across the value chain. Of the 114 studied circular economy definitions, 38% included aspects of environmental quality in their definition, compared to 46% and 20% for economic prosperity and social equity respectively (Kirchherr et al. 2017). For many, the concept is closely associated with the Ellen MacArthur Foundation's "butterfly diagram", which through different tiers illustrates the continuous flow of both biological and technical materials that underpin the circular economy (Ellen MacArthur Foundation 2022a).

The Finnish Innovation Fund Sitra defines the circular economy as an economic model that aims to optimise the system as a whole and tackle the root causes of biodiversity loss, climate change and depletion of natural resources. Rather than producing more and more goods, in a circular economy we get more value from what we have, and we keep that value in the economy for as long as possible through smarter design, digital solutions and a shift from owning products to using services.

Only a limited number of studies have established a link between circular economy interventions and biodiversity. Consequently, this link remains imperfectly understood (INEC 2021). For instance, the European Commission's (2014) scoping study recognises the potential impact of some sectors, such as the food and construction sectors, on biodiversity, but climate change remains the focus of environmental impact considerations. A study published by the Finnish Ministry of the Environment is one of the first to quantitatively assess the ways in which circular economy actions can protect biodiversity at the national level (Ruokamo et al. 2021).

2.3 Aligning understanding of the circular economy and biodiversity

The circular economy offers tangible solutions to reduce the impacts on biodiversity by reducing resource use, but there is a need to align the concept of the circular economy and associated policies effectively with biodiversity. The circular economy is built on lessons learned from nature – from biomimicry to industrial ecology and other schools of thought, which together provide the basis for the circular economy as an umbrella concept (Blomsma and Brenna 2017). From this follows that circular solutions, which synthesise existing knowledge while also leveraging new design, digital and business model innovation, represent a pathway that is larger than the sum of their parts and largely additional to existing biodiversity actions. As the transition to a circular economy represents a direction of travel more than a fixed destination, plausible circular economy scenarios still imply some limited environmental impacts resulting from today's linear economy. In other words, this study represents not a scenario of complete circularity, but a trajectory thereto.

This study examines a wide variety of circular economy interventions that could affect biodiversity. The interventions can be divided into two groups (see Figure 5), the largest of which features circular economy measures which reduce the pressures on biodiversity by avoiding and reducing the demand for resources, by increasing the lifetime, use rate and circulation of products, components and materials (Boyer et al. 2021). Second, a smaller set of circular interventions are concerned with improving biodiversity outcomes in areas under production – regardless of the demand or resource produced – especially through regenerative principles applied to produce food and other biomass. While the first group mainly avoids and minimises negative impacts, the second group can also generate positive biodiversity outcomes. Drawing on these building blocks, this study rests on the following understanding of the concept:

> *The circular economy is a systemic approach to production, consumption and materials management that maximises both value and use, and applies regenerative principles. It prioritises non-toxic, renewable[2], and recyclable resources, and minimises waste by closing resource flows. This approach reduces the environmental pressures of resource extraction, production, consumption and waste to benefit habitats, species and genetic diversity.*

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2 "Renewability – using renewable and recyclable materials as well as renewable energy in product design and manufacturing". Source: Sitra 2019

A circular economy offers possibilities to address the fundamental drivers of biodiversity loss at source.

Figure 5. Hierarchy of biodiversity actions in line with a circular economy

Note: Figure 5 is based on the Science Based Targets Network's ARRRT action framework introduced in their initial guidance for businesses on science-based targets for nature. As mentioned in the guidance document, the distinction between avoidance and reduction strategies is largely a result of the baseline that is selected.
Source: Sitra, based on the Science Based Target Network's action framework ARRRT

1. AVOID

Prevent impact from the outset by rethinking the need to own things through new business models, virtualisation, and by designing out waste, for example with the help of alternative proteins and by making better use of existing buildings.

2. REDUCE

Minimise impacts, for example by increasing recycling of textiles to make new garments and by substituting inputs in production, for example protein sources for cattle or recycled content in paper.

3. REGENERATE

Drive regenerative outcomes in agriculture and other parts of the bioeconomy, to improve soil health, carbon sequestration, nutrient retention and diversity to build resilience.

RESTORE

Circular interventions can also be complemented by efforts to assist the recovery of degraded ecosystems.

4. TRANSFORM

Drive systemic change, notably by tackling the root causes of biodiversity loss across different drivers.

3 Selecting key sectors to tackle biodiversity loss by going circular

3.1 Framework for identifying the sectors most relevant for the circular economy scenario

The analysis focuses on four sectors that have the highest impacts on terrestrial biodiversity and have the potential for a range of circular economy solutions. To narrow down the sectors, a longlist of sectors collates the results of six prior studies that examine sectoral biodiversity impact. These studies are used to conduct a meta-analysis to narrow down the longlist to four sectors which are to be modelled in detail. This process is described in the following section. Four "screens" are used to identify the four sectors to be modelled, as follows.

- **Screen 1:** Which sectors have or will have the largest terrestrial biodiversity impact?
- **Screen 2:** In which sectors can the circular economy make the largest contributions to tackling biodiversity loss?
- **Screen 3:** For which sectors can we model terrestrial biodiversity impacts?
- **Screen 4:** Does this list adequately account for sector interlinkages?

This screening process is summarised in Figure 6. The sector definitions roughly align with industry standards on sector classification using definitions from the International Standard Industrial Classification (ISIC) and North American Industry Classification System (NAICS). The following sections summarise the screening exercise in more detail.

The full methodology for sector selection is included Appendix 1 – Sector selection methodology.

3.2 Final sector selection

The screening process described above determines that four sectors best capture the options for how the circular economy could affect terrestrial biodiversity.
These sectors are:

- Food and agriculture
- Forests
- Buildings and construction
- Fibres and textiles

These four sectors drive most of the world's total terrestrial biodiversity impacts; Figure 7 shows some of these impacts.

Figure 6. Four "screens" are used to filter the number of sectors to the four to be modelled in detail in this study

Source: Vivid Economics

LONG LIST (Screen 1)	HIGH-IMPACT SECTORS (Screen 2)	CIRCULAR ECONOMY-RELEVANT SECTORS (Screen 3)	SHORT LIST (Screen 4)
Food and agriculture	Food and agriculture	Food and agriculture	Food and agriculture
Forests	Forests	Forests	Forests
Buildings and construction	Buildings and construction	Buildings and construction	Buildings and construction
Fibres and textiles	Fibres and textiles	Fibres and textiles	Fibres and textiles
Other manufacturing	Other manufacturing	Other manufacturing	Other manufacturing
Water and wastewater	Water and wastewater	Water and wastewater	Water and wastewater
Transportation	Transportation	Transportation	Transportation
Fishing and aquaculture	Fishing and aquaculture	Fishing and aquaculture	Fishing and aquaculture
Mining	Mining	Mining	Mining
Oil and gas	Oil and gas	Oil and gas	Oil and gas
Tourism and recreation	Tourism and recreation	Tourism and recreation	Tourism and recreation
Hunting	Hunting	Hunting	Hunting
Solid waste	Solid waste	Solid waste	Solid waste
Power generation	Power generation	Power generation	Power generation

○ **Candidate sector** ○ **Screened out sector**

Screen 1: Which sectors have or will have the largest terrestrial biodiversity impact?

Screen 2: In which sectors can the circular economy make the largest contributions to tackling biodiversity loss?

Screen 3: For which sectors can we model terrestrial biodiversity impacts?

Screen 4: Does this list adequately account for sector interlinkages?

Figure 7. Food and agriculture, forests, buildings and construction, and fibres and textiles drive between 60% and 80% of total terrestrial biodiversity impacts

Source: Vivid Economics, figures from PBL (2014), WEF (2021), BCG (2021a), Natural Capital Coalition (2013)

60% of the expected **mean-species abundance loss** by 2050

75% of **terrestrial biodiversity** pressures

80% of **species threatened or near-threatened** by business activities

Annual damage to **natural capital** worth over **US$2.2 trillion**

4 Methodology

4.1 Modelling biodiversity and the circular economy

This study links circular economy interventions to tangible biodiversity impacts using a land-use modelling framework. Land-use change is a major driver of biodiversity loss, particularly for the sectors modelled here, and so presents a means of quantifying the biodiversity impact of each individual sector and lever within each sector. Within a land-use framework, the interactions, conflicts and synergies between competing land uses can be captured, giving a fuller picture of biodiversity loss than if they were modelled separately.

At the core of the modelling framework is MAgPIE, a state-of-the-art land-use model that is deployed to model how a shift to a circular economy impacts biodiversity. MAgPIE is a global, open-source model designed to explore land-use dynamics in the context of global environmental policies. It includes most of the key drivers of biodiversity loss of the four sectors identified, facilitating an in-depth analysis of global biodiversity impact to 2050. Box 2 describes the MAgPIE modelling suite in greater detail.

MAgPIE outputs allow us to understand the drivers and consequences of land-use change on a regional scale, over time and between scenarios. Biodiversity is quantified using the Biodiversity Intactness Index (BII), an indicator of biodiversity developed by Scholes and Biggs (2005). BII is an indicator of the average abundance of wildlife in a geographical area, relative to pre-modern times. It has been adopted by IPBES as a core indicator of progress towards the Convention on Biological Diversity's Aichi Targets 12 (Extinction prevented) and 14 (Ecosystems and essential services safeguarded), and it is used in the Planetary Boundaries framework (Martin et al. 2019, Steffen et al. 2015).

MAgPIE is used in this analysis to model a business-as-usual and a circular economy scenario to investigate whether a shift to a circular economy can support global biodiversity recovery up to 2050. The four sectors – food and agriculture, forests, buildings and construction, and fibres and textiles – were modelled together but in a way that enables us to identify the most important sectors and circular economy measures to support biodiversity recovery.

Some key impact channels are omitted from the analysis as a result of modelling limitations. These include the extraction of minerals used in construction, such as for steel or concrete, wild-catch and aquaculture fisheries, and impacts of water pollution on freshwater and marine ecosystems.

Box 2. MAgPIE model description

The Model of Agricultural Production and its Impact on the Environment (MAgPIE) is a global land-use allocation model designed to explore land-use dynamics in the context of global environmental policy. Developed by the Potsdam Institute for Climate Impact Research (PIK), MAgPIE is a spatially explicit, partial equilibrium model that calculates the allocation of land uses and investment in technical change to meet future demand for food and materials of agricultural origin, based on assumed population, GDP and food consumption growth. It also allows for land to be protected and set aside. It produces outputs in five-year time steps based on policy assumptions, such as carbon pricing and land-related policies. MAgPIE accounts for both biophysical constraints on yield, land and water, as well as for regional economic conditions. In addition to producing a land-use change raster, MAgPIE generates indicative cost estimates of policy instruments associated with a given action scenario.

These cost estimates include land conversion costs, inputs to global food and material production and investment in productivity enhancement and irrigation. The model outputs aggregate food and agricultural commodity prices. Thus, the model indicates producers' costs, costs to consumers and the strength of incentives needed to effect change.

MAgPIE also estimates the greenhouse gas emissions intensity of land use. It models three GHGs: carbon dioxide, nitrogen compounds and methane. It accounts for carbon dioxide emissions from loss of terrestrial carbon stocks, including the depletion of organic matter in soils. Nitrogenous emissions are estimated based on nitrogen budgets for croplands, pastures and the livestock sector. Methane emissions are based on livestock enteric fermentation, animal-waste management and rice cultivation areas. When regrowth of natural vegetation occurs, it is recorded as negative emissions in the GHG accounts.

4.2 Building a circular economy scenario

Four-step approach for building a circular economy scenario

To model the terrestrial biodiversity impacts of the circular economy out to 2050, two scenarios are needed: a business-as-usual (BAU) scenario and a circular economy scenario. Four steps are followed to construct and model these scenarios, outlined as follows.

1. Define narratives for the circular economy and BAU scenarios
2. Determine the "exogenous" economic, demographic and policy assumptions that match to these scenario narratives
3. Identify the circular levers to be pulled in each sector in the circular economy scenario and map these levers to switches in MAgPIE[3]
4. Assign values and assumptions to each of these switches based on literature

The following sections cover each of these steps in detail.

3 Levers refer to circular economy actions or combinations of actions that can be taken; switches refer to parts of the MAgPIE modelling interface we can use to model these levers.

Step 1: Define narratives for the circular economy and BAU scenarios

Defining a circular economy narrative first requires outlining a working circular economy definition. The circular economy definition in this study has been described in the last section of the chapter on the role the circular economy.

This definition is then used to establish a more detailed circular economy scenario narrative and a BAU scenario narrative. Common to both scenarios are the assumptions that economic and population growth follow middle-of-the-road forecasts and that trade policy moderately liberalises. The scenarios differ in the circular economy's emphasis on increasing product lifetimes, use rates and circulation, as well as regenerating areas under production. This is outlined in the next two paragraphs.

Under business as usual: Historic linear production and consumption systems persist. This results in substantial increases in material consumption as populations grow and incomes rise. Food production both expands in area and relies on increasingly intensive production methods to feed this growing and increasingly affluent population.

In the circular economy: The world transforms production and consumption systems to significantly reduce waste and pollution, increase product use rates, extend product lifetimes and regenerate areas under production. Policies and preferences shift so that consumption of new materials decreases substantially, for example through shifting to alternative source of protein, extending the use of clothes and increasing recycling. Producers use techniques that reduce pressures on biodiversity, such as reducing synthetic fertiliser use, using more timber in construction and constructing buildings and materials to last longer.

Step 2: Determine the exogenous economic, demographic and policy assumptions for the scenarios

To establish a robust vision of what the future looks like under both scenarios, assumptions are made about how society develops outside of any transition. This includes demographic, economic and policy trajectories such as population and GDP growth, as well as nature protection policies. These assumptions are mostly consistent between scenarios as they are not directly related to the circular economy. Specific assumptions are set out in table 10 in appendix 2.

Step 3: Identify circular economy levers and map these levers to switches in MAgPIE

For each sector, circular economy levers were identified and mapped to the model switches available in MAgPIE. This is outlined in Figure 8, where levers map to model switches of the same colour. Multiple circular levers can be accounted for by a single model switch. For example, the construction timber savings switch encompasses recycling of construction timber, reduced overspecification of buildings (i.e., designing out unnecessary material use) and extending building lifetimes.

The levers included in this study have co-benefits that cannot always be captured in the land-use modelling. For example, timber-framed buildings are lighter, thus requiring less concrete in building foundations. This lower concrete demand would alleviate biodiversity pressures from mineral extraction, but this is not captured here.

The circular economy transition that takes places in each sector is as follows.

Food and agriculture: A shift to a circular economy minimises pollution and food loss and waste across the supply chain, increases the efficiency of production to reduce input requirements, particularly for proteins, sparing more land for natural ecosystems, and uses regenerative agriculture to reduce agriculture's impact to reverse biodiversity loss in and around cultivated areas, through a selective application of no-till methods, crop rotation and polyculture, biochar, precision agriculture, and organic and agroecology principles.

Forests: The circular economy reduces the demand for new timber by improving product lifetimes and reusing products and materials. Lower timber demand reduces the land needed for timber forestry, freeing up land for nature. New wood is sourced from forests that are managed according to regenerative principles to secure a fuller range of ecosystem services, including by keeping old, decaying and dead trees, native species, and by using a mix of age classes and species. This ensures that forestry land is managed to improve biodiversity outcomes, while also providing co-benefits from more diverse forest management.

Buildings and construction: The circular economy uses less material input by extending building lifetimes, optimising their active use, reducing overspecification in buildings and reusing and recycling materials. Urban area densities are increased to reduce demand for land. More sustainable materials are sourced, principally use of timber products such as cross-laminated timber (CLT) in place of structural steel and concrete. This creates tensions with timber demand reductions in forestry, a theme that will be explored in the results section of the report.

Fibres and textiles: The circular economy reduces demand for new materials by increasing the durability, use rates, reuse and recycling of clothing. For clothing demand that is met by using new materials, regenerative methods of cultivation are used. These practices reduce the sector's impact on biodiversity through sparing more land for natural ecosystems and actively contributing to increased biodiversity in cultivated areas.

Step 4: Assign values and assumptions to each of these switches based on literature

To attempt to arrive at a set of consistent values for circular economy levers, the levers in each sector were given values according to assumptions that entail significant and far-reaching shifts, but which are considered technically feasible. The most rigorous values were sought, from a combination of existing literature, current global best practice (that could be adopted globally) or existing policy targets for future resource efficiency or use. Scenarios from the literature include those outlining possible future policies or resource-use scenarios, such as timber construction demand from Churkina et al. (2020). Alternatively, where these are not available, policy targets or current best practice are used, such as with construction timber recycling.

The description of all the levers, the switches they map to and the circular economy values they are assigned are all outlined in detail in table 11 in appendix 2. This also includes information on the baseline values and sources for these assumptions.

Figure 8. Circular economy levers are mapped to model switches available in MAgPIE

Note: Circular economy levers map to model switches of the same colour.
Source: Vivid Economics

CIRCULAR ECONOMY LEVERS	MODELLING SWITCHES
FOOD AND AGRICULTURE	
• Increased feed quality • Alternative proteins • Fadeout of first-generation biofuels • Animal-waste management • Improved field residue use • Reduced food loss and waste • Regenerative agriculture	**Alternative proteins** Alternative proteins, feed quality **Food waste** Food waste, field residues, animal waste management, biofuels **Regenerative agriculture** Farmland BII, nitrogen uptake efficiency, irrigation efficiency
FORESTS	
• Managed forest share of timber production • Renegenerative forest management • Paper processing efficiency and recycling • Reduced paper use • Furniture processing efficiency, longevity and recycling	**Forest land-use planning** More timber produced from forests managed according to best practice **Regenerative forestry** Regenerative forest management **Forestry timber savings** Timber demand savings
BUILDINGS AND CONSTRUCTION	
• Greater use of timber in construction • Extending building lifetimes • Reduce building overspecification • Reuse and recycling of construction timber • Urban density increases	**Construction timber demand** Increased timber demand for construction **Construction timber savings** Reduced timber demand for construction **Urban density** Reduced urban area growth
FIBRES AND TEXTILES	
• Increased lifetime of clothing • Textile recycling • Regenerative agriculture on cropland used for fibre production	**Textiles demand** Cotton, leather and wool demand **Regenerative fibre cultivation** BII on cropland used for fibre production

Figure 9. The circular economy halts and reverses biodiversity loss and helps mitigate climate change by 2050
Note: The circular lever changes result in drivers of impacts measured as land-use change, either as forests or agricultural land, regardless of in which sector the lever change occurs. For example, the changes to the 280 million hectares of natural forests accrue from reductions in demand for textiles, food and building material, as well as timber.
Source: Vivid Economics

CIRCULAR LEVER CHANGES		→ DRIVERS OF IMPACTS
FOOD AND AGRICULTURE	• **Meat** consumption falls by **50%** and **dairy** consumption falls by **67%** • **Food waste** per capita falls by **50%** • **Regenerative** principles are applied on **60%** of croplands and **18%** of pasturelands	**Agricultural land** area falls by **640 million hectares**
FIBRES AND TEXTILES	• **Use rate of clothing** increases by **50%** • **Recycling** of clothing increases to **75%** • **Regenerative** principles are used on **60%** of the land used for cotton cultivation	**Cotton cultivation** area falls by **24 million hectares**
BUILDINGS AND CONSTRUCTION	• **Construction timber** efficiency savings reduce demand by **50%** • **Urban density** increases by **51%**	**14 million hectares** are spared from **urban area** development
FORESTS	• **Paper use** falls by **55%** • **Recycling** reduces new pulp demand by **48%** • **Regenerative** principles are applied in **20%** of secondary forests and in **all** other managed forests	**280 million hectares** of **natural forest** is spared

IMPACTS

Biodiversity loss is halted and biodiversity recovers to 2000 levels by 2035

By 2050, **1 Gt of CO_2** is sequestered a year through land use change

Methane emissions from agriculture fall by almost **90%**

5 Results

5.1 The implications for biodiversity of the circular economy

This section first outlines the modelled biodiversity impact of the circular economy across key sectors on a global scale and compares these findings to existing studies. It then considers how these impacts vary regionally. Finally, the synergies in the results between biodiversity recovery and climate change mitigation are examined. The results are summarised in the infographic in Figure 9. Following this, some of the economic impacts of the transition to the circular economy are explored.

Results and comparison to similar studies

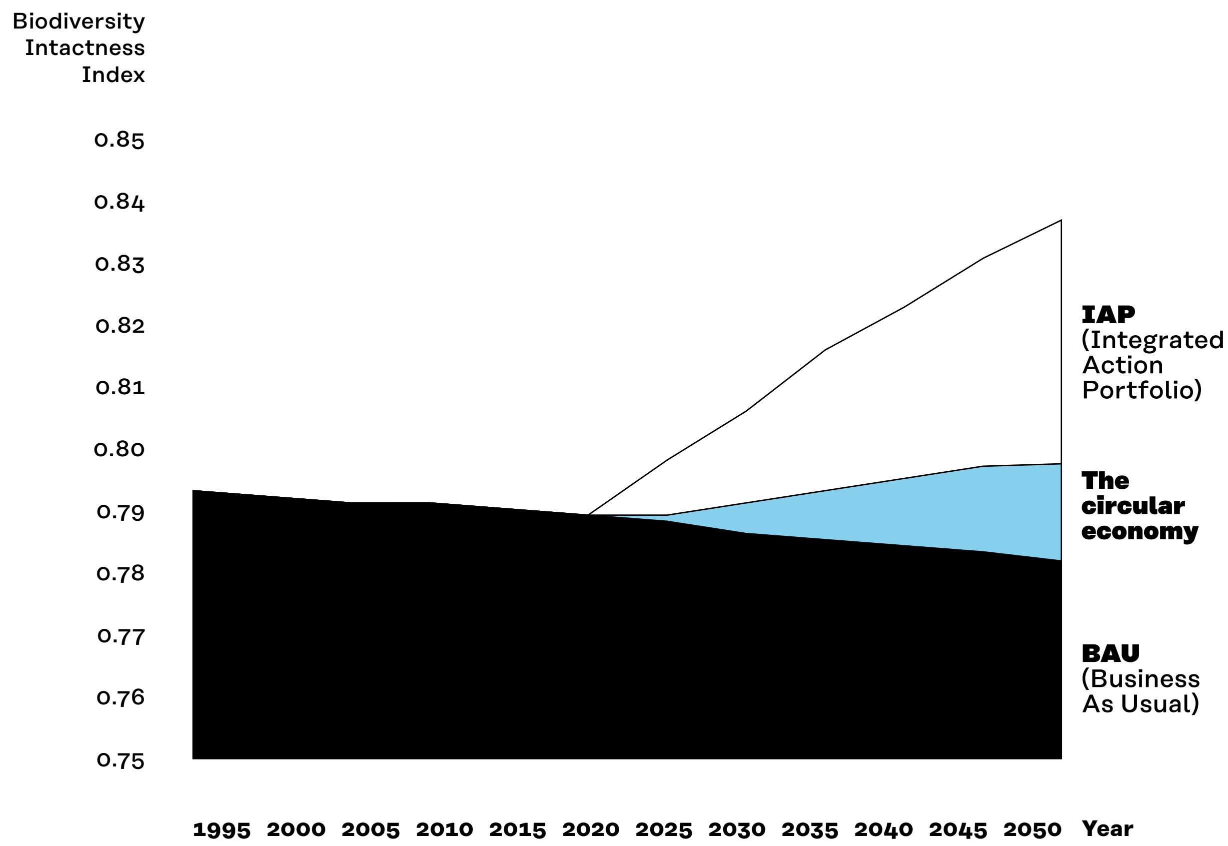
This study finds that the transition to a circular economy could halt and begin to reverse global biodiversity loss. Under the circular economy scenario, the global Biodiversity Intactness Index (BII) increases from 0.7900 today to 0.7984 in 2050. Under the business-as-usual scenario, it falls to 0.7825 in 2050. This means that, under the circular economy, species populations would recover to almost 80% of their pre-modern levels by 2050, compared to 78% under business as usual. This difference would approximately be the equivalent of moving from the BII of Italy (0.65) to the BII of Germany (0.67) (RSPB 2019). Because biodiversity recovers above 2020 levels, approximately 47% of biodiversity impact modelled here involves reducing biodiversity loss, while the remaining 53% increases biodiversity relative to today, for example through freeing up farmland, which can return to a state of natural forest.

The circular economy scenario fulfils 28% of the progress needed to fully "bend the curve" of biodiversity loss, that is, halting and substantially improving levels of biodiversity. Bending the curve refers to an ambitious scenario developed by Leclère et al. (2020), the Integrated Action Portfolio (IAP) Scenario, to get BII halfway towards its planetary boundary of 0.9 by 2050. 13% of this improvement compared to our BAU can be attributed to halting further biodiversity loss and 87% to far-reaching restoration efforts which increase BII above today's level. In other words, the scope of the IAP largely exceeds the scope of this study since it combines changes in resource production and consumption with a large expansion in protected areas and payments for biodiversity recovery. The IAP scenario is chosen for this comparison because it is prominent in the literature, for example informing WWF's Living Planet Report (2020a), and as it does not rest on assumptions about uncertain future technologies. The IAP scenario and the circular economy scenario in this study are shown in Figure 10.

Research by UNEP's International Resource Panel also lends support to our findings regarding the centrality of biomass (IRP 2019). It agrees on the importance of our modelled sectors for terrestrial biodiversity: it finds that more than 90% of global biodiversity loss, and about half of global GHG emissions are caused by resource extraction and processing. In their modelling, the study from the International Resource Panel focuses on one of the drivers of biodiversity loss rather than on the solutions needed to halt biodiversity loss. Our circular economy scenario successfully halts biodiversity loss.

Figure 10. The circular economy scenario fulfils 28% of the progress towards the Bending the Curve scenario

Source: Vivid Economics



However, it does not accomplish this by eliminating all of the 90% of land use-related biodiversity loss due to extraction and processing activities – as these activities are not altogether halted by 2050 – but rather through a combination of interventions that reduce the demand for resources that drives their extraction and land-use change, by freeing up land for nature and by regenerating areas under production. As described in the previous paragraph, our circular economy scenario does not include complementary protection and restoration policies.

Other studies on stemming biodiversity loss have produced different results to our study, with biodiversity loss continuing despite interventions. For example, Schipper et al. (2020) model an alternative sustainability scenario, in which less meat is consumed, protected areas are expanded and agricultural productivity improves, but biodiversity still declines. Our study models more policies and sectors, which could help explain the greater biodiversity impact. There are however some similar findings: Schipper et al. (2020) do find large future biodiversity losses in Sub-Saharan Africa, which is a finding in this study under business as usual. Similarly, in a study by the Netherlands Environmental Assessment Agency (PBL), modelled nature protection policies have the greatest benefits in regions with greater current biodiversity (Kok et al. 2020), which is in line with our study.

Box 3. The overlap between the circular economy and the bioeconomy

The bioeconomy broadly relates to the production and use of biological resources that replace fossil and other mineral resources to provide goods and services (Bugge et al. 2016). One of many definitions describe it as the "production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products (such as packaging) and bioenergy" (European Commission 2012).

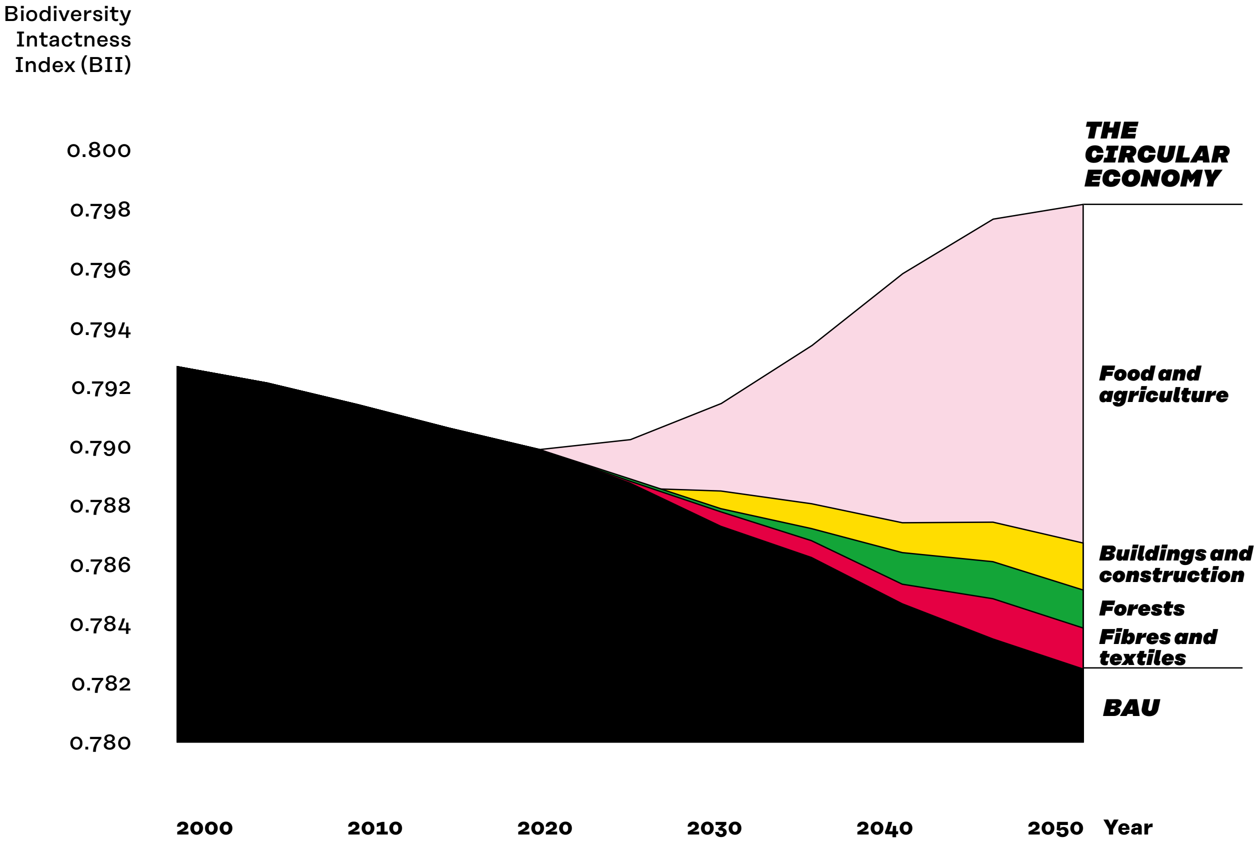
A "circular bioeconomy" has emerged – with different interpretations. The circular bioeconomy has gained traction in an attempt to integrate the two concepts. It can be interpreted as either i) a (conditional) part of the circular economy; ii) an intersection between the bioeconomy and the circular economy; or iii) more than the sum of the two (Stegmann et al. 2020). One of a few definitions describes "more efficient resource management of bio-based renewable resources by integrating circular economy principles into the bioeconomy" (Hetemäki et al. 2017). This implies a conditional understanding, where principles of the circular economy to varying degrees are applied as a resource management approach to the bioeconomy, with the relationship between the three concepts following from the extent to which circular principles are ultimately applied.

More value from limited biomass resources. The overlap between the concepts is particularly important given the centrality of biomass in driving biodiversity loss. Moreover, a study from 2021 underlines that there is not enough biomass to meet growing demand (Sitra 2021a). In line with the value hierarchy presented by Stegmann et al. (2020), the study implies that biomass be reserved primarily for high-value applications, mainly for materials, pulp and other fibres, as well as chemicals, while updates to the EU Renewable Energy Directive can be considered necessary.

Biodiversity recovery resulting from the circular economy

The food and agriculture sector has the greatest impact, making up 73% of the positive biodiversity impact in the circular economy. Figure 11 provides a breakdown of each sector's contribution over time. Buildings and construction, fibres and textiles, and forests contribute 10%, 9% and 8%, respectively. The importance of the food and agriculture sector presents an opportunity to policymakers but also a challenge: without reforming the food and agriculture sector, biodiversity decline is lessened but not altogether halted. These results are expected, given that agriculture currently uses approximately half of the world's habitable land.

Figure 11. The food and agriculture sector makes the greatest contribution to biodiversity recovery
Source: Vivid Economics



Land-use drivers of biodiversity recovery

Changes in biodiversity in this study are largely driven by changes in land use, both in terms of what land is used for and how it is used. Understanding the impact of land-use drivers of biodiversity sheds light on some of the causal mechanisms of the circular economy interventions. It also gives some indication of the type of habitats that the circular economy does and does not benefit.

Changes in agricultural land area is the major driver of biodiversity recovery, with 640 million hectares – an area roughly one and half times the size of the European Union – freed up in a circular economy by 2050 relative to business as usual. Figure 12 provides a visual comparison of global hectares of agricultural land under the two scenarios. Differences in agricultural land between scenarios are primarily driven by a reduction in livestock production and food waste, which fall by 78% and 74% respectively in 2050, compared to business as usual. Freeing up of agricultural land area (Figure 12) is therefore mostly driven by reductions in pastures and rangeland (Figure 13), with only modest falls in cropland area.

Some 280 million hectares of natural forest is spared, including 84 million hectares of primary forest – two and a half times the size of Finland.[4]

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4 Primary forest refers to undisturbed forest areas, while secondary refers to areas that have previously been deforested but that are regrowing. Once primary forest is lost it cannot be recovered, although mature secondary forest can have similar levels of biodiversity to primary forest. Natural forest refers to the grouping of primary and secondary forest (natural forest = primary forest + secondary forest).

This is facilitated by 40% less timber being extracted from forests every year, as well as forests spared from conversion to agricultural land. Urban areas are 13.5 million hectares smaller compared to business as usual as urban density increases, and land used for growing cotton falls by 75%, or 24 million hectares, as a result of increasing circularity in the textiles sector.

Some loss of primary forest does still occur in the circular economy scenario. This is illustrated in Figure 15. The modest recovery of natural forests between 2020 and 2050 in the circular economy (Figure 14) is driven by regrowth of secondary forests. This suggests that, while the circular economy leads to biodiversity recovery on the global scale, it does not mean that all valuable primary forest habitats are saved. This confirms the need for accompanying nature protection policies, which were not included in this analysis. Having said this, reduced demands on land use under the circular economy scenario would leave room for nature and reduce the trade-offs associated with protecting land.

5.2 How different aspects of the circular economy affect biodiversity

Identifying the impact of individual circular economy levers

Examining the impact of individual levers helps identify the most important policy priorities. This way, interventions with the most impact can be easily identified by companies and policymakers. Looking within sectors also highlights potential conflicts between circular interventions, for example with any negative impacting levers, which otherwise could be accepted within a suite of sector policies.

The use of alternative proteins in the food and agriculture sector is the single most effective lever, alone accounting for 47% of the circular economy scenario. Alternative proteins encompass a range of, often plant-based, alternatives to conventional proteins such as meat and dairy (see Box 7). Reducing food loss and waste accounts for another 20% of the circular economy scenario. These results are unsurprising given the amount of land allocated to meat and dairy production and the scale of global food loss and waste. Regenerative fibre cultivation and forest land-use planning levers have only modest impacts as they concern relatively small areas of land.

Importantly, construction timber demand, in which more timber is demanded for use in buildings, has a negative impact on biodiversity as extraction of timber increases. Figure 16 illustrates the contribution of each lever to overall biodiversity recovery from business as usual to the circular economy in 2050.

Food and agriculture

In the food and agriculture sector, the alternative proteins lever (see Box 7) makes the greatest contribution to biodiversity recovery. In switching from meat and dairy to mostly plant-based alternatives, livestock products are reduced by 74%, freeing up 350 million hectares of agricultural land and increasing natural forest and other natural land by 120 million hectares and 220 million hectares, respectively. The food waste lever frees up 146 million hectares of agricultural land, creating space for forest and other natural land increases. The regenerative agriculture lever alone causes inputs of nitrogen onto croplands and water withdrawals by agriculture to decrease by 25% and 17%, respectively. The biodiversity outcome from regenerative agriculture is an underestimate, as lower water and fertiliser use would reduce water pollution into aquatic habitats. Impacts on aquatic habitats are not captured in this study.

Figure 12. The circular economy affects global biodiversity by freeing up agricultural land
Source: Vivid Economics

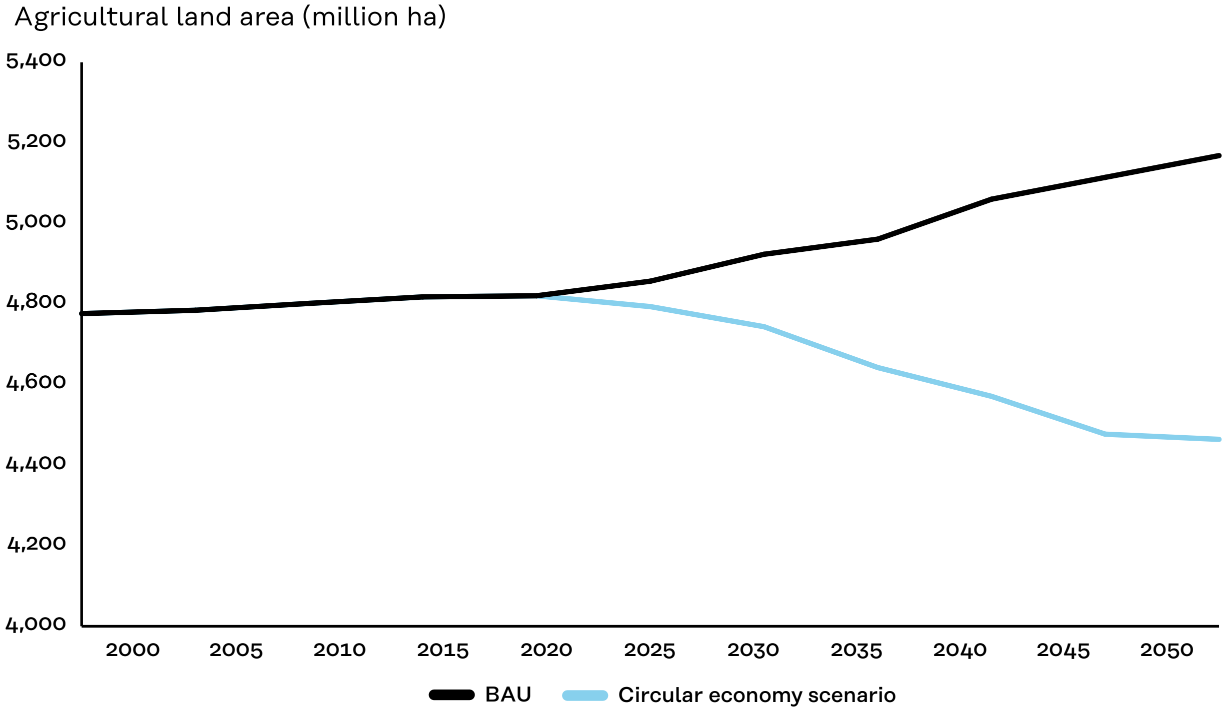


Figure 13. The large reduction in agricultural land is mostly due to reductions in pasture and rangelands
Source: Vivid Economics

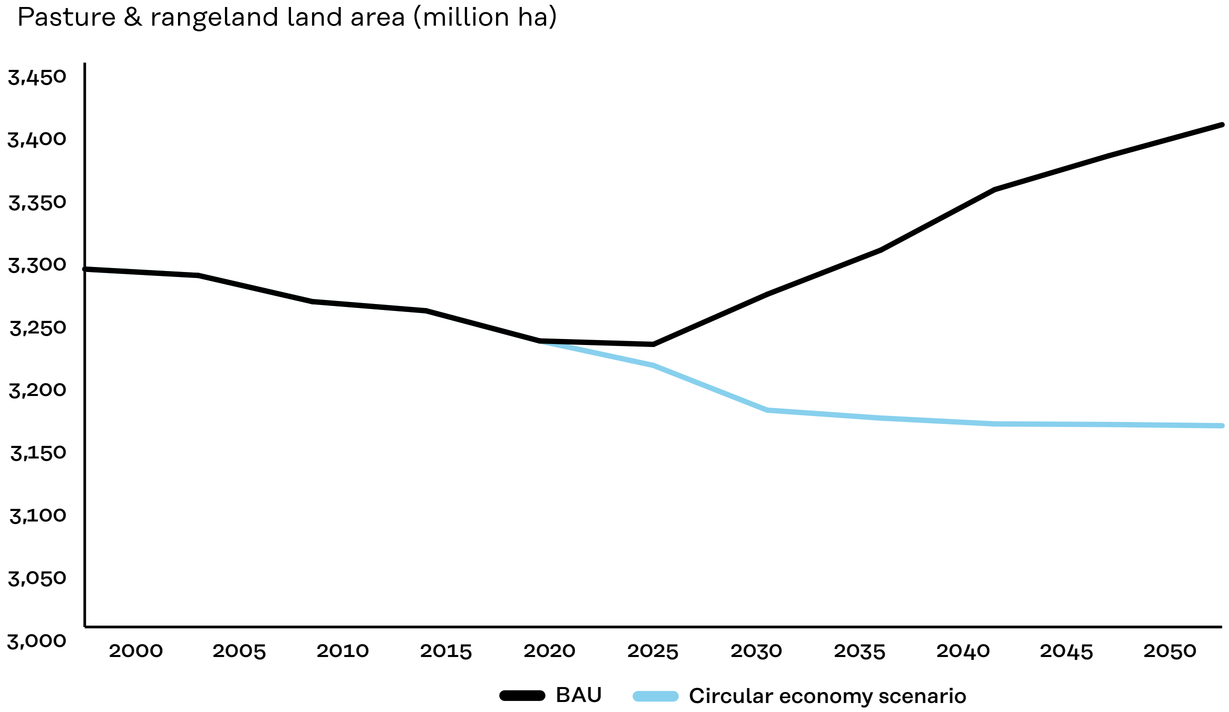


Figure 14. A modest recovery of natural forests occurs in the circular economy scenario
Source: Vivid Economics

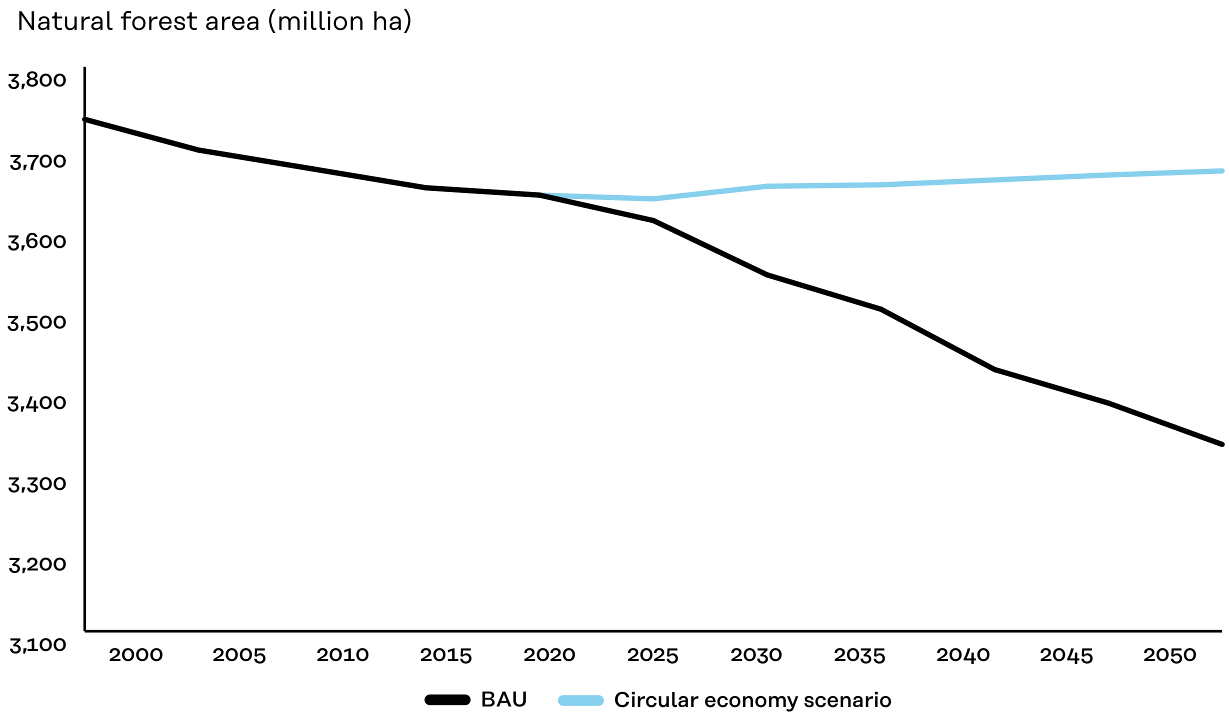


Figure 15. The circular economy still foresees a small loss of primary forest
Source: Vivid Economics

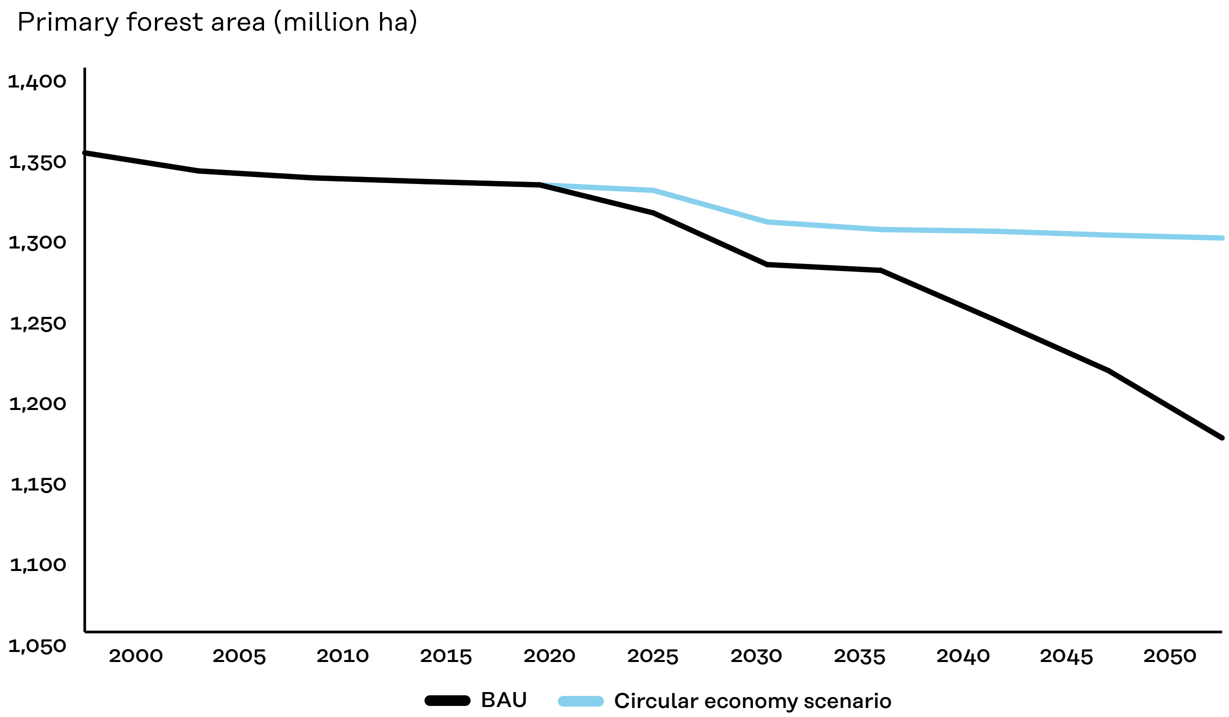
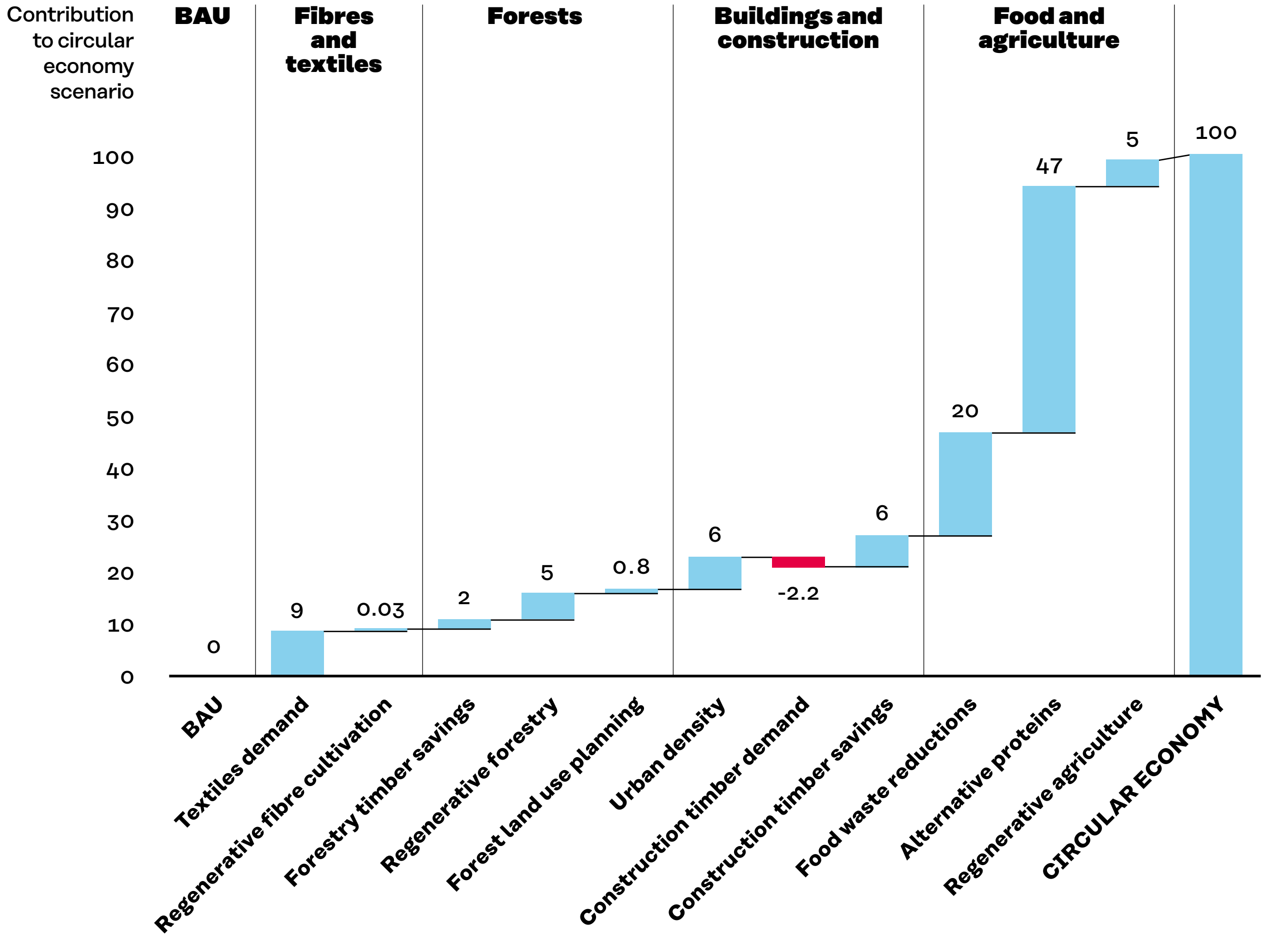


Figure 16. Alternative proteins and food waste reductions make the greatest contributions to overall biodiversity recovery in the circular economy
Note: Figures express the percentage of total change in the Biodiversity Intactness Index (BII) in 2050 that occurs when moving from business as usual to the circular economy.
Source: Vivid Economics



Box 4. Agroforestry

Agroforestry is an agricultural method that mimics natural ecosystems by introducing greater biodiversity into agriculture activities. In agroforestry, woody perennials (trees, shrubs, palms, bamboos) are deliberately used on the same land as agricultural crops and animals (FAO 2015). Through holistic management and smart design, various components like crops, trees, plants and livestock combine to form a diverse, resilient and more sustainable production system (WEF 2019). Practical applications typically take two forms.

Agrisilviculture – A cropping system featuring multiple layers of trees and crops. The blend of plants varies by region and culture, but it includes macadamia and coconut, black pepper and cardamom, pineapple and banana, shade-grown coffee and cacao, as well as rubber and timber (Drawdown 2022a). Layered agroforestry provides habitat, erosion control and improved water quality that support enhanced biodiversity (Torralba et al. 2016). These systems have also been seen to create a diverse tree cover in agriculture, supporting plant and invertebrate biodiversity, as well as ecosystem functions, such as an abundance of crop pollinators (Barrios et al. 2016). These practices are most frequently found in the tropics, in locations such as the Dominican Republic, Brazil, India or Central Africa (Lazaro 2022), but are also practised on millions of hectares of cropland in highly mechanised regions of China and Europe (Drawdown 2022b).

Silvopasture combines forestry and grazing of domesticated animals, replacing conventional livestock grazing on pasture and rangeland (FAO 2015). Silvopastoral systems tend to have greater species diversity and richness than degraded pasture (Jose and Dollinger 2019). Traditional silvopasture systems, such as the dehesa in Spain and forest pastures in Scotland, have existed for centuries. They are also highly suitable for Latin American grasslands (Drawdown 2022c).

Agroforestry practices can deliver increased productivity, diversified revenue streams and resilience to climate change alongside biodiversity improvements. Across Malawi and Zambia, farmers mixing crops with so-called "fertiliser trees" have boosted maize yields to 400% of the national average (Ventola 2013). Tree intercropping provides erosion control and water control, thereby making farming systems more resilient to extreme weather events (Drawdown 2022b). However, several barriers exist to greater uptake of agroforestry practices. These include different harvesting times, the need to tailor practices to local ecology, weak supply chains of inputs, and high upfront costs combined with delayed returns (Weiss 2020, Hoffner 2021, Mighty Earth 2021). Many initiatives are underway globally to enhance the adoption of agroforestry and to maximise its impacts.

Forests

In the forest sector (which in this study covers both forestry and the forest industry), regenerative forest practices have the greatest positive biodiversity impact, highlighting the importance of improving biodiversity outcomes in areas under production, given that today forest cover amounts to four billion hectares of the earth's surface. In this context, forestry timber savings are also important. These savings are made possible by cascading wood materials and products and by keeping the wood in the economy, sparing eight million hectares of primary forest, which has positive impacts on biodiversity. However, timber savings also mean that less managed forest is planted on farmland to meet timber demand – this may reduce the positive impacts on biodiversity because forests on average are more biodiverse than farmland. The forest land-use planning lever makes only a modest contribution to biodiversity improvement of 0.8%. This impact is contingent on where and how managed forest is planted. For example, integration of managed forest with farmland can provide additional habitats, while the conversion of natural forest to managed forest for timber would result in negative biodiversity impacts.

Buildings and construction

In the buildings and construction sector, construction timber savings and urban density levers have similar positive biodiversity impacts. Eighty-three million hectares of primary forest is spared from construction timber savings alone – an area similar to the combined land area of Spain, Portugal and the UK, freed up by designing out unnecessary material use in buildings, longer building lifetimes and reuse and recycling of construction materials. Urban density changes reduce urban areas by 14 million hectares, by using existing space more effectively through smarter design and planning, and flexible and shared use of urban space. This creates space for other natural land. The timber for construction lever increases timber production by 4%, causing the loss of 40 million hectares of primary forest, which drives its negative contribution to biodiversity, as well as climate change mitigation in the short term. Increasing timber use in buildings would however store significant amounts of carbon in the built environment, mitigating climate change over a longer time frame.

Fibres and textiles

In the fibres and textiles sector, changes in demand for textiles and fibres have the greatest positive biodiversity impact. The demand for leather and wool has implications for livestock production, here causing an 8% decrease in red meat production and a 3% decrease in pasture and rangelands compared to business as usual. Land for cotton cultivation also decreases, through lower demand, by almost 40% from this lever alone, resulting in a reduction of 1% in global cropland compared to BAU. These reductions are made possible by shifts in how we produce, consume, manage and recycle textiles. Through smarter design and repair, textiles can remain in use longer, while rental, resale and as-a-service business models can increase the use rates of these textiles. Part of their value can also be kept through garment-to-yarn recycling.

The regenerative fibre cultivation lever has only very modest biodiversity benefits captured in this study, as cotton cultivation accounts for less than 1% of total agricultural land by 2050, and practices which drive regenerative outcomes are only applied on an additional 39% of this area. However, although land use is the main driver of biodiversity loss on land overall, the textiles sector causes considerable pollution, which drives biodiversity loss in both soils and in waterways. Estimates vary, but as much as 16% of pesticides are used for cotton (The World Counts 2022), while the fashion industry currently accounts for nearly 20% of global industrial wastewater and as much as 8% of global greenhouse gas emissions (UN 2019a).

Box 5. Driving regenerative outcomes in boreal forests

As the world's largest land biome, boreal forests contain more than 35% of carbon stocks (Gerasimov et al. 2012), but they face particularly large threats, as temperatures there are rising faster than the global average. For the climate, these forests are one of the challenges – and solutions. The same holds true for biodiversity, and the type of management practices applied play a central role in either driving – or halting – biodiversity loss.

Regenerative principles, highlighted as one of three parts in the Ellen MacArthur Foundation's circular economy definition, build on the understanding that there is no waste in nature – everything is food for something else. By marrying old ideas with new insights and technology, regenerative agriculture has in the last few years fast gained traction as a way to rethink how we grow crops in ways that rebuild soils, increase resilience and have positive impacts on biodiversity both on and around farms (Oberč and Schnell 2020). Common methods in Finland include crop rotation and cover crops, and active efforts to increase carbon content in soils and retain nutrients (Sitra 2021b).

Albeit a key part of the circular economy, this same regenerative frame has not been extended to the forest sector, and more research is needed to ascertain the effectiveness of different practices. Yet, applied at the beginning of the sector's value chain, regenerative production in line with a circular economy presents a significant potential for boreal forests, strengthening carbon stocks and biodiversity, as well as the economics of forestry, by building resilience and giving us more from what we have, as with the following principles.

- **Diversifying production across more species** – The boreal forest industry is centred around wood from a few conifer species. Yet, more could be gained by increasing the presence of other species. The prevalence of broad-leaved trees is a key biodiversity indicator central for reducing storm damage and allowing for steadier, mixed revenues and regenerative outcomes. This also applies to biomass in forests besides trees, which yields consistent yearly revenues and is central for biodiversity. In Finland, the area needed to grow one tonne of pulp produces 220 kg of berries and mushrooms (forest.fi 2015). Yet only 1% of edible mushrooms are picked (Natural Resources Institute Finland 2015). Collectively, herbs, berries, mushrooms, sap and other biomass present a large, underused resource.
- **Unlocking the full value of forest biomass** – We can also valorise more of the biomass at hand, in line with a circular bioeconomy. For example, broad-leaved trees, key to driving regenerative outcomes, can generate more high-value applications, such as sap for the cosmetics industry (Nordic Koivu 2022), and biomass for textiles, and as high-value applications in furnishings in houses (e.g., veneer) (Natural Resources Institute Finland 2017). Beyond trees, companies such as Kääpä Health, Innomost and Lumene have also shown that mushrooms and berries can be valorised into valuable health products. Synergies between species are key. By inoculating tree saplings with truffle ectomycorrhiza, each tree can also generate more value (Juva Truffle Centre 2022). By seeing forests as gardens, we can, by design, increase their value and diversity, driving regenerative outcomes.
- **Strengthening natural processes** – Nature provides a range of services which benefit production in boreal forests, increasing the value that can be harnessed, from pollination to pest control, by allowing biodiversity to thrive. More natural forests (which can accommodate more diversity, carbon, native species and greater age spans) are more resilient (Thompson et al. 2009). Native species as well as decaying and dead wood are particularly key for sustaining insects and fungi (Sandström et al. 2019). Similarly, nature has the capacity to circulate nutrients, and by managing soils more lightly and avoiding leakage of nutrients, improved soil health allows for higher long-term productivity.

Box 6. Using circular economy principles in mass timber construction (MTC)

The production of concrete and steel, the main materials used in construction, have wide-ranging impacts on nature. For example, sand mining required for concrete disrupts and destroys aquatic ecosystems (Churkina et al. 2020). Similarly, although mines cause little land-use change, poor management of mining waste has often led to the contamination of areas with exceptionally high biodiversity (Carmo et al. 2020). The construction industry is also responsible for around 30% of global greenhouse gas emissions (Crawford and Cadorel 2017). With increasing future demand for buildings, the sector could claim up to 60% of the remaining carbon budget.[5]

Several initiatives have demonstrated the potential of MTC in lieu of concrete and steel, reducing the impact of construction on nature. The 20-storey high Sara Cultural centre in Skellefteå, Sweden has all its structural features made of locally sourced timber (Dezeen 2021). The Dalston Works complex in London is one of the world's largest cross-laminated timber (CLT) buildings, where CLT facilitated a taller building than thought feasible at the site (Waugh Thistleton Architects 2022). Transitioning to MTC while promoting circularity could mitigate the impacts of the growing construction industry and capture additional benefits through the following channels.

- **Reduced use of steel and concrete** – Emissions from a 12-storey CLT building could be about 70% lower than that of a reinforced concrete building (Chen et al. 2020). Additionally, as timber buildings have lower weights, they need a smaller foundation, which is predominantly made of emissions-intensive concrete. In fact, timber primary structures need only half the materials per capita compared to steel and concrete (Churkina et al. 2020).
- **Reuse of materials** – As MTC structures are often built with mechanical fastenings, disassembly and reuse of timber elements is easier compared to conventional buildings (William McDonough and Partners 2019). Circular design can maximise the potential for reuse. With conventional materials, reuse is currently limited with shortcomings on recycling as well, but initiatives such as the Baltimore Wood Project have shown the potential. While over 90% of steel is currently recycled, this involves an energy-intensive process of remelting, and concrete recycling faces barriers from costs and structural integrity (Watson and Sefton 2021).
- **Co-benefits for carbon storage** – Timber buildings can act as a carbon store. In a mid-rise city, the carbon content of timber buildings could surpass that of soil and trees (Churkina et al. 2020). Yet, the implication of carbon storage in MTC depends crucially on appropriate end-of-life practices (Boyer et al. 2021).

The opportunities offered by MTC have translated into policy. The international building code (IBC) was changed in 2021 to allow MTC buildings up to 18 storeys without separate approval (WoodWorks 2018). Finland has set a target to double the use of timber in construction by 2022 as part of the timber construction scheme (Finnish Ministry of Environment 2022). Similarly, France mandated that public buildings must contain 50% wood by 2022 (Walter 2020).

Scaling up global timber supply for MTC in a sustainable manner presents a potential barrier. Increase in timber demand incentivises illegal logging and deforestation, threatening to counteract the benefits of MTC. Hence, increased timber use should be combined with strong legal and political commitment to protecting ecologically valuable sites and managing forests sustainably (Pomponi et al. 2020). In areas with local, sustainable timber supply, MTC presents a nature-friendly and viable alternative to mineral-based building materials.

5 Based on limiting global temperature increase to 2 °C, from Churkina et al. (2020).

5.3 Geographical breakdown of drivers and impacts

Geographies of biodiversity loss

This section outlines future regional trends in biodiversity loss under business as usual, before exploring regional variations in sectoral importance.

Understanding how circular economy levers result in biodiversity outcomes and where these occur is crucial for policymakers, producers and consumers to understand how they can improve biodiversity outcomes. It is necessary to establish which regions are most at risk of biodiversity loss and which pressures are particularly acute. This can help guide sectors to understand where impacts are occurring and guide further biodiversity measures where these are necessary.

Exploring geographical patterns is not intended to single out individual regions and assign them responsibility for preventing future biodiversity loss. Rather, the intention is to highlight how circular economy policies actioned in one area of the globe interact with impact biodiversity in other parts. For example, due to growing global resource demands and current intactness of habitats, Latin America and Sub-Saharan Africa are expected to account for much of the loss of primary forest and biodiversity to 2050 under business as usual. This is despite several of the drivers linked to biodiversity loss happening outside of these regions. Similarly, understanding whether circular levers have positive biodiversity impacts affecting particular regions, would enable decision-makers, for example in the EU, to develop effective circular economy and biodiversity strategies at home.

Future trends in biodiversity loss

Under business as usual, biodiversity loss is particularly acute in Sub-Saharan Africa, Latin America and South Asia.[6]

In Sub-Saharan Africa and Latin America, this is driven by increases in agricultural land and decreases in primary forest, pressures that increase in response to global increases in income and population. These trends in biodiversity loss are particularly concerning as these regions contain crucial biodiversity hotpots. They contain biomes that may be subject to tipping points in the face of significant habitat change, making biodiversity losses permanent. Economies are also more dependent on ecosystem services in low- and middle-income economies. In contrast, the EU and the UK experience an increase in biodiversity, as agricultural land falls.

Regional patterns in circular economy actions and biodiversity recovery

Understanding where levers are actioned and where biodiversity improvements occur is needed to inform policymakers, businesses and consumers about how they can improve biodiversity outcomes. Given that the environmental impacts of resource-intensive and extractive industries are often offshored by high-income countries to low-income countries, it is important to ascertain for which sectors this is an observable pattern. If levers implemented in one region have implications for biodiversity in another region, what is here termed “outside-region impact”, then this has implications for global policymaking. This spatial alignment or misalignment of sectoral impact is summarised in Table 3. These results will in part

6 South Asia here does not refer to China, India or Japan, as these are separate regions in MAgPIE. It refers to a region in MAgPIE that includes ASEAN countries such as Indonesia, Thailand and Vietnam, as well as other Asian countries such as Bangladesh, Mongolia and Pakistan, and the Pacific islands.

reflect which levers were and were not included in this analysis and thus may not imply essential characteristics of each sector.

Food and agriculture regional patterns

Shifts to alternative proteins occur most in per capita terms in Canada, Australia and New Zealand, the EU plus the UK, and the USA. The greatest changes in agricultural land area, and subsequent improvements in biodiversity, take place in Latin America, Sub-Saharan Africa and India, as well as in the USA. This is intuitive as, despite significant meat production in high-income countries, animal feeds can be imported from low- and middle-income regions. For example, the EU is a net importer of soy used for oil production and animal feed (EEA 2017).

Regional patterns in the forest sector

In forest scenarios, timber demand reductions lead to decreases in timber production across timber-producing regions. Decreases in timber production appear to be consistent with decreases in timber demand in each region, suggesting that impacts are felt predominantly within-region. However, Latin America is a clear exception to this rule, which could indicate that timber demand reductions made in other regions could provide biodiversity benefits to Latin America. Forestry land-use change is salient in Latin America and Sub-Saharan Africa, where a combined 91% of primary forest saved in the circular economy scenario by 2050 is located (see Figure 18).

Table 3. Textiles and food levers mostly have land-use implications in countries other than those where they are implemented, while the forest and building sectors are characterised by within-region land-use impacts

Note: For the purposes of this geographical variation analysis, changes in timber demand in the forest and buildings and construction sectors are combined into the forest sector as they affect the same set of land-use variables. Low, middle and high income are used as descriptive labels of regions despite significant variation within regions.
Source: Vivid Economics

Sector	Where circular economy actions take place	Where land-use change takes place	Impact pattern
Food and agriculture	Mostly high-income regions: USA, EU, Canada, Australia, New Zealand (in per capita terms)	Mixed: mostly low- and middle-income regions + USA	Outside-region impact (with USA the exception)
Forests	Mixed regions: USA, EU, Latin America, Sub-Saharan Africa	Mixed: USA, EU, Latin America, Sub-Saharan Africa. Latin America sees disproportionate land-use change.	Within-region impact (with some outside-region impact on Latin America)
Buildings and construction	Mixed regions: USA, EU, Latin America, China	Mixed: USA, EU, Latin America, China	Within-region impact
Fibres and textiles	Mostly high-income regions	Mostly low- and middle-income regions + USA	Outside-region impact

Box 7. What are alternative proteins and how could they help stem biodiversity loss?

The land intensity of conventional animal proteins is a leading cause of biodiversity loss. For instance, 39% of habitable land, 40 million km², is used to farm livestock for meat and dairy production (Ritchie and Roser 2019). Traditional animal proteins also have high greenhouse gas emissions intensity, high water use, significant adverse health impacts and animal welfare concerns. Beef production uses 20 times more land per tonne of protein than the production of pulses (Ranganathan et al. 2016), demonstrating the potential of alternative proteins to reduce biodiversity impacts.

Alternative proteins present a key circular solution, which gives us more from what we have, by relying on fewer inputs compared to meat and dairy, designing out polluting excess nutrients and waste from animals' metabolism as they are reared, and by learning from nature by mimicking structures of life and harnessing natural processes such as fermentation.

Table 4. Main categories of alternative proteins

Note: “Blue” foods (fish and seafood) are important sources of protein globally. Making better use of underused wild fish can help reduce pressure on biodiversity (Ellen MacArthur Foundation 2022b). Alternative blue proteins such as cultured fish, however, remain at an early development stage; proteins are the focus in this analysis, but alternatives are also being developed for other commodities central to driving biodiversity loss, such as lab-grown coffee (VTT 2021).

Category	Description	Examples	Market size
Classic plant-based	Traditional substitutes for meat	Tofu, seitan, pulses and algal protein	Large: already produced at scale
Novel plant-based	Protein concentrates from plants such as soy or pea that mimic animal protein	Beyond Meat, Beanit, Impossible Foods	Medium: fast-growing and increasingly popular
Fermentation-based	Produced from fermentation of biological feedstocks such as yeast or fungi	Quorn, The EVERY Company, Solar Foods, egg white protein by VTT	Medium: emerging production methods and used for human or animal consumption
Cultured meats	Cultured and grown animal cells identical to animal protein	Upside foods	Small: high price and not yet produced at scale

Investment in alternative proteins tripled in one year, reaching over US$3 billion (GFI 2020). However, alternative proteins face barriers to scale and currently make up a small fraction of the protein market. Mainstream popularity will depend on reducing price and improving product design for humans and animals. Alternative proteins are a heterogeneous product segment. Compared to plant-based options, cultured meats will need more time to reach price parity with animal-based protein products.

Figure 17. Roundwood production falls disproportionately in Latin America

Source: Vivid Economics

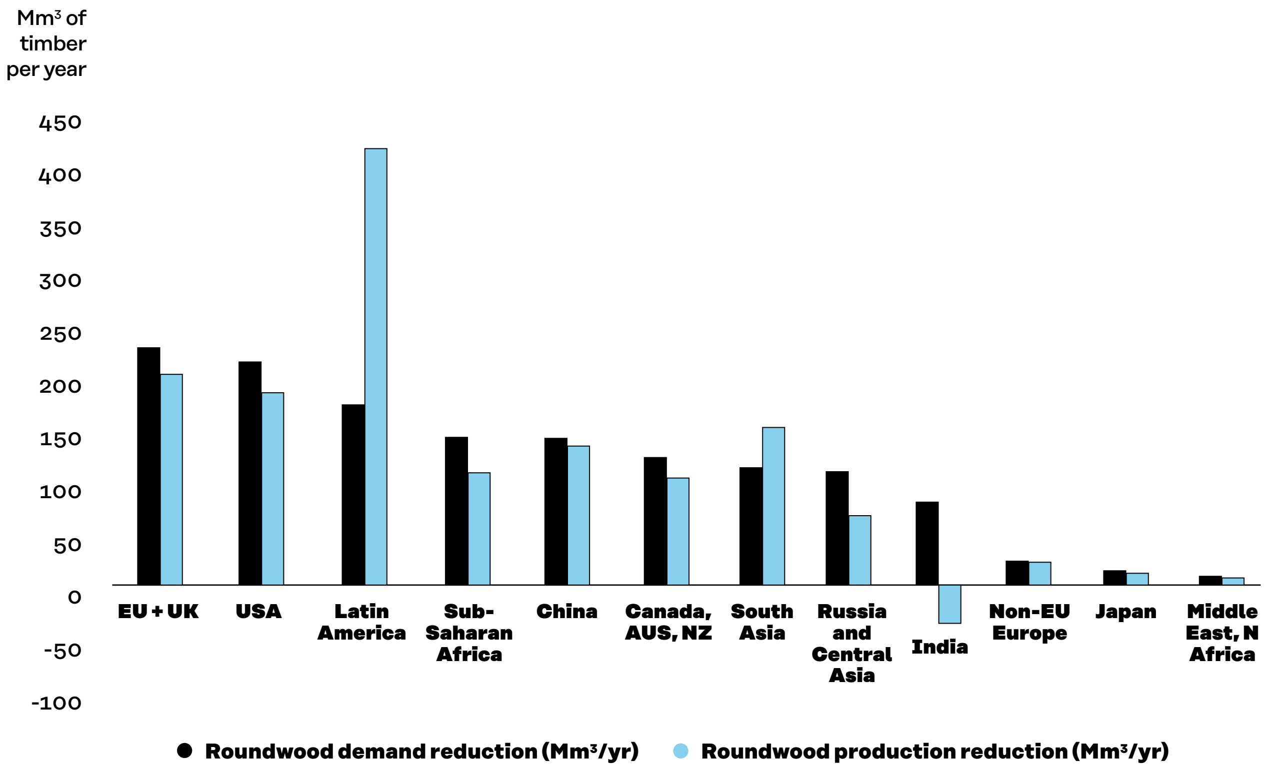
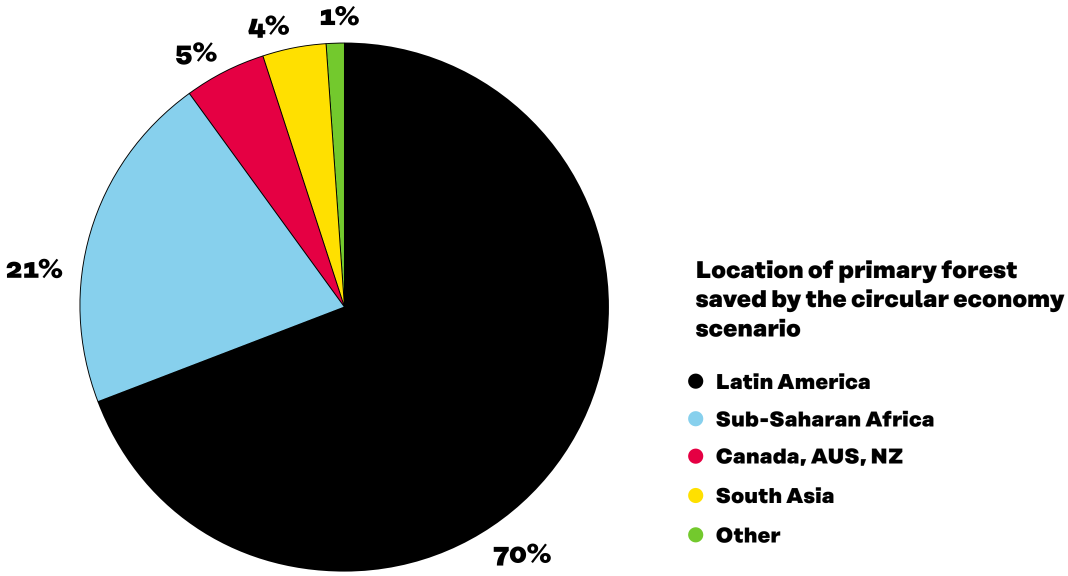


Figure 18. The majority of primary forest saved by the circular economy is located in Latin America

Source: Vivid Economics



Buildings and construction regional patterns

Increases in urban density free up the most land for alternative uses in regions characterised by urban sprawl. Within the model architecture, urban density increases consistently across regions in percentage terms, but this means that in absolute terms, increases in urban density are borne mostly by countries that already have dense urban areas. This includes India, Sub-Saharan Africa and South Asia. Regions such as the USA and Canada and Australia and New Zealand experience only modest absolute increases in urban density. Changes in urban land area only have within-region impacts on land use in the model, although it is likely that urban density changes will affect materials demand, which will in turn have implications for land use in different regions.

Fibres and textiles regional patterns

Cotton demand reductions in the fibres and textiles sector free up land predominantly in the key cultivation regions of India and the USA. MAgPIE does not account for which regions textile demand reductions are coming from. However, given that fast fashion models and use cycles are a facet of many clothing retail sectors, it is likely that circular economy changes to textiles demand should be focused on areas where clothing consumption is high. Therefore, while China, India and South Asia account for the majority of global fibres processing, much of the final textile products are sold onto mature markets in North America and Europe. Further biodiversity improvements that are not modelled here would accrue to regions with high textile manufacturing, given the significant biodiversity pressures exerted on freshwater habitats by clothing manufacturing and dyeing (McKinsey 2020).

Regional variations in sector impact under a circular economy

In the circular economy, biodiversity increases in all regions relative to business as usual, but the relative contribution of different sectors to this improvement varies between regions. Some results stand out. China sees 65% of its biodiversity recovery come from the forest sector. This is caused by the regenerative forestry and forest land-use planning levers. China has over a third of the world's managed forests so would see significant biodiversity improvements from sustainable forest management, and the forest land-use planning lever increases managed forest area by 20 million hectares in China alone. Textiles make a negative contribution to biodiversity in South Asia, Russia and Central Asia, and the USA. This is likely to be caused by decreases in pasturelands, in response to lower leather and wool demand, freeing up space for cropland, which typically has lower biodiversity value.

5.4 Climate change mitigation synergies

The sectors covered in this analysis are central to climate change mitigation. Buildings and AFOLU (agriculture, forestry and other land use) alone account for approximately 43% of global emissions according to the Intergovernmental Panel on Climate Change (IPCC 2014)), while fashion and textiles may account for as much as 8% (UN 2019b).

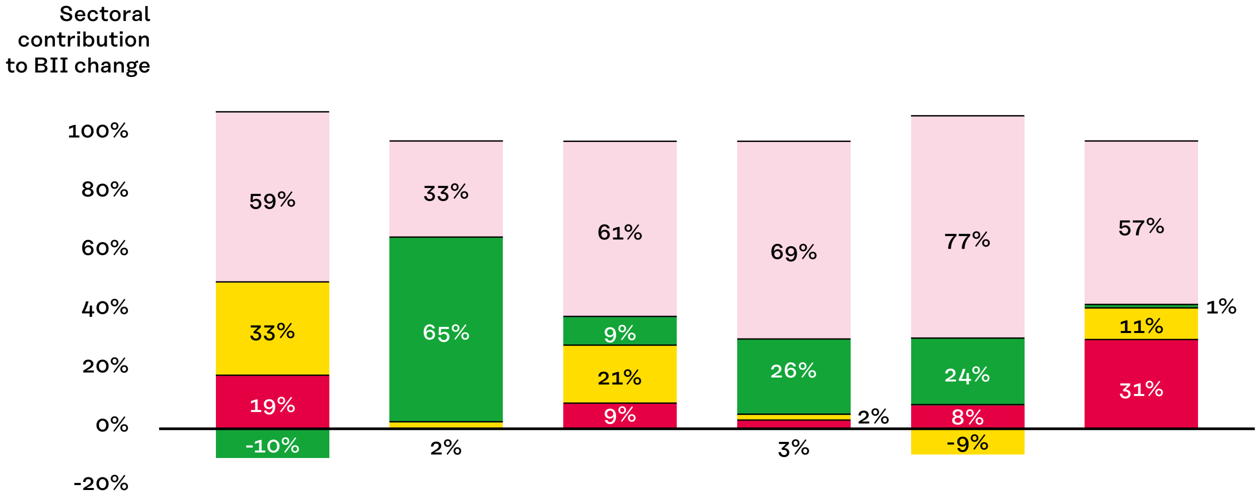
The circular economy helps to cut emissions in several ways across production and consumption, and can serve as a powerful means of climate change mitigation (Sitra 2018). One example is by reducing land-use emissions. Figure 20 describes how methane emissions from agriculture fall by almost 90% in the circular economy scenario, driven by reductions in livestock production, a major source of agricultural methane emissions. This is important as methane has been responsible for almost a quarter of radiative forcing since 1750 (Etminan et al. 2016). Figure 21 shows that, in the circular economy, land-use change moves from a source of atmospheric CO_2 to a sink, sequestering 1 Gt CO_2 per year from 2040 – almost 30% of the emissions generated by industry and households in the EU in 2020 (Eurostat 2022). All else being equal, the increase in the carbon sink from land-use change in the EU alone would be enough for the bloc to meet its proposed target of net removal of 310 Mt CO_2 per year from the land-use and forestry sector by 2030 (European Panel Federation 2018, European Commission 2021a).[7]

Methane emissions from agriculture fall by almost 90% in the circular economy scenario.

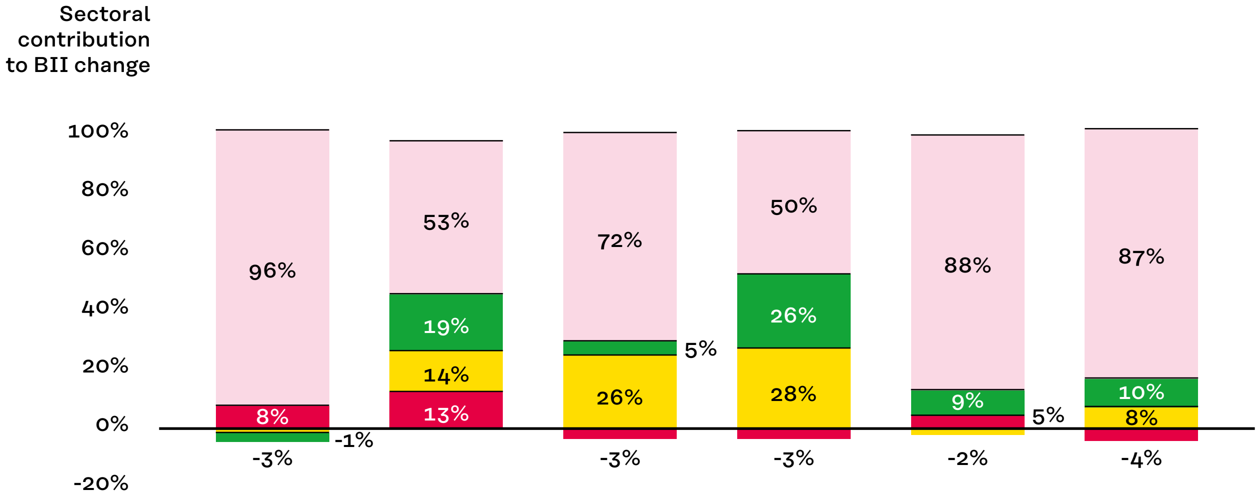
7 The UK is included in the EU region in MAgPIE outputs.

Figure 19. The relative contribution of different sectors to total biodiversity improvement varies regionally

Source: Vivid Economics



	CA + AUS + NZ	China	EU + UK	India	Japan	Latin America
Food and agriculture	59%	33%	61%	69%	77%	57%
Forests	-10%	65%	9%	26%	24%	1%
Buildings and construction	33%	2%	21%	2%	-9%	11%
Fibres and textiles	19%	0%	9%	3%	8%	31%



	Middle East + North Africa	Non-EU Europe	South Asia	Russia + Central Asia	Sub-Saharan Africa	USA
Food and agriculture	96%	53%	72%	50%	88%	87%
Forests	-3%	19%	5%	26%	9%	10%
Buildings and construction	-1%	14%	26%	28%	-2%	8%
Fibres and textiles	8%	13%	-3%	-3%	5%	-4%

Figure 20. In the circular economy scenario methane emissions from agriculture fall by almost 90%
Source: Vivid Economics

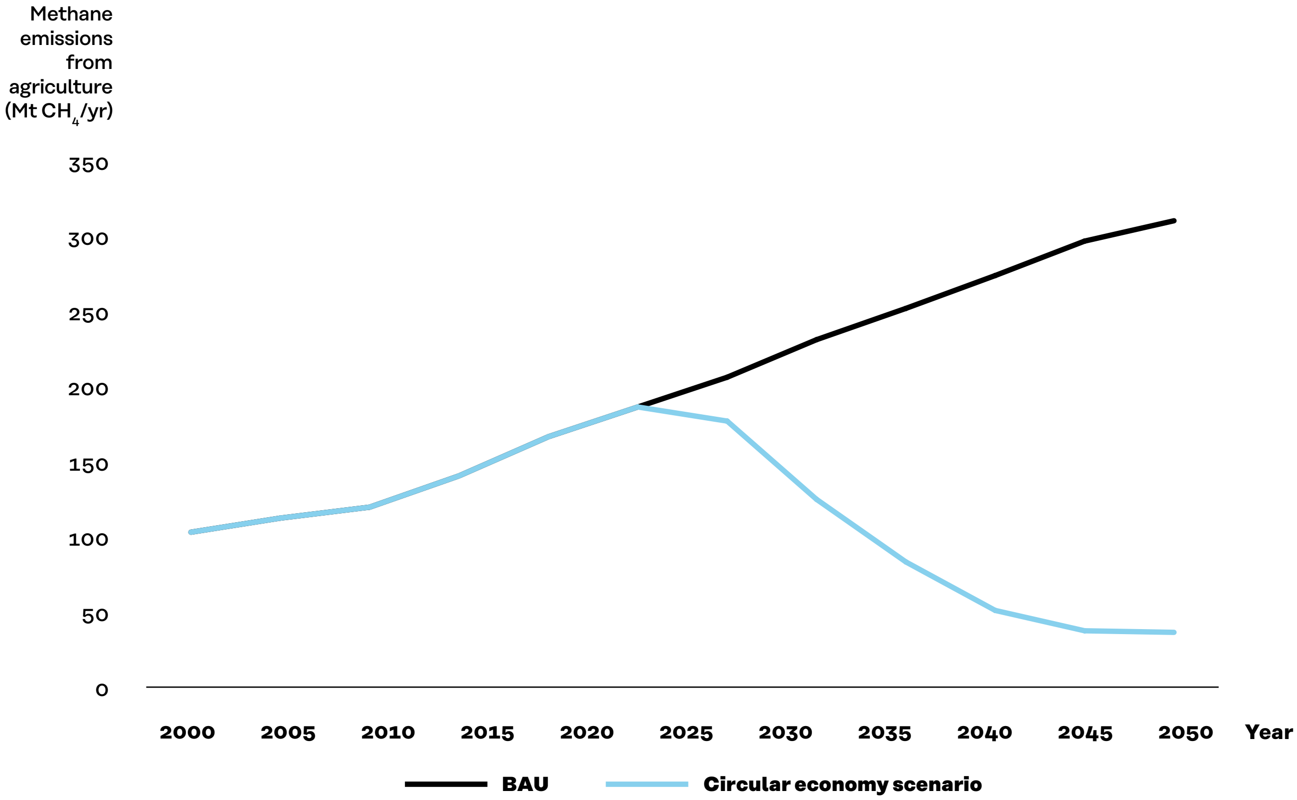
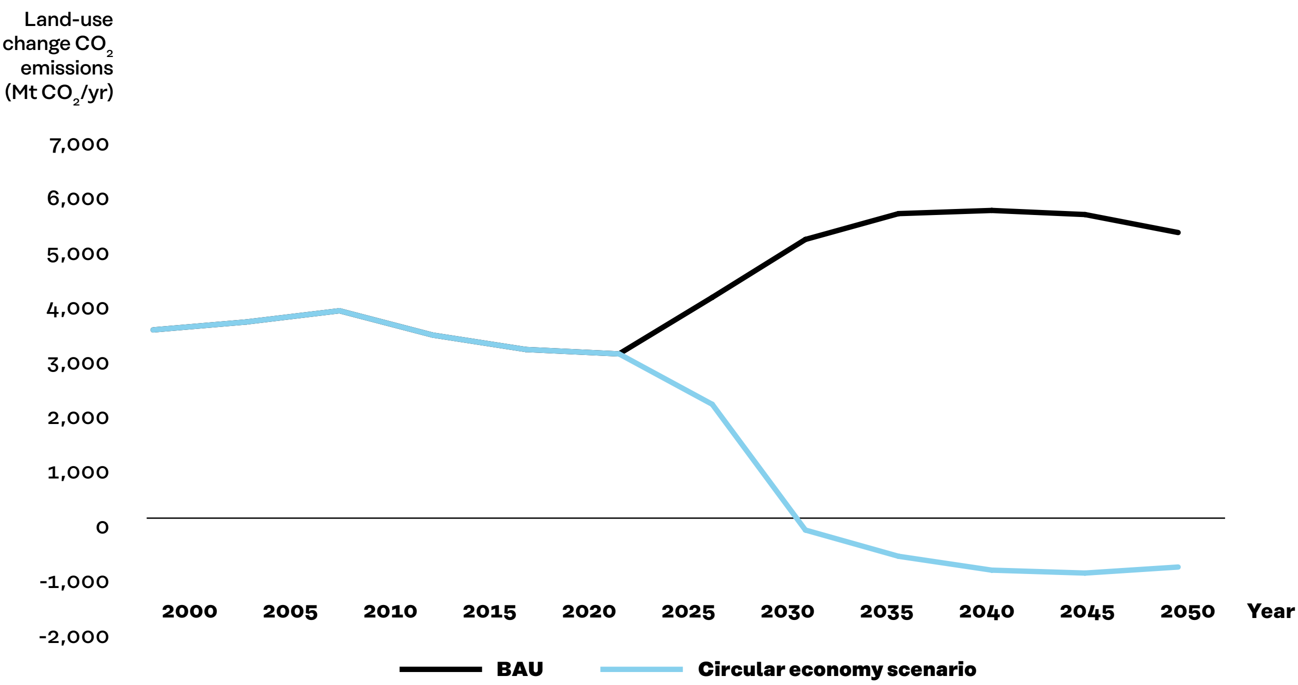


Figure 21. Land-use change sequesters rather than releases carbon from 2030
Note: Land-use change emissions are used here instead of land emissions for CO_2, as the land emissions variable includes CO_2 fertilisation and other information generally not used in land-use carbon emissions reporting.
Source: Vivid Economics



6 Economic methodology and results

6.1 Rationale for economic analysis

This section of the report sets out several of the economic benefits and potential investment needs for key circular economy levers across the sectors. A shift towards a circular economy will require additional investment and operational costs but can yield substantial economic benefits alongside environmental ones. Quantifying these impacts is important for understanding the political and economic feasibility of circular solutions. It also helps companies identify potential opportunities for gaining competitive advantages.

The literature on economic costs and benefits of a circular economy transition is limited, in part due to the uncertainties regarding future technological change, resource costs and supply chain complexity. The existing literature emphasises that circular economy reforms could increase employment and could do so with more skilled jobs. Further, the circular economy could save companies costs by reducing the material intensity of production, in the process reducing exposure to volatile primary resource prices, increasing access to goods and services and reducing health costs from pollution (Ellen MacArthur Foundation 2018). In particular, key findings are as follows.

- Net employment could increase in a circular economy transition, despite job losses in certain sectors, in part due to the labour intensity of many new jobs created (Circle Economy 2020).
- A circular economy could add 900,000 jobs in the EU alone from additional recycling plants, repair services and consumer spending as a result of money being saved from the sharing economy. The jobs created in these sectors would more than offset jobs lost in other sectors (Cambridge Econometrics et al. 2018). A different study suggests that existing circular economy activities will create one million new jobs across the EU and UK by 2030 (Weghmann 2017). Many of the jobs created from the circular economy would be skilled jobs, particularly in closed-loop recycling, remanufacturing and biorefining (Green Alliance 2015).
- An increased focus on repair and refurbishment would lead to an increase in labour intensity in some sectors, partially offsetting the move to more capital-intensive business models resulting from workforce automation (Cambridge Econometrics et al. 2018).
- A meta-analysis of 300 circular economy scenarios found that, on average, they could increase employment by 1.6% by 2030 if implemented over the period 2020 to 2050 (Aguilar-Hernandez et al. 2021).
- The OECD's material fiscal reform implemented on a global scale could decouple primary materials use from economic growth by reducing global primary materials use by 27% for metals and 8% for non-metallic minerals, with an overall reduction in materials use of 7% (Bibas et al. 2021).

6.2 Approach for estimating future investment needs and economic benefits

For the nine individual circular levers (see Table 4), four key elements of economic costs and benefits are modelled in this analysis. These are as follows.

- Investment need. This indicates the investment required to implement the lever by 2050. This cost estimate can be interpreted as the size of the investment opportunity.
- Gross value added (GVA). GVA is measure of contribution of the lever to GDP, measuring output minus any intermediate consumption. GVA is modelled here as a proportion of the investment amount, and is therefore typically smaller than the investment need. However, GVA does not capture all economic and social benefits, which will be covered in more detail later, and so this is not to be interpreted as costs of the circular economy exceeding benefits.
- Jobs supported. New investments and new markets in the circular economy will create new jobs. Employment loss or reallocation are not modelled, as the simultaneous implementation of multiple levers has uncertain impacts on labour market dynamics. Costs associated with re-training the workforce are also not modelled but may be significant in some sectors.
- Efficiency savings. Efficiency savings are modelled for recycling-based levers, and are conceptualised as savings that accrue to producers, retailers or consumers from reduced resource consumption resulting from efficiency gains. For example, reducing food waste could lead to consumers spending less on food and farmers spending less on fertiliser inputs.

The analysis does not assess all possible circular economy levers, nor does it evaluate the total economic costs and benefits. Instead, the work is intended to provide a preliminary understanding of the main economic benefits that can be expected from the uptake of new practices. This methodology implies that the economic costs will always be higher than the direct (GVA) benefits, but this does not mean that the levers are not worth implementing. This is in part due to the large disparity between individual investment opportunities in terms of return on investment, and in part because this analysis does not attempt to provide an exhaustive account of financial and economic benefits. Economic costs required for the implementation of circular economy levers can also be understood as indicative of the size of investment opportunities. Notable omissions from the analysis include potential additional costs of training employees in new sectors, efficiency savings from as-a-service business models and likely economies of scale on investment in new technologies and sectors. Beyond the firm level there is a wide set of other benefits not captured in this analysis, including health benefits, for example from eating more alternative sources of protein, avoided costs from natural disasters, climate co-benefits and a full set of ecosystem services.

6.3 Estimates of future investment needs and economic benefits

The food and agricultural sector contains 73% of total cumulative investment needs to 2050, which is in line with its relative biodiversity impacts. The investment required for the transformation of the agriculture sector alone reaches nearly U$ 1 trillion per year by 2050. This is driven by the significant area of agricultural land shifting to regenerative production and the rapid development of an entirely new industry in alternative proteins. The alternative proteins lever within food and agriculture accounts for nearly 60% of total investment needs.

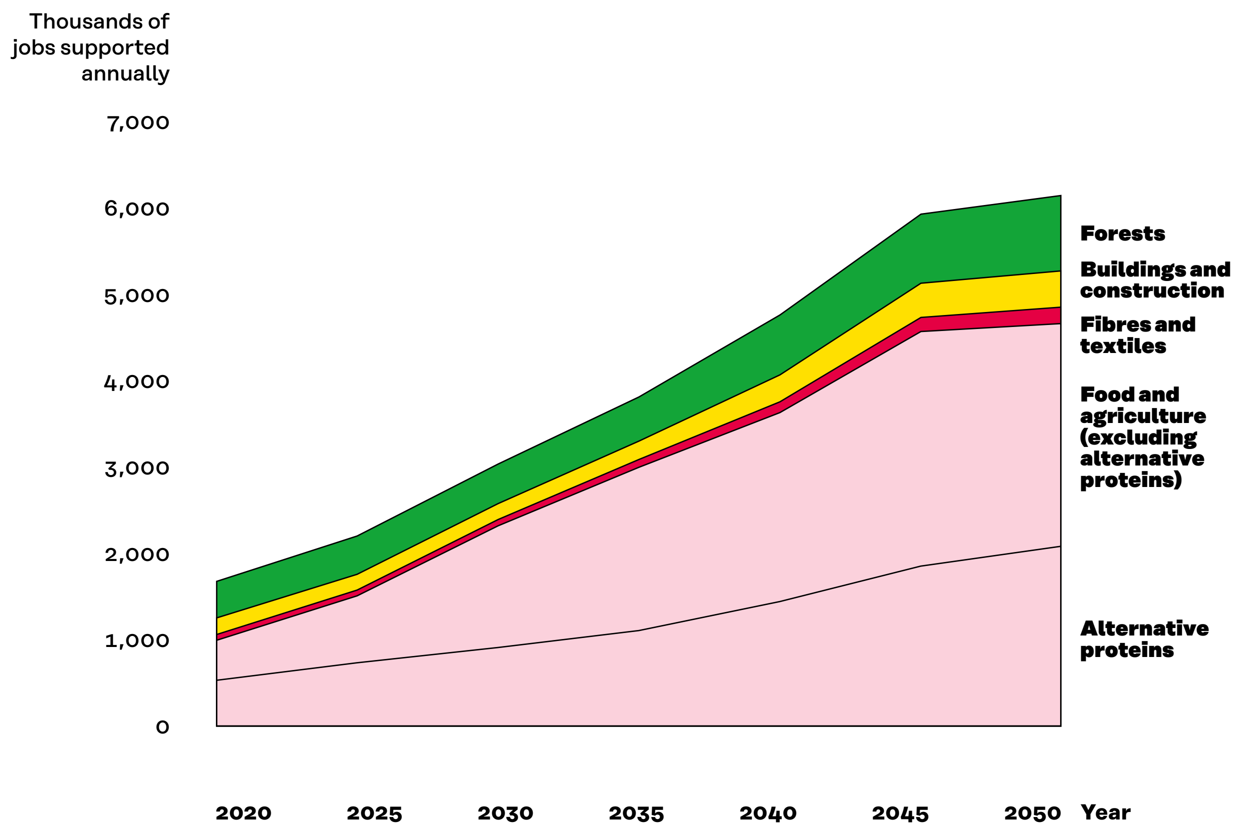
As the analysis relies on land-use modelling, it is intuitive that sectors with the greatest land-use changes would also see the greatest economic costs. The estimates of transition costs for fibres and textiles and for buildings and construction would be likely to be higher if additional upstream and downstream impacts unrelated to land use were included in the modelling.

The transition to alternative proteins could provide annual benefits of US$1.7 trillion by 2030, rising to US$5 trillion by 2050, while also accounting for 44% of total jobs supported by the circular economy transition. This is highlighted in Table 4. Much of the remaining job gain in the agricultural sector is driven by regenerative agriculture. The GVA from alternative protein products currently stands at US$29 billion, with plant-based milk being the main contributor. With rapid deployment of plant-based products, cellular agriculture and alternative dairy products, GVA is expected to grow by 9% per year, reaching US$320 billion in 2050. Of this increase, plant-based options account for 27%; cellular agriculture 52%; and plant-based dairy 20%. By 2050, the alternative protein market could support nearly three million jobs, some of them requiring highly skilled workers with specific technical expertise.

Sectors like forests, textiles and construction highlight the potential benefits beyond

Figure 22. Alternative proteins and other agriculture levers make up a significant proportion of jobs supported

Source: Vivid Economics



gross value added that would stem from a move to a circular economy. In addition to direct spillovers, there are several other sources of benefits from the circular economy. For example, the GVA benefits from construction timber recycling, at US$170 billion to 2050, are dwarfed by the efficiency gains from roundwood recycling that this would bring, at US$1.5 trillion. Similarly, cotton recycling and paper recycling bring significantly more in efficiency gains than they do in GVA. This is highlighted in Figure 23. Efficiency gains estimates included here do not account for all possible efficiencies, but they do provide an indication of the wider benefits from circular economy levers beyond GVA and jobs.

Efficiency gains from falls in resource demand and waste are additional benefits that may stem from a move to a circular economy. Lower input costs and increased consumer spending are other economic mechanisms through which the circular economy would provide benefits. This is highlighted in Figure 24, which documents the fall in nitrogen demand and the annual household expenditure savings from the food loss and waste lever. Household savings can be spent elsewhere more productively and falls in nitrogen use could reduce the negative impacts imposed on other producers from nitrogen pollution.

Table 5. The greatest investment opportunities and GVA benefits are within the alternative proteins lever

Source: Vivid Economics

Lever	Investment needs by 2050 (US$ billion)	GVA benefits to 2050 (US$ billion)	Efficiency savings to 2050 (US$ billion)	Annual jobs supported in 2050 (000s)	Notes
Regenerative agriculture	4,700	1,700	N/A	1,400	
Food loss and waste	120	42	1,300	770	Efficiency savings from reduced processing
Alternative proteins	10,000	5,000	N/A	2,600	
Cotton recycling	170	70	630	170	Efficiency savings from reduced cotton purchasing
Regenerative fibre production	65	23	N/A	20	
Construction timber recycling	460	170	1,500	430	Efficiency savings from roundwood recycling
Regenerative forestry	580	200	N/A	220	
Forestry timber recycling	580	210	550	670	Efficiency savings from paper recycling
Forest land-use planning	32	11	N/A	3.4	

Figure 23. GVA and efficiency gains from recycling-based levers in 2050
Source: Vivid Economics

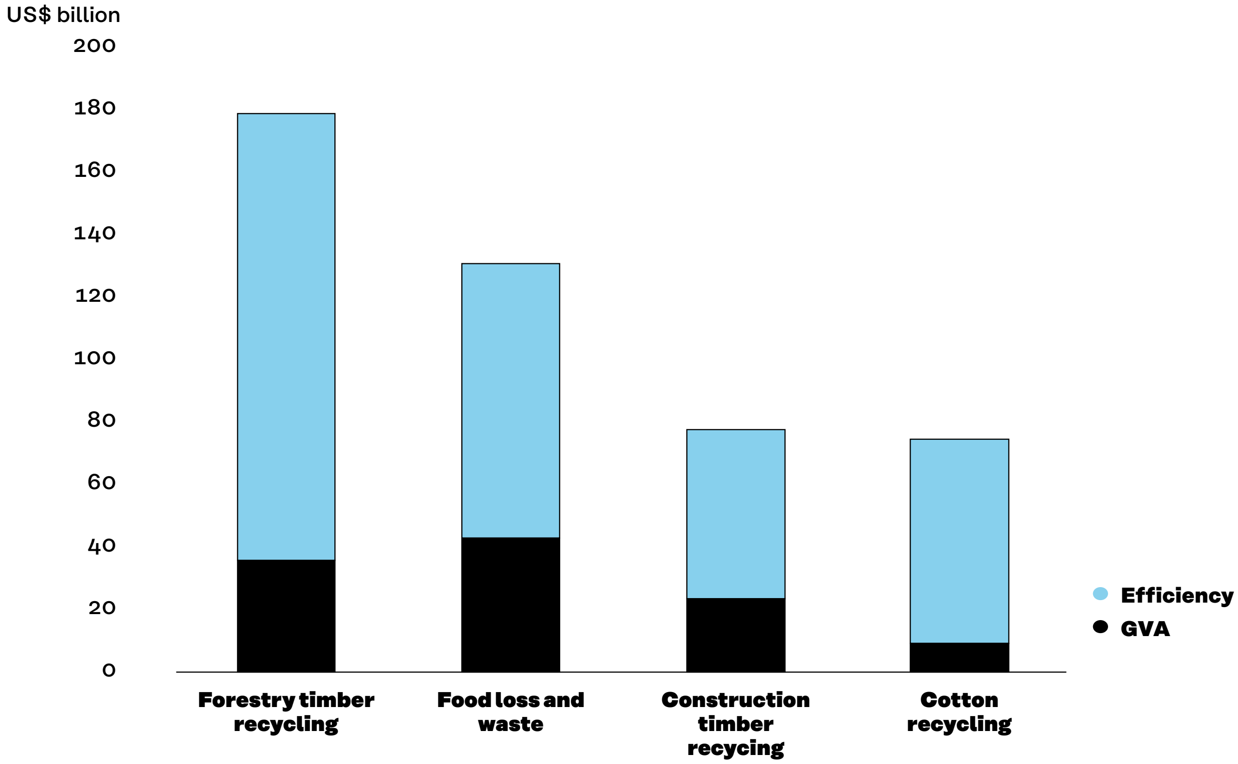
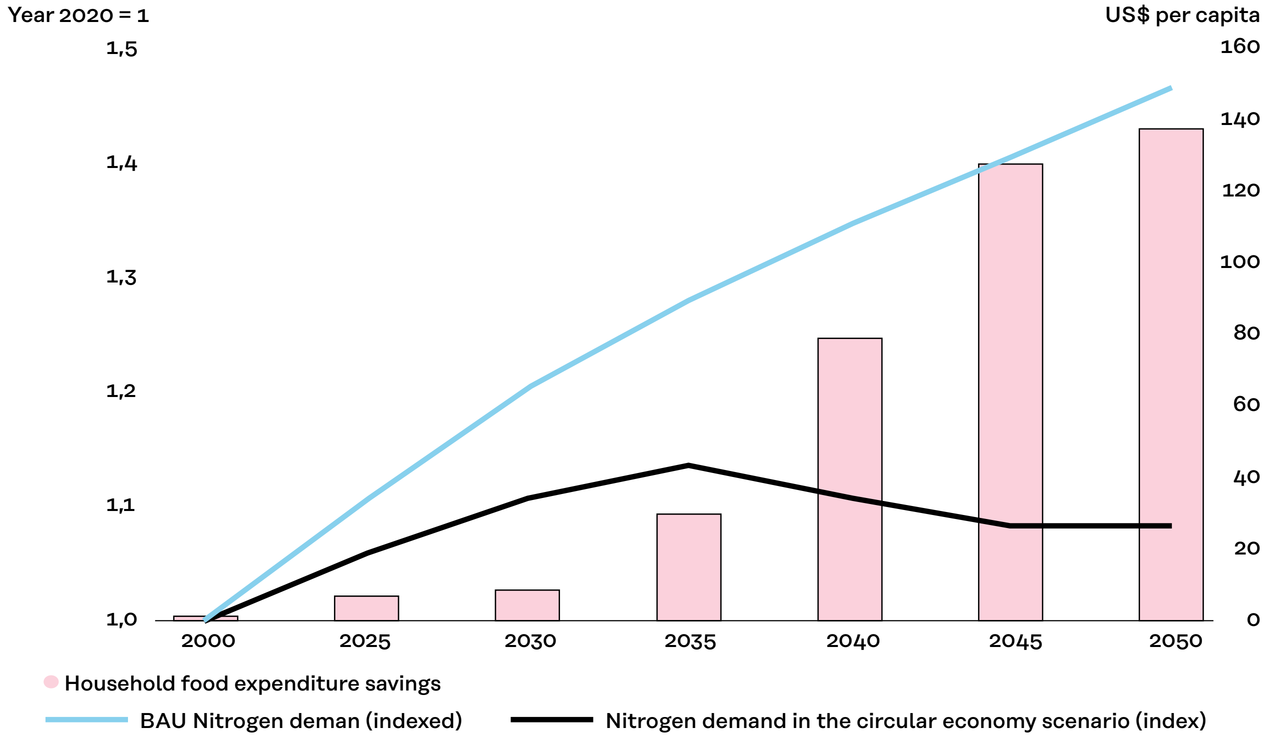


Figure 24. Nitrogen demand change (left axis) and annual household savings per capita (right axis) to 2050 as a result of activation of the food loss and waste lever
Note: Pre-lever scenario refers to the combined circular economy levers applied before the food waste lever (all textiles, buildings and forest levers combined). Rather than comparing to BAU, this isolates the effect of the food waste lever alone.
Source: Vivid Economics



7 Limitations and opportunities for future work

This analysis presents the first set of results on the potential for the circular transition to halt and reverse biodiversity loss. Similar to most initial analyses, it is subject to limitations that can be improved upon to further develop the understanding of the circular economy's potential to halt global biodiversity loss. These limitations are grouped into several categories and are addressed below.

Coverage of ecosystems and habitats. This work was limited to terrestrial biodiversity and so did not consider the implications for the circular economy on freshwater or marine habitats. Future work could build on this analysis by conducting similar analysis for marine and freshwater biodiversity. It could also couple these models together to develop a richer understanding of the interactions between different ecosystems and habitats. This would be particularly interesting when considering the impacts of land-based pollution on aquatic ecosystems.

Coverage of drivers of biodiversity loss. The land-use model deployed in this study is highly suitable for assessing changes to biodiversity driven by land-use change. It is not suitable for studying how a circular economy transition affects other drivers of biodiversity loss, including pollution and invasive alien species. In addition, this work does not study the impact of indirect drivers of biodiversity loss.

Coverage of sectors. This analysis is limited to the four sectors that have an impact on terrestrial biodiversity the most. Several other sectors that have high potential to deploy circular practices, including energy, waste, transport, packaging and plastics, and water, are not studied here. Additional work to assess where the circular economy can have meaningful impacts on biodiversity in these sectors' value chains is required to support decision-makers in these sectors to develop strategies for the future.

Scenarios. This analysis constructs a single circular economy scenario and compares it with a business-as-usual scenario. The circular economy scenario is intended as a plausible vision of what a circular economy transition could look like and is not meant to be predictive. This is informative but limited in two aspects. First, it does not facilitate a comparison with different circular economy scenarios under varying assumptions. Second, the scenario does not account for uncertainty about assumptions or conduct a sensitivity analysis on the set of likely future outcomes.

Assumptions about the speed of technological change and effectiveness. Related to the point above, there is significant uncertainty about how quickly new technologies will mature, particularly for the cultured meats segment of alternative proteins. This analysis uses assumptions from existing work that has studied the potential for technologies and practices to be deployed at scale. The analysis is not intended to predict how effective these technologies will eventually become. There also remains healthy debate around the effectiveness of large-scale regenerative strategies in agriculture, while similar applications in forestry remain embryonic.

In light of this uncertainty, this analysis assumes biodiversity improvements achieved are at the conservative end of current estimates.

Economic analysis. The economic analysis presented here is limited in several regards. First, the analysis does not calculate the overall net benefits of the transition, owing to the range of costs and benefits that need to be considered in any thorough economic analysis. Second, the range of benefits and costs do not consider losses to other sectors that may lose market share or decreases in demand for these products caused by the transition.

8 Implications for policymakers and business

The results of this study suggest that a shift towards circular economy practices in four key sectors of the global economy could reverse the decline in biodiversity by 2035. This modelling however assumes that circular interventions are deployed at scale now and continually increase in uptake until 2050. This window of opportunity remains open but is rapidly shrinking due to the urgency of avoiding further biodiversity loss and the scale of the transformation required. The following discussion focuses on the implications for policymakers and business in working to close this gap and the opportunities this presents.

Policymakers

This report has shown the central role policymakers – with a special emphasis on the EU and national governments as well as multilateral organisations – play in the transition towards a circular economy and halting biodiversity loss. They can drive change by doing the following.

- **Stressing the role of the circular economy as a tool for halting biodiversity loss across policy areas.** The potential of the circular economy to tackle many of the root causes driving biodiversity loss is currently an overlooked opportunity. The consequence is that a wide set of options to stem biodiversity loss are not considered. Future biodiversity and circular economy policies, as well as other policy areas central to this interface – such as forests, buildings and, in particular, food and agriculture could increase their effectiveness in achieving biodiversity outcomes by highlighting the circular economy as a tool.
- **Prioritising circular economy policies that have significant overlaps between climate and biodiversity.** The circular economy interventions covered in this study also make a significant contribution to climate change mitigation, particularly through alternative proteins and less food waste. This also extends to lowering demand for textiles and forest products, and by using buildings and building materials more efficiently. 10% of our circular economy scenario biodiversity impact is also attributed to regenerative approaches in forestry and agriculture that are central to carbon sequestration. Given these overlapping benefits and the increasing significance of climate change on biodiversity loss, these should be prioritised by governments seeking to address both issues.
- **Using circular principles to reduce land use – in particular from biomass production.** This analysis underlines policies that reduce demand for land as central to halting global biodiversity loss. Accordingly, biomass needs recognition as a limited resource reserved for high-value applications in line with a circular bioeconomy, giving us more value from what we have. Market-based instruments can reduce overall consumption or help less harmful alternatives reach price parity by lowering the price differential through, for example, taxes on primary materials and food based on climate and biodiversity impacts. Redirecting tax revenues can also be used to ensure a fair transition. This study also highlights the importance

of avoiding and reducing waste at the outset, from food, textiles and wood products, requiring regulatory support for long-lasting products and business models that increase product lifetimes and use rates.

- **Addressing key global biodiversity pressure points in the system.** Biodiversity loss cannot be solved solely by efforts confined within countries' own borders. It is a global problem, and it needs to be addressed as such – through international free-trade agreements to local public procurement. This study finds that much of the ongoing biodiversity loss happens in biodiversity hotspots far away, driven by increased demand for a few commodities, including meat and dairy, cotton and wood. Regulation targeting these and other key commodities can prevent countries from driving further biodiversity loss.[8] However, demand can still increase from other regions not covered by such legislation. Therefore, the circular economy is a central complement as it reduces the total load on the system, through waste reduction and business model innovation, as well as through nature-inspired design of substitutes, which still hold a large untapped potential to reduce global demand for targeted commodities.

Box 8. The circular economy as a tool in COP 15

The Fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 15) is the key event of the decade for raising global ambition for biodiversity action. This study shows that implementing circular interventions can significantly contribute to reaching global goals on transforming consumption and production, reducing pollution and managing areas under agriculture and forestry sustainably. COP 15 offers policymakers an opportunity to establish the circular economy as an enabling condition for leaving nature room to flourish and including circular interventions in national biodiversity strategies and action plans to help advance biodiversity action in an economically smart way. Some key circular interventions to consider include investing in food products with smaller impacts, especially alternative proteins, designing out waste and promoting regenerative land-use practices.

Business and industry

To lead the way in the transition, business and industry have many opportunities to transform production and unlock more value from existing resources central to biodiversity loss, which firms can identify by first measuring and reporting biodiversity risks and impacts, and then address through biodiversity targets. The circular economy serves as a key delivery mechanism for reaching biodiversity targets. Some of these leading implications and opportunities for business are as follows.

- **Identify overlaps between biodiversity and climate impacts and actions.** This study finds that the sectors most central to halting biodiversity loss are also central to climate change mitigation efforts, implying that the solutions analysed here ought to be prioritised to save resources and maximise positive impacts. As climate change will increasingly drive biodiversity loss in the future, it will

8 A European Commission (2021b) legislative proposal lists beef, palm oil, soy, wood, cocoa and coffee among key commodities that drive deforestation: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0706.

become more important for all sectors with climate impacts to complement and align existing climate strategies with biodiversity strategies. As an effective force for addressing both climate change and biodiversity loss, the circular economy can serve as an important bridge.

- **Highlight the role of land use from global biomass production, especially for food.** Given the centrality of biomass, most companies could effect change by reducing their land-use footprint from biomass use and reserving biomass for high-value applications, through their own activities and those of their suppliers. This study has identified a set of soft commodities key to biodiversity outcomes, including meat and dairy, wood and cotton. In line with a circular economy, efforts to reduce demand for these commodities include waste reduction, business model innovation and nature-inspired substitutes – according to this study, alternative protein sources could present a US$ 10 trillion investment opportunity up to 2050.
- **Apply a hierarchical circular approach for reaching biodiversity goals.** The circular economy is a broad solutions framework that rethinks how we produce, consume and manage products and materials, giving us more value from existing resources and driving regenerative outcomes in areas under production. Businesses have a multitude of potential options for increasing circularity and improving biodiversity outcomes across their value chains, and these vary depending on sector, firm size and geography. To guide decisions, businesses can use hierarchical frameworks, such as that presented for Science-Based Targets for Nature, which has been interpreted in Figure 5 in this study.

The circular economy serves as a key delivery mechanism for reaching biodiversity targets.

Appendix 1 – Sector selection methodology

Screen 1: Which sectors have or will have the greatest impact on biodiversity?

Framing biodiversity loss across sectors

To begin thinking about what interventions may halt biodiversity loss, it is essential to understand what sectors are driving it. As with the climate crisis, there are a small number of sectors that contribute more than others, and these sectors will need to be the focus of interventions to halt biodiversity loss. This section summarises the leading global evidence on each sector's contribution to biodiversity loss.

Only terrestrial biodiversity impact is considered when assessing sectoral impact. The evidence base on terrestrial biodiversity impacts is much more mature and robust than for freshwater and marine biodiversity. For example, the model intercomparison work undertaken for the IPBES Global Assessment Report focused solely on terrestrial biodiversity, drawing upon the results of 14 models. In contrast, the model results presented in the Global Assessment Report for freshwater and marine ecosystems rely only on a small handful of studies, and for marine ecosystems only assess the impact on total animal biomass. Therefore, this study focuses on terrestrial biodiversity to draw upon the larger evidence base.

Climate change is an important driver of biodiversity loss, but tensions between climate and biodiversity outcomes mean biodiversity has to be considered more broadly. Carbon-reducing circular economy levers have both direct and indirect benefits for biodiversity loss. The direct benefits reflect that climate change and biodiversity loss have common drivers: reduced extraction of minerals would mitigate both climate change and biodiversity loss together. The indirect effects reflect that mitigating climate change alleviates a key driver of biodiversity loss, as temperature and precipitation changes under climate change disrupt natural habitats. Biodiverse environments can in turn help climate change mitigation, as well functioning ecosystems sequester more carbon. Climate change mitigation and biodiversity can in some contexts be in tension, for example hydroelectric power may be a source of low-carbon energy but can also disrupt vital freshwater species migrations.

Approaches to assessing sectoral impact

Ranking sectors by biodiversity impact is challenging as there is no internationally agreed-upon metric for measuring biodiversity loss. There are multiple theoretical scales of biodiversity, such as genetic, species and functional diversity, and different measures, including species richness, Margalef's diversity index, richness-evenness indices, range-rarity indices, beta diversity, gamma diversity and the Species Habitat Index. There are also more general metrics, such as mean species abundance, that assess humanity's impact on biodiversity with reference to a pre-modern baseline. The existence of many different metrics makes it difficult to rank sectors in terms of biodiversity impact as the order may differ depending on the metric used.

To assess sectoral biodiversity impact for this screen, several different metrics and sectoral impact studies are synthesised. Table 5 summarises the sources and metrics reviewed. Using WEF's number of threatened or near-threatened species accounts for the absolute impact sectors have on biodiversity, while PBL's mean species abundance accounts for the change a sector has caused to an ecosystem relative to its prior undisturbed state. The other sources are based on aggregated and qualitative analysis, summarising the results of many studies using multiple metrics themselves.

Results: Sectors with greatest biodiversity impact

Across the six sources reviewed, there is broad alignment on which sectors have the largest terrestrial biodiversity impact. All six studies report that food and agriculture has the largest impact on terrestrial biodiversity.[9] WEF and BCG agree that forestry has the second-largest terrestrial biodiversity impact, however CBD and PBL ranks transportation and power generation, and tourism, recreation and hunting above this. WEF and BCG both place buildings and construction third in terms of terrestrial biodiversity impact. While not included in the six sources initially reviewed, these results also align well with the International Resource Panel's Global Resources Outlook (IRP 2019). It is worth noting here that the sectoral boundaries vary between studies, for example between infrastructure and mobility, and that, unlike this study, pressures are not tied to biodiversity loss in a spatially explicit manner.

Food and agriculture, forests, and buildings and construction appear to drive the most terrestrial biodiversity loss. Within food and agriculture, crop production has the largest biodiversity impact, followed closely by livestock farming and ranching. Within the forest sector, wood harvesting drives most biodiversity impacts, with pulp and paper contributing a relatively small fraction of the sector's impacts. Housing and urban areas account for most of the biodiversity pressures from buildings and construction.

Table 6. Sources used in sectoral biodiversity impact meta-analysis

Note: The data from the World Economic Forum report is given by business activity. Vivid Economics mapped business activities to sectors to produce the numbers used here. Source: Vivid Economics

Source	Metric
Boston Consulting Group (2021a)	Contribution to biodiversity pressures
CBD and PBL (2014)	Mean species abundance
IPBES (2019)	Qualitative score based on Global Assessment Report
Natural Capital Coalition (2013)	Natural capital cost from top 100 harmful activities (US$ billion)
UNEPFI (2020)	Qualitative rank of sectors based on their biodiversity impact
World Economic Forum (2020a)	Number of threatened/near-threatened species

9 Natural fibres cultivation is included within agriculture in all studies except for BCG (which measures drivers that are not translated into area-specific biodiversity outcomes) so the biodiversity impact of textiles cannot be assessed as broadly as other sectors. However, we can consider that fibre crops are a particularly intensive part of agriculture: cotton production accounts for only 2.5% of the world's cultivated land but accounts for 16% of global insecticide use (Soil Association (n.d.)).

Tourism and recreation, hunting, transportation, and fibres and textiles also make significant contributions to biodiversity loss. Hunting is predicted to decline in impact over the next 30 years without intervention. This is at least partially driven by increasing urbanisation and decreasing natural areas which is expected to reduce people's reliance on hunting in many parts of the globe (Schipper et al. 2020). The primary biodiversity impact of the transportation sector is habitat fragmentation caused by roads and railways.

Some studies find power generation and mining to have significant terrestrial biodiversity impact, while others find the sectors to have minimal impact on a global scale. Power generation and mining together cover less than 1% of the habitable surface on Earth, while agriculture covers approximately 50% (Ritchie and Roser 2019). This suggests their impact is minimal compared to agriculture, although they may have a larger impact on freshwater and marine biodiversity through pollution. Mining activities are also likely to expand by 2050 to meet demand for electric vehicle components such as lithium for batteries.

Screen 2: Which sectors are most relevant to the circular economy?

To understand how the circular economy could have an impact on biodiversity loss, the sectors with the largest potential to deploy circular economy interventions must be identified. This is done in two steps.

1. Identify the circular economy levers in each sector relevant to biodiversity.[10] The literature was reviewed to identify parts of the value chain in each sector that drive biodiversity impact. This focused on identifying both the current resource flows between segments of the value chain and where potential circular economy levers may exist.

Once the sector and its circular economy levers are mapped, the levers that are relevant to terrestrial biodiversity are identified, based on whether they could affect one of the five IPBES biodiversity pressures. This is important because some sectors have circular levers which have large potential for changing resource flows, like transportation and lithium-ion battery recycling, but these levers will have relatively limited impacts on terrestrial biodiversity.

2. The importance of these levers to the circular economy are measured using two metrics where data is available:

Waste prevention potential: the percentage of the goods or materials produced by the sector currently wasted. This metric provides a proxy for how linear a sector currently is and the proportion of goods or materials that are disposed of in landfills or incinerated. It also sets the size of the gap between a circular and linear economy in the "size of waste" metric.

Climate change mitigation potential: the size of emission savings from deploying circular levers. The CO_2 mitigation potential of the circular levers is used as a proxy for the potential for circularity in the sector. While this is an imperfect proxy for circular economy relevance, it is quantifiable and therefore easier to compare between sectors than for waste prevention potential. Mitigation potential gives us a consistent metric to proxy for circular economy relevance.
Based on this information, each high biodiversity-impacting sector is qualitatively ranked in the following section.

10 Any intervention, whether it be a policy, technology or consumer-preference change, that is related to the circular economy is referred to as a "circular economy lever". Since this study considers the circular economy's impact on terrestrial biodiversity, the focus is on circular economy levers that are relevant to terrestrial biodiversity.

Table 7. Results of the sectoral impacts meta-analysis

Note: The sectors assessed in each study differed and so Vivid Economics mapped results from each paper to the sector classification used here, excluding upstream and downstream impacts in each sector. Note that the data from the World Economic Forum report is given by business activity. Vivid Economics mapped business activities to sectors to produce the numbers used here. Also note that where possible Vivid Economics excluded impacts on freshwater and marine biodiversity in reporting the above data. However, for some studies, such as the Natural Capital Coalition, natural capital cost is not provided by impact on terrestrial, freshwater and marine biodiversity. Therefore, the reported natural capital cost of fishing and aquaculture, and water and wastewater includes freshwater and marine biodiversity impacts. The BCG percentages add up to 90%, this is because they include an "other" category that we do not present here.
Source: Vivid Economics, based on sources in Table 6.

		PBL (terrestrial MSA loss driven by sector)						
Sector	**WEF (no. of threatened/ near-threatened terrestrial species)**	**2010**	**2030**	**2050**	**UNEPFI (rank of sector based on impacts on terrestrial biodiversity)**	**Natural capital coalition (natural capital cost from top 100 harmful activities, US$ billion)**	**BCG (contribution to terrestrial biodiversity pressures)**	**IPBES (qualitative score of terrestrial biodiversity impact based on Global Assessment Report)**
Food and agriculture (excluding fibres)	17,030	-18%	-20%	-21%	1	2181.2	36%	High
Forests	11,950	-2%	-3%	-4%		36.1	20%	Medium
Buildings and construction	8,030						15%	Medium
Tourism and recreation	4,424	-5%	-4%	-4%				Low
Hunting	2,100							Medium
Other manufacturing	0	0%	-1%	-1%			0%	Low
Fibres and textiles							4%	
Transportation	2,047	-7%	-9%	-11%	2		5%	Medium
Power generation	118						5%	Low
Mining	1,085				4		5%	Low
Solid waste	200							Low
Oil and gas	68				3			Low
Fishing and aquaculture	0					80	0%	Low
Water and wastewater	0					370.8		Low

Results: In which high biodiversity-impacting sectors can the circular economy tackle biodiversity loss the most?

Food and agriculture stands out among the high terrestrial biodiversity impact sectors as being the most relevant to the circular economy. Currently over a third of food is lost or wasted each year and the sector contributes about 15% of the world's greenhouse gas emissions at 8 $GtCO_2e$/year (Stoddart 2021, UNEP 2019, WWF 2021). Through a circular economy, the sector could reduce food loss and waste significantly, mitigating approximately 6.7 $GtCO_2e$/year (Lembachar et al. 2021). The circular economy levers that exist in food and agriculture are particularly relevant to biodiversity loss, given the global land area used for agriculture.

The terrestrial biodiversity-relevant levers in transport, buildings and construction, fibres and textiles, and the forest sector are all ranked as having medium relevance to the circular economy. We set out the rationale below.

- **In transport**, the mitigation potential from non-motorised and shared transport is 2.0 $GtCO_2$/year (Lembachar et al. 2021). Shared mobility solutions would lower the need for transport infrastructure such as roads, which would free up land for other uses and reduce habitat fragmentation (Ritchie and Roser 2019).
- **For buildings**, circular design can reduce greenhouse emissions significantly, but the terrestrial biodiversity circular levers are more limited, mainly impacting terrestrial biodiversity through affecting timber demand or urban density.
- **Fibres and textiles**. The sector's waste generation and greenhouse emissions could be reduced considerably through circular solutions. For example, increasing the use of clothing, and therefore reduced demand for new fibres, could reduce emissions by 44%. Fibre crops such as cotton can also be cultivated using regenerative agriculture, which improves on-farm biodiversity and reduces water pollution (Ellen MacArthur Foundation 2017a, 2021b).
- **Forest sector**. Best practice in some countries already partly overlaps with circular economy principles; for example, almost 50% of paper is currently recycled (van Ewijk et al. 2021) and wood waste already accounts for approximately a third of the global pulp and paper sector's energy needs (ECE 2019, IEA 2020). However, circularity can be increased and improving logging practices in tropical regions alone could reduce emissions by ~1.4 $GtCO_2$/year (Sasaki et al. 2016).

Tourism and recreation is predominantly a serviced-based industry, and so has few terrestrial biodiversity-linked circular economy levers within it. This is consistent with the fact that most of the sector's carbon footprint comes from upstream sectors such as food and transport, rather than directly from the sector (Einarsson and Sorin 2020). For example, the emissions associated with tourism are largely from the airline industry, while the biodiversity impacts are largely from buildings, although this depends on where the lines between sectors are drawn.

Table 8 summarises the ranking of biodiversity-impacting sectors from the perspective of circular economy potential.

Table 8. Ranking of circular economy relevance of each high biodiversity-impacting sector

Source: Vivid Economics

Sector	Circular economy relevance	Explanation
Food and agriculture	Very High	• Over a third of food is lost or wasted each year (WWF 2021) • Circular interventions in the sector could lead to 6.7 $GtCO_2e$/year mitigated (Lembachar et al. 2021)
Transportation	High	• ~2.0 $GtCO_2$/year mitigation potential from non-motorised and shared transport alone (Lembachar et al. 2021) • Increasing non-motorised and shared transport has the potential to open up large areas for green space in urban areas (Plumer (n.d.))
Buildings and construction	High	• Circular design can reduce GHG emissions by 61% in the European buildings sector (from ~1.1 $GtCO_2$/year) (Climate Action Tracker 2020, EEA 2020) • Recovery of demolition waste can exceed 80%. Currently less than 50% in some countries (Ren and Toniolo 2020)
Fibres and textiles	High	• 73% of material flow in clothing is landfilled or incinerated (Ellen MacArthur Foundation 2017a) • Doubling the average number of times a garment is worn would reduce industry GHG emissions by 44% (from ~1.2 $GtCO_2$/year) (Ellen MacArthur Foundation 2017a)
Forest sector	High	• Best practice in forest sector largely overlaps with circular economy principles and paper recycling is already practised in many countries (ECE 2019, IEA 2020) • In tropical regions, however, reduced-impact logging can reduce emissions by ~1.4 $GtCO_2$/year (Sasaki et al. 2016)
Tourism and recreation	Low	• The majority of the sector's carbon footprint comes from upstream sectors, not directly from the sector itself (Einarsson and Sorin 2020). Impacts are often attributed to tourism's component parts, such as travel, infrastructure and food.

Screen 3: For which sectors can we model terrestrial biodiversity impacts?

Assessing which sectors can be modelled

Land-use modelling frameworks are central to examining scenarios for biodiversity loss, which places limits on which sectors biodiversity pressures can be modelled for. For example, land-use models do not directly account for the biodiversity pressures on marine ecosystems from wastewater pollution, invasive alien species from transport or habitat fragmentation from infrastructure projects. This screen is therefore needed to ensure the biodiversity pressures exerted by sectors can be accounted for in a robust manner.

Results: In which sectors can be terrestrial biodiversity impact be modelled?

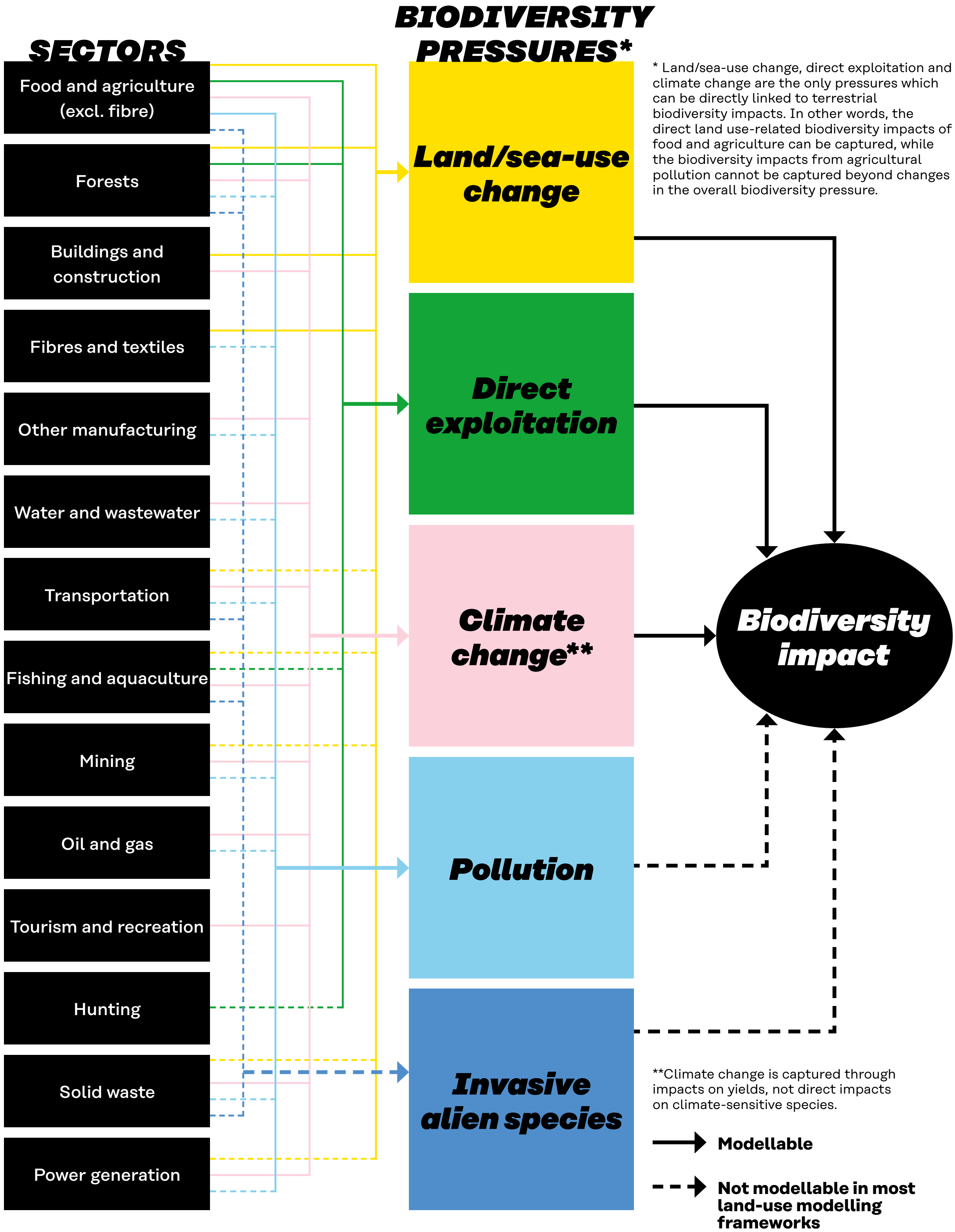
Transportation is dropped as the sector impact largely comes from habitat fragmentation, which most land-use models are not set up to model. Figure 25 outlines the modelling feasibility of different sectors.

Screen 4: Does this list adequately account for sector interlinkages?

The four remaining sectors capture important interlinkages between sectors. The sectors have been defined to be largely vertically integrated, ensuring that many upstream and downstream impacts are captured within one sector. For example, buildings and construction includes the upstream harvesting of timber used in construction. This ensures that key levers and biodiversity impacts are not omitted from the analysis.

Figure 25. Land-use modelling frameworks place limits on which sectors biodiversity pressures and impact can be modelled for

Source: Vivid Economics



Appendix 2 – Methodology materials

MAgPIE capabilities

Table 9. MAgPIE capabilities support project objectives
Source: Vivid Economics

Modelling objectives	MAgPIE capabilities	MAgPIE limitations
Robust analysis	MAgPIE has been used in dozens of peer-reviewed publications and has fed into IPCC reports.	Like with all integrated assessment models, there is large uncertainty in the forward-looking assumptions input into the model. These include population and GDP assumptions, as well as the cost of yield-enhancing investments.
Internally consistent	MAgPIE models all major land-based economic activities in a cohesive modelling framework. Links and competition between sectors are captured.	Since MAgPIE is a land-use and agriculture model, it does not represent sectors with a small land footprint – relative to agriculture and forestry – in significant detail. For example, the buildings and construction sector is represented relatively crudely.
Flexible to allow the design of a circular economy scenario	MAgPIE includes close to 100 policy, technology, consumer preference and demography options in its default form. More can be added with additional effort.	Some parts of the value chain of the circular economy sectors in this study cannot easily be modelled in MAgPIE, for example gravel extraction for use in concrete.
Global scale results with regional dives possible	MAgPIE is connected to the dynamic vegetation model LPJmL, which uses a grid with a spatial resolution of 0.5° x 0.5°. Outputs are aggregated at the regional and global levels.	Cells are assigned to one of 15 economic regions and grid cells are clustered to make global computation tractable. This makes raw results unsuitable for localised estimation.
Measures impact on biodiversity	MAgPIE calculates the change in Biodiversity Intactness Index from land-use changes under the chosen policy, technology, consumer preferences and demographic assumptions.	MAgPIE only measures impacts on terrestrial biodiversity and does not include impacts on freshwater or marine biodiversity.

Central economic and demographic assumptions common to scenarios

Table 10. Economic and demographic assumptions are needed to frame the world land economy in 2050

Source : Vivid Economics, from PIK's MAgPIE documentation

Variable	Description	Source	Values for scenarios
Population	Population growth trajectory between now and 2100, based on SSPs (shared socio-economic pathways)	SSP database	SSP2 – "Middle of the road" consistent pathways Population reaches 9.2 billion by 2050
GDP	GDP growth trajectory between now and 2100, based on SSPs	SSP database	SSP2 – "Middle of the road" consistent pathways Global GDP more than doubles by 2050
Mitigation policy	Global price trajectories for CO_2, N_2O, CH_4	IIASA Database and PIK-integrated assessment modelling exercise	No global, mandatory carbon prices are implemented in the land-use sector
Nature protection	Areas that are off limits to resource extraction and land conversion	Leclère et al. 2018	Land protection remains at current levels No biodiversity price
Bioenergy demand	Demand for second-generation bioenergy crops (only used for fuel production, not for food)	IIASA Database and PIK-integrated assessment modelling exercise	Second-generation bioenergy demand increases very modestly to around 4 EJ/year by 2050 First-generation bioenergy demand and wood fuel demand vary by scenario
Trade	Trade patterns (this has a large impact on how efficiently land can be used)	Schmitz et al. 2012	Small increase in liberalisation of trade relative to today
Future cost of investment	The required amount of investment into R & D to produce a one unit increase in agricultural yields	Dietrich et al. 2014	Cost of future productivity improvement in line with historical costs

Assumptions used for land-use levers

Table 11. Land-use lever assumptions

Source: Vivid Economics

Sector	Model switch	Lever	Lever description	BAU value	Circular economy value in 2050	Source
Food and agriculture	Food waste	**Reduced food loss and waste**	Households and businesses can reduce food waste, decreasing total food demand. Increasing the shelf life of products through processing can help reduce food waste. This includes greater use of mobile processing units, solar dryers, graters and pressers. Food loss in production can be reduced by increasing the use of underused by-products and damaged products, using appropriate storage and reducing overproduction.	Food loss and waste rates remain constant	Food waste and losses reduced by 50% per capita	50% reduction in total food waste and losses by 2050 (compared to today) consistent with less ambitious of two Project Drawdown (2021) scenarios. This can be compared with SDG 12.3, which prescribes a 50% reduction in per capita food waste and a reduction in food losses. Food waste is also modelled endogenously, so can fall further in response to food price increases.
	Food waste	**Improved field residue use**	Reducing the burning of residues on fields allows for increased recycling of residues back into fields, retaining soil nutrients and increasing their use for bioenergy. This increases productivity, reduces GHG emissions from burning and reduces the need for land to be devoted to growing energy crops.	15-25% above-ground biomass field residue burnt, varying by region	Field residue burning falls from 15-25% to 0-10% of above-ground biomass burnt, varying by region	MAgPIE database
	Food waste	**Animal-waste management**	Improvements to manure storage can improve nitrogen retention in manure, improving the nutrient value when used as fertiliser and reducing pollution. Manure can also be separated from liquid slurry and used to boost phosphorous levels in arable fields.	Current practices continued	Best practice adopted throughout agricultural system	MAgPIE database
	Food waste	**Fadeout of first-generation biofuels**	First-generation biofuels typically derive from edible biomass such as sugarcane or corn, while second-generation biofuels typically derive from non-edible biomass such as agricultural and forest residue and municipal solid waste. First-generation biofuels are therefore in greater competition with food production for finite land resources, and second-generation offers greater potential for producing both food and fuel simultaneously through use of residues.	First-generation biofuels increase and remain constant from 2030	First-generation biofuels faded out	MAgPIE database
	Alternative proteins	**Increased feed quality**	Reliable, quality feed can improve productivity and reduce emissions from enteric fermentation. This could include substituting conventional feed and fodder for single-celled protein (SCP). This decreases the required inputs per unit meat produced, increasing the value added in livestock products and freeing up land for natural ecosystems.	No replacement of animal feeds and fodder with single-celled protein	70% of animal feed and fodder protein is replaced with single-cell protein	Consistent with increase in alternative proteins for human consumption. BCG (2021b) notes that market for alternative proteins for feed is likely to grow quicker than for humans.
	Alternative proteins	**Consumption of alternative proteins**	Replacing livestock products with consumption of alternative proteins results in a large decrease in the inputs required to produce each unit of protein. This frees up land and water for natural ecosystems and decreases pollution from livestock production.	The share of livestock products consumed stays the same over time, resulting in substantial increases in meat demand due to population and income growth	50% decrease in beef consumption and 67% decrease in dairy consumption	Consistent with Kearney (2020) alternative proteins forecast. Slightly more ambitious than BCG (2021b). Dairy transition in line with Credit-Suisse (2021).
	Regenerative agriculture	**Regenerative agriculture**	This includes a wide range of potential measures, including but not limited to a selective application of organic farming principles, no-till methods, agroecology, climate-smart agriculture, crop rotation, precision agriculture, use of biochar, polyculture (growing multiple crops together) and permaculture (maintaining permanent soil cover). This has implications for on-farm biodiversity, nitrogen uptake efficiency (NupE) and irrigation efficiency. These practices can enhance biodiversity in cultivated areas and in some cases can increase yields, opening up space for natural ecosystems.	Area under regenerative agriculture remains constant. Nitrogen uptake efficiency remains at global average of 60%. Irrigation efficiency remains constant.	Regenerative agriculture practices increase from being used on 21% and 8% of cropland and pastureland today to 60% and 18%. Nitrogen uptake efficiency increases from 60% to 85%. Irrigation efficiency reaches 90%.	Expansion of cropland and pastureland under regenerative agriculture and the associated biodiversity impact is taken from Systemiq (2019). Zhang et al. (2015) suggest a 25% increase in nitrogen-use efficiency (NUE) is required and feasible to reduce nitrogen pollution to sustainable levels. NUE and NupE are slightly different metrics but highly related. Evans and Sadler (2008). Irrigation efficiency improvements can lead to increased water consumption if not part of a broader water-management scheme. Hence, here we couple efficiency improvements with environmental flow policies.

Sector	Model switch	Lever	Lever description	BAU value	Circular economy value in 2050	Source
Forests	Forestry timber savings	**Paper processing efficiency and recycling**	More efficient processing and use of processing wastes for other products would reduce demand for new timber. Energy demands would have to be met by alternative energy sources.	No additional timber savings from paper	48% reduction in new timber demand from pulp Timber savings replicated in wood fuel savings	48% reduction in new timber demand for paper, from van Ewijk et al. (2021)
	Forestry timber savings	**Furniture processing efficiency, longevity and recycling**	Includes designing wood products to be more durable and reserving wood for products with longer lifetimes. Improved durability and longevity would reduce demand for new timber by reducing the need to replace products. Wood products can be reused, repurposed or transformed into other uses, reducing the demand for new timber.	No additional timber savings from furniture	54% reduction in new timber demand from furniture Timber savings replicated in wood fuel savings	54% reduction in wood demand for furniture from European Environmental Bureau (2019)
	Forestry timber savings	**Reduced paper use**	Greater use of the internet and computers could make some uses of paper increasingly redundant.	Paper use remains constant	Paper use falls by 55% Timber savings replicated in wood fuel savings	55% reduction in paper use extrapolated to 2050 from Johnston (2016)
	Regenerative forestry	**Regenerative forestry**	Includes practices such as keeping decaying and dead wood and old trees, continuous tree cover, mix of age classes, use of native species and use of a mix of species. Regenerative principles can be applied to both managed and natural forests. Increases in biodiversity are modest to reflect that significant increases in biodiversity, such as by leaving old trees in place, could negatively impact yields.	Managed forest has the biodiversity of clear-cut, single species forests	Regenerative principles applied in all managed forest and 20% of secondary forests. BII in managed forests increases to be equal to the coefficient for managed forests – minimal intensity in PREDICTS database. BII in young and intermediate age classes of secondary forest increases to coefficient for secondary forest – minimal intensity by 2050.	NHM – PREDICTS database
	Forest land-use planning	**Managed forest share of timber production**	Timber can be produced more effectively when managed according to best practice. Therefore, sourcing a greater proportion of timber from managed forests could spare natural forest from harvesting, provided natural forest is not converted to managed forest.	Managed forest share trajectory from MAgPIE database, Australian Bureau of Agriculture and Resource Economics (ABARE) and Jaakko Pöyry Consulting 1999	Approximately 10% higher managed forest area, with regional variation	Managed forest share trajectory from MAgPIE database, working paper GFPOS/WP/03 prepared for the 1999 Global Forest Products Outlook Study 1999
Buildings and construction	Construction timber demand	**Greater use of timber in construction**	Glue-laminated beams and cross-laminated timber (CLT) can be used in place of steel and concrete as a structural material. Timber in buildings can be an effective carbon store and also reduces building weight, decreasing the amount of concrete needed in building foundations. Timber structures have demonstrated fire resistance in buildings up to 18 storeys tall.	Predominant use of concrete and steel for building structures remains as per the status quo	6% increase in total industrial roundwood demand Countries with capacity to manufacture mass-timber products or countries located close to those with manufacturing capacities primarily use engineered timber for the construction of new urban buildings	Churkina et al. (2020)
	Construction timber savings	**Reuse and recycling of construction timber**	Timber salvaged from building refurbishments or demolitions can be reused or recycled into lower-grade timber materials such as fibreboard, reducing demand for new timber.	No change in construction timber reuse and recycling	Construction timber recycling increases by 23% Timber savings replicated in wood fuel savings	Meeting EU Waste Framework Directive recycling target rate for 2020 (70%) from current EU timber recycling in construction levels (47%) (European Commission 2008)
	Construction timber savings	**Reduced building overspecification**	This involves greater design quality to ensure that the minimum amount of materials are used, without compromising the structural integrity of buildings. Buildings are typically built to unnecessarily high structural integrity.	Overspecification of buildings continues at its current levels	Construction timber demand falls by 15% due to reduced overspecification Timber savings replicated in wood fuel savings	Allwood et al. (2019) estimated savings for structural steel; Cramer (2021) suggests overspecification is also a problem with timber in construction

Sector	Model switch	Lever	Lever description	BAU value	Circular economy value in 2050	Source
	Construction timber savings	**Extending building lifetimes**	Increasing the renovation of existing buildings instead of demolishing them keeps materials in use, as many impractical buildings contain functional structures and materials that are lost to landfill otherwise.	Building lifetimes continue at their current level	Construction timber demand falls by 12% due to increased building life Timber savings replicated in wood fuel savings	IEA (2019) estimate for reduction in steel demand from building life extension
	Urban density	**Urban density increases**	Urban areas can take up less space if they are developed to be higher density. Urban areas can be designed to make better use of existing space for multiple purposes, and in a way that higher densities do not inhibit liveable urban spaces with sufficient green space.	Urban density of 111 persons/ha	Urban population density increases by 51%, from 111 people/ha to 168 people/ha This causes urban area to decrease by 38% compared to BAU	S75 scenario from Güneralp et al. (2017)
Fibres and textiles	Textiles demand	**Increased lifetime of clothing**	The lifetime of textiles can be improved by designing products to last longer. This reduces the need to replace items of clothing through wear and tear and makes it more likely that textiles can be repurposed and reused rather than thrown away. Clothing rental models would reduce the occurrence of clothing items worn only a small number of times and would incentivise clothing repair. Increased warranty and free refitting and repair services, such as those offered by some leading retailers, could reduce demand for new clothing from damage or loss of fit. Consumer demand for new products can be reduced through awareness campaigns. Resale of used clothes is becoming increasingly popular, with consumer appetite for "vintage" clothes and platforms set up to accommodate second-hand clothing sales. Overstocking waste can be reduced through on-demand distribution and nearshoring and automation. Slow fashion models may assist by reducing stocking levels and speeds.	The baseline textile demand trajectory is consistent with Ellen MacArthur Foundation (2017), which is a tripling of clothing sales by 2050 relative to 2015, with almost all materials coming from virgin sources. The share of cotton in total clothing fibres demanded falls from 25% in 2020 (Ellen MacArthur Foundation 2017) to 22.5% in 2030 (Global Fashion Agenda and BCG 2017) to 17.5% in 2050 (by extrapolating this trend). However, the increase in total clothing demand more than compensates for this, leading to an increase in cotton demand for textiles from 13 Mt to 42 Mt. Clothing lifetimes remain unchanged.	Clothing lifetimes increase by 50% Total demand for virgin organic fibres decreases by 83% relative to the baseline, to 7 Mt	Use of clothing increases by 50%, consistent with the Ellen MacArthur Foundation (2017) circular economy modelling assumption. This is modelled as a 50% increase in the lifetime of clothes.
	Textiles demand	**Textile recycling**	Recycling of textiles has significant environmental benefits by avoiding production of new items. Collection and sorting of textiles at scale improves the business case for textile recycling.	Same baseline textile demand trajectory as above Textile recycling remains constant	Textile recycling reaches 75% Total demand for virgin organic fibres decreases by 83% relative to the baseline, to 7 Mt	75% of natural fibres come from recycled sources by 2050. This can be compared with global collection and recycling rates reaching 75%, equivalent to the collection rate among current world leaders such as Germany (Ellen MacArthur Foundation 2017). In this case it is not inconsistent to assume recycled content equals the recycling rate due to the increasing usage rate making the equivalence of recycling and recycled content rates possible.
	Regenerative fibre cultivation	**Regenerative agriculture on cropland used for fibre production**	Production of bio-based textiles brings with it additional demands on water, land and chemical use in their cultivation. Regenerative agriculture describes a diverse range of methods and practices such as polyculture, organic farming and no-till practices that can reduce demands for inputs and can maximise long-term land productivity.	Constant share of production based on regenerative principles	Production based on regenerative principles is used on 60% of fibre cropland, up from 21% in 2020	Expansion of cropland under regenerative agriculture and the associated biodiversity impact is taken from Systemiq (2019).

Appendix 3 – Economic impacts materials

Economic costs and benefits methodology

This section outlines the assumptions taken from the literature that allow for the estimation of economic impacts. Contrary to the biodiversity modelling, levers here are generally not divided between sectors of the economy but between broad groupings of levers, for example regenerative levers, as their economic impacts are calculated in similar ways.

Key economic impacts are captured by translating the circular levers into a set of economic impact channels. Figure 26 provides an indicative overview of the entire four-step process, using the agriculture sector as an example. The four-step process is as follows.

1. MAgPIE outputs for each sector are categorised into four impact channels: land-use changes, efficiency changes, input changes and demand changes.
2. The physical impact of these channels is converted into costs and benefits based on parameters from the literature.
3. The costs and benefits of the levers are estimated using the MAgPIE outputs and parameters mentioned above. Three types of economic benefits are considered: economic gains, efficiency gains and employment gains. For a sector like food and agriculture, some levers are grouped together to facilitate the analysis, as highlighted in the next section.
4. Results are aggregated to obtain global estimates of costs and benefits.

The first step in the analysis is estimating how much it would cost to implement the circular economy levers. This refers to the upfront capital costs and ongoing maintenance costs required for new innovations. For example, transforming the current agricultural system into a regenerative one will require significant upfront investment in irrigation systems, tree planting and new equipment, followed by annual upkeep costs. The development of new industries altogether, such as alternative proteins, will require more significant investment. The overall costs for implementing each lever are calculated using MAgPIE output data and cost data from the literature.

Estimates of costs are then coupled with additional analysis to estimate the value added from the levers. As shown in Figure 27, the parametrisation of costs is used to calculate the gross value added (GVA) of a lever by multiplying the costs by a value-added-per-dollar-invested ratio. For all sectors, the GVA/turnover ratios are based on GVA/turnover ratios for the UK, from the Office for National Statistics' Annual Business Survey.

Estimates of GVA are then multiplied with a jobs/GVA ratio to provide an estimate of the potential job creation of a lever. The jobs/GVA ratios for all sectors are also based on the Office for National Statistics' Annual Business Survey but are adjusted using IMF data to account for differences in labour productivity across regions. On average, for every million dollars of value added, seven new circular jobs are supported. This is in line with other literature sources. Employment loss or reallocation are not modelled, as the simultaneous implementation of multiple levers has uncertain impacts on labour market dynamics. While some of these levers may lead to job losses, the literature suggests that circular economy solutions should have net positive impacts on employment (Aguilar-Hernandez et al. 2021). For example, if the alternative protein industry becomes a significant part of the proteins market, manufacturing jobs to produce equipment such as bioreactors would be supported.

For recycling-based levers, estimates of efficiency savings from new innovations are also calculated. These benefits accrue to farmers, supply chains and consumers. Circular economy levers provide indirect economic benefits through efficiency savings. For example, reducing food waste can lead to consumers spending less on food and lower fertiliser needs for farmers. Accordingly, these efficiency benefits are estimated where appropriate. Efficiency gains are modelled for four levers: food loss and waste; timber recycling in construction; paper and furniture recycling; and textile recycling. These estimates of benefits will not be exhaustive but should provide a more accurate account of the potential benefits from these levers.

Figure 28 provides an example of the methodology using the regenerative agriculture sector. Regenerative agriculture requires upfront costs to transform existing agricultural land into regenerative land, followed by annual costs to keep the farms and equipment running. Coefficients are based on the relevant industries in the Annual Business Survey and are then calibrated to be more globally representative.

Figure 26. Four steps are taken to derive global estimates* of economic costs and benefits from MAgPIE outputs

Note: Efficiency impacts are estimated for levers when relevant and are not calculated systematically; the circular economy levers listed in this figure represent a more granular breakdown of levers covered in the study.
*Efficiency estimates are only estimated for sectors where relevant and possible, for example timber recycling
Source: Vivid Economics

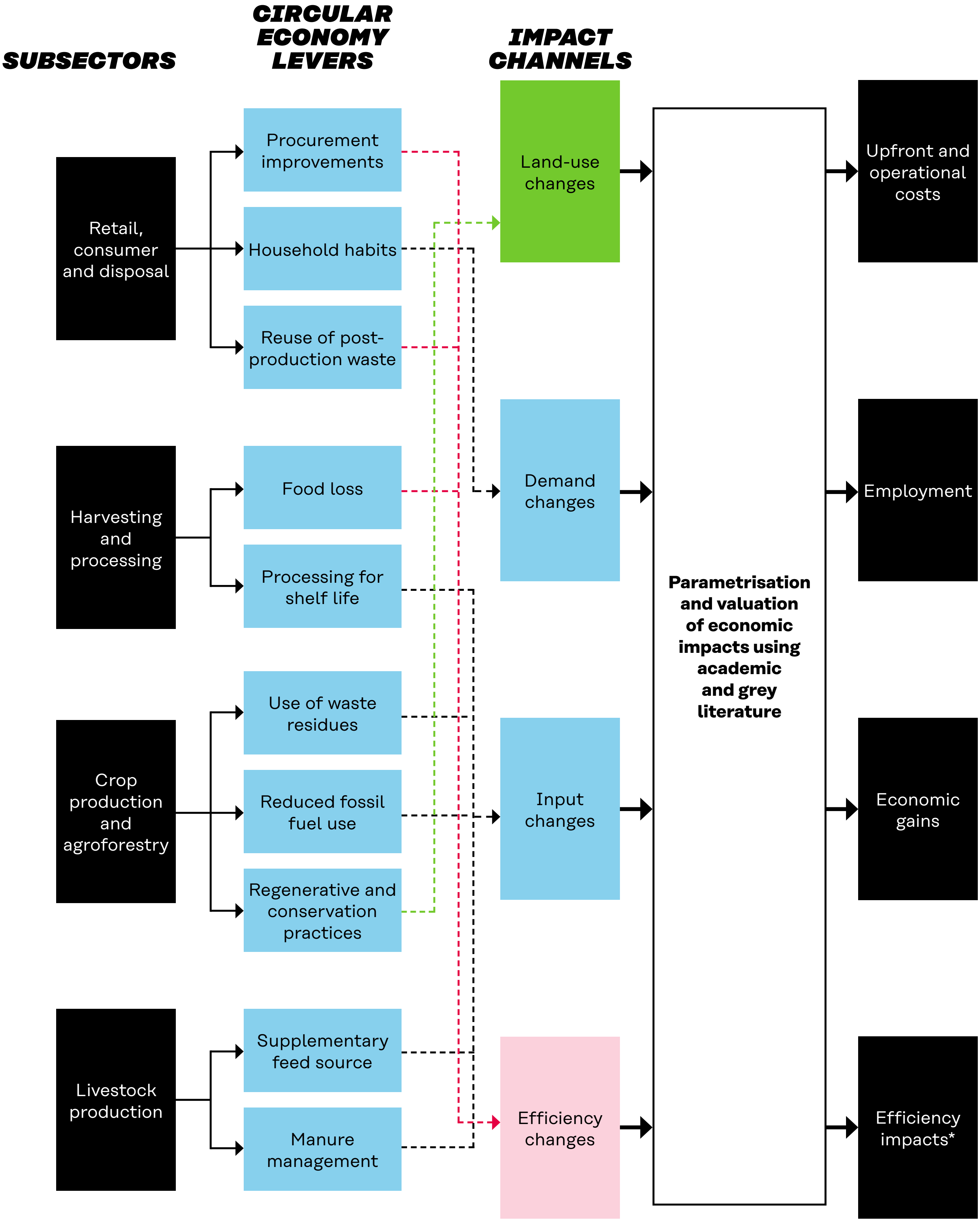


Figure 27. Parametrisation and valuation of economic impacts

Note: Efficiency gains are only done for a few recycling-focused levers. To estimate value/cost and jobs/value ratios, we use data from the Office for National Statistics (UK) Annual Business Survey, and calibrate it with global data from the IMF.

Source: Vivid Economics

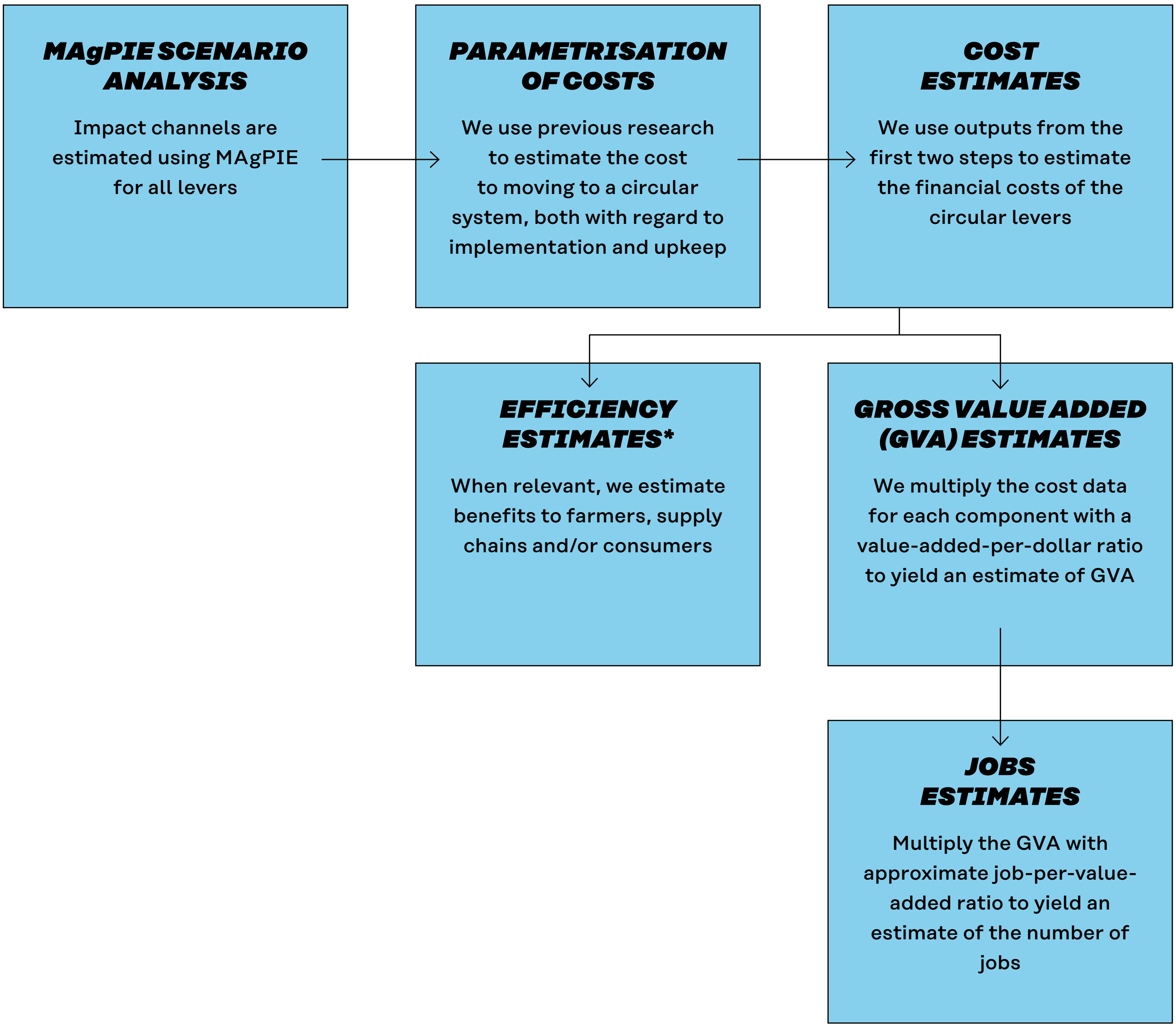


Figure 28. Estimation example: regenerative agriculture

Note: No efficiency analysis in this sector; values are rounded to make the example clearer
Source: Vivid Economics

MAgPIE SCENARIO ANALYSIS	**Farmland area** forecasts are taken from a MAgPIE scenario run with the relevant levers. Between 2020 and 2050: • **Cropland** changes from **1,600 million ha** to **1,400 million ha** • **Pastureland** changes between **3,200 million ha** and **3,000 million ha**
PARAMET-ERISATION OF COSTS	Based on a FOLU report • Capex: **$600/ha** • Opex: **$120/ha until 2030**, then **$150** Based on the previous biodiversity analysis: • **Regenerative agriculture** uptake between 2020 and 2050 **increases from 21% to 60% for crops**, and **8% to 18% for livestock**
COST ESTIMATES	Using the two previous steps we get for 2050: **$25 billion** needed for **new regenerative farming** investment **$170 billion** ongoing costs from **existing regenerative farmland**
GVA ESTIMATES	Using a value added/costs ratio, we estimate that **$1 in costs** equates to **GVA by $0.35**, equalling **$60 billion of value added** in 2050
JOB ESTIMATES	Using a jobs/value added ratio, we estimate that **every $ added creates 0.06 jobs**, leading to **1.4 million jobs** supported globally in 2050

Details on the parametrisation of levers

This section summarises the key assumptions used on top of the MAgPIE modelling to estimate economic costs and benefits. The modelling approach for each sector is outlined below.

Three levers in the food and agriculture sector are modelled: regenerative agriculture; food loss and waste; and alternative proteins. These levers drive changes in land use, efficiency and demand changes, respectively. Assumptions are summarised as follows.

- **Regenerative agriculture**. Data sourced from the literature concerns capital costs, ongoing costs and regenerative farming uptake between 2020 and 2050. These assumptions are in part based on analysis done by FOLU in the Growing Better report (Food and Land Use Coalition 2019).
- **Food loss and waste**. This uses the costs required to recycle a tonne of waste, based on analysis done by ReFED (2016) and are broadly in line with estimates from WRAP (2015).
- **Alternative proteins**. This lever mostly concerns significant market growth in alternative proteins. The cost data here is based on previous analysis done by Vivid Economics for Climateworks as part of the Global Innovation Needs Assessment (Climateworks 2021). Useful data concerns price ratios between traditional and alternative proteins, uptake of alternative proteins and growth rate of the market.

Two levers are modelled in the fibres and textiles sector: an increase in cotton textiles recycling and regenerative fibre. These bring about changes in efficiency and land use. Key data inputs are summarised as follows.

- **Cotton recycling**. Data required includes that on the costs of recycling cotton, the increase in proportion of recycled content from the land-use modelling and current worldwide cotton production and recycling. The cost of recycling cotton is taken from a WRAP (2019) case study and the cost of cotton from World Bank (2021b) data.
- **Regenerative cotton cultivation**. As with regenerative agriculture, this requires information on capital costs, ongoing costs and uptake of practices that drive regenerative outcomes between 2020 and 2050. Uptake for regenerative cotton farming practices is assumed to be equal to that of regenerative farming in general, as are costs.

One lever is modelled for construction: construction timber recycling. Assumptions concern current market size, current roundwood and wood fuel production and the price of roundwood and wood fuel. Data on roundwood and wood fuel is sourced from the UK Forest Research (2021).

Three levers are modelled in the forest sector: regenerative forestry; timber savings; and forest land-use planning. These amount to two land-use levers and a recycling-focused lever. Assumptions are summarised below.

- **Regenerative forestry**. Input data includes that on current managed forest and uptake to 2050, potential growth rate, estimates of managed forest growth every year, capital costs and ongoing costs. These assumptions are based on in-house modelling and on not yet published data on forestry management costs. These are part of research done for the Inevitable Policy Response by Vivid Economics, published in December 2021.
- **Forestry timber savings**. This uses data on the cost of recycling per tonne of paper and the current size of the market. Current size of the market is based on data from market research websites and the cost of recycling paper from a commodity pricing index (Recycling Markets 2022).
- **Forest land-use planning**. This uses data on the capital and ongoing costs of forest management, based on Vivid Economics analysis for the Inevitable Policy Response.

Table 12. Land-based levers assumptions
Source: Vivid Economics

Lever	Description	Capital costs (capex)	Operational costs (opex)	Uptake speed	Calibrations
Regenerative agriculture	Regenerative methods such as polyculture and permaculture practised	Capex for new regenerative farmland are fixed at 600 US$/ha	Opex costs for regenerative farmland are at 120 US$/ha to 2030 and increase to 150 US$/ha for the 2030-2050 period	Regenerative agriculture to reach 60% of cropland from 21% in 2020 Regenerative agriculture to reach 18% of pastureland from 8% in 2020	FAO data is used as a baseline for 2020 and then is forecasted using MAgPIE growth rates
Forest land-use planning	Greater proportion of timber produced from managed forests	Capex to manage forests are 1,700 US$/ha	Opex required for forest management are 28 US$/ha	Managed forests increase by 10% by 2050	N/A
Regenerative forestry	Forests are managed to drive regenerative outcomes and boost biodiversity	Capex to convert regenerative forestry are 28 US$/ha	Opex after converting are 3 US$/ha	Assumed 0% of managed forests are regenerative today, rising to 100% by 2050 13.5 Mha of secondary forests move to regenerative forestry every year	N/A
Regenerative fibre cultivation	Regenerative methods such as polyculture and permaculture practised	Capex for new regenerative farmland are fixed at 600 US$/ha	Opex costs for regenerative farmland are at 120 US$/ha to 2030 and increase to 150 US$/ha for the 2030-2050 period	Regenerative fibre production to reach 60% of cotton land from 21% in 2020	Land used for cotton production in 2020 estimated to be 34 Mha

Table 13. Recycling-based levers assumptions
Source: Vivid Economics

Lever	Description	Fall in demand between levers due to recycling	Unit cost	Recycling cost	Calibrations
Forestry timber savings	Paper and furniture recycling reduces demand for new timber	100% (as this is the only forest lever that impacts demand)	Woodchip costs 110 US$/tonne	Recycling paper costs 107 US$/tonne	Paper recycling market in 2019 worth US$45.5 billion
Construction timber savings	Construction wood recycling reduces demand for new timber	30%	Roundwood costs 206 US$/tonne	Recycling roundwood costs 200 USD/tonne	FAO figures for roundwood production equal to 3,966 million m³ in 2019 Chipboard market size in 2020 estimated at US$21 billion
Textiles demand	Lower clothing use reduces demand for cotton, leather and wool	75%, with the rest a result of increases in clothing use	Cotton costs 1,600 US$/tonne	Recycling cotton costs 538 US$/tonne	FAO figures for cotton production equal to 32 million tonnes in 2018 Recycled textile market industry worth US$5.6 billion

Table 14. Alternative proteins assumptions

Note: This is based on analysis by Vivid Economics for Climateworks Global Innovation Needs Assessments.
Source: Vivid Economics

Lever	Description	Market shares	Price ratios	Annual growth rates
Alternative proteins	Alternative proteins replace most meat and dairy consumption	Market share of novel vegan proteins, cultured meat and conventional meat in the meat market is defined based on Kearney (2020. This report provides values for 2025, 2030, 2035 and from 2040 onward. Alternative feed is assumed to include half of the market of feed additives in 2020 and the whole feed additive market in 2030.	Price ratio of novel vegan to traditional meat is 2 in 2020. Price ratio of alternative milk to traditional meat is 2.5 in 2020. Price ratio of cultured meat to traditional meat is 40 in 2020. Novel vegan (meat and milk) achieves price parity with traditional meat in 2024. Alternative dairy achieves price parity with traditional dairy in 2025. Cultured meat achieves price parity with traditional meat in 2032.	Annual growth rate of novel vegan price 2025-2030 is half of that of 2020-2025, and that of 2030-2050 is equal to conventional foods. Annual growth rate of cultured meat price 2025-2030 is half of that of 2020-2025, and that of 2030-2050 is same as conventional foods. Annual growth rate of alternative dairy price 2025-2030 is half of that of 2020-2025, and that of 2030-2050 is same as conventional foods.

Table 15. Food loss and waste assumptions

Source: Vivid Economics

Lever	Description	Reduction in food loss and waste	Recycling costs	Efficiency gains
Food loss and waste	Food loss and waste reduced across supply chain	This reaches 400 Mt DM/year in 2050 (DM = dry matter)	Recycling costs are taken from ReFEd data for the US and are assumed to be around 3,600 US$/tonne	Efficiency gains are defined as the difference in house-hold food expenditure (US$/capita) and the difference in supply chain processing costs (US$ millions)

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