Circular Australia

Research Appendix

Integrating circular economy climate & biodiversity

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UTS Institute for Sustainable Futures

Research Appendix

About the Appendix

This Appendix provides detailed findings from the research on "Integrating circular economy, climate change and biodiversity. Current practice and future direction". The research aims to provide policymakers and government stakeholders in Australian states and territories with insights on the intersections between the circular economy, climate change and biodiversity, which can support them in developing a holistic circular economy agenda.

The research identified six key themes where we found intersections. The main report succinctly discusses the key findings, along with a range of recommendations or considerations that could facilitate their integration in practice, as well as four case study vignettes.

This appendix document provides information about the rationale for looking at the intersections between circular economy, climate change and biodiversity (research background), the detailed methodology, and the findings supporting the six themes.

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1. Research background

The integration of the circular economy, climate mitigation and nature agendas present a range of potential benefits. Recent work in both the scholarly and grey literature has attempted to articulate the connections between circular economy, climate mitigation and/or nature. An understanding of those interlinkages is crucial to understand the synergies and trade-offs to minimise the unintended consequences of strategies within each area, and to pursue a sustainable future which is just and equitable to the environment, economy and society. Some benefits of an integrated approach are listed below:

Enables a more holistic approach to environmental challenges, with a focus on 'strong sustainability'
The circular economy has been conceptualised variously [1], with a risk that prevalent discourse diminishes circular economy to a material focus, relying on recycling as the primary strategy to mobilise materials back into the economy. The integration of climate and nature considerations in the circular economy discourse could reinforce an interpretation of the circular economy focusing on 'strong sustainability' – that is a circular economy that looks more broadly at the way resources are used, putting emphasis on strategies including avoiding or reducing the use of materials or keeping materials in use through reuse or repair notably [2].

Shifts emphasis to the 'biological cycle' of the circular economy
One of the circular economy experts interviewed mentioned that "biological cycles are maybe not that well understood", but when considering the interlinkages between the circular economy and biodiversity, the biological cycle takes centre stage, as many of the circular economy strategies that can reduce biodiversity impacts have to do with the biological cycles (e.g. food systems, forestry)

Complements the renewable energy transition and reduces the biodiversity impacts generated by renewable energy infrastructure
Electrification and the renewable energy transition are the leading approaches to tackle climate change. However, the Ellen MacArthur Foundation anticipates a 55% achievement of the UN GHG emission reduction targets through electrification, outlining the role for strategies such as the circular economy to steer the systemic shift in product, consumption and value recovery of resources [3].

In the case of Europe, Enkvist and colleagues estimate that, if the energy transition and energy efficiency were the only measures adopted to decarbonise the economy, emissions from the industrial sector would amount to 530 million metric tons of CO2 by 2050, falling short of meeting Europe's net-zero targets [4]. They argue that by integrating a circular economy approach where materials are more readily recirculated, material efficiency is improved and circular business models are adopted, European CO2 emissions could drop to 234 million tonnes (56% reduction)[4].

Additionally, the resources impact of the renewable energy infrastructure needed to electrify our economic system are under-represented in material and energy projections. The consequent increase in mined materials and adverse biodiversity impacts need urgent attention [5]. Increasingly, the role the circular economy can play in reducing the environmental impacts of the energy transition is acknowledged [6].

1. Research background cont.

Contributes to reducing biodiversity impacts
Biodiversity is declining the world over, with the IPBES stating that overall, ecosystems have experienced a decline of 47% in size and condition since first estimates, while 25% of animals and plants groups for which data were analysed are at risk of extinction [7]. Australia is following the same trend with most indicators showing declines in animal and plant species [8]. According to the IRP, material extraction is responsible for 90% of impacts on water and biodiversity [9].

Logically, avoiding and reducing material extraction through the adoption of circular economy strategies could lead to a reduction of adverse biodiversity impacts. Recent reports by Sitra [10] and the Ellen MacArthur Foundation [11] have attempted to quantify the potential benefits of the circular economy for biodiversity. The Ellen MacArthur Foundation argues that the circular economy can contribute to reducing impacts on biodiversity by minimising waste and pollution, reducing the land footprint of human activities and adopting regenerative practices [11].

An emerging evidence-base on the integration of circular economy, climate and nature
Scholars and practitioners often underline that the conceptual relationship between the circular economy and sustainability is more often implied than demonstrated and that quantitative evidence is scarce [2], [12].

Similar observations are made when considering the link between circular economy and climate mitigation [13] or biodiversity [14].

One of the circular economy experts interviewed nuanced these observations, by arguing that the link between circular economy and climate was more established in policy and practice, than between circular economy and biodiversity. One of the reasons that may explain this situation, is that circular economy and climate mitigation have long been driven by twin concepts that can work hand in hand: "the circular economy is driven by the concept of resource efficiency and the climate issue is driven by this energy efficiency". Additionally, the connection between the energy transition and the need to reduce material extraction so as to avoid a "material related crisis or a shortage of supply" appeared early on. This resulted in a "dialogue [opening] between these two policy domains". In contrast, our interviewee mentioned that the "biodiversity part is the most difficult one [to integrate]".

This research builds on emerging knowledge and research on the intersections between circular economy, climate change and biodiversity and identifies potential pathways for integration.

2. Methodology

Literature review

We identified academic and grey literature focusing on the intersections between the circular economy, climate mitigation, and nature through keywords searches on Google and Google scholar (Table 2). For searches conducted on Google Scholar we considered articles published between 2019 and 2024. Searches on Google are not time bound. However, we focused mainly on recent publications (less than 10 years old). Once 'key themes' started to emerge, additional searches were conducted to identify further literature on those specific themes (e.g. bioeconomy, regenerative agriculture) and their interactions with circular economy, climate and biodiversity.

Table 2: Literature review methodology

Intersection	Search words	Sources identified
Circular economy – climate mitigation - nature	Circular economy AND climate mitigation AND nature OR biodiversity OR nature positive OR regeneration OR restoration	Reports: 2 Academic articles: 4
Circular economy – climate mitigation	Circular economy AND climate mitigation	Reports: 9 Academic articles: 11
Circular economy - nature	Circular economy AND nature OR biodiversity OR nature positive OR regeneration OR restoration	Reports: 6 Academic articles: 5
Circular economy - sustainability	The search words mentioned above also led to the identification of academic articles looking more specifically at the intersection of the circular economy with sustainability development goals or sustainability more generally	Academic articles: 7

Policy review

Policies relevant to circular economy were identified in Australia and overseas, since 2018, to investigate how these considered issues around climate mitigation and biodiversity. We consulted with the states and territories to confirm the focus of the policy review and arrived at a further shortlist, based on the relevance to circular economy as the underpinning framework, and to ensure the more recent policy documents and strategies were included. In the findings we present the leading examples of policy approaches, both in Australia and overseas, where we found evidence of direct or implied intersections between circular economy, climate mitigation and/or biodiversity.

Interviews

We interviewed three experts on circular economy and regenerative agriculture to seek their perspectives on the intersections using semi-structured interviews. Based on the insights from these interviews, we identified additional resources for review and developed recommendations outlining the key considerations for intersections.

Findings

During the literature review, six themes emerged which spoke to the intersections between circular economy, climate mitigation and biodiversity. These are: i) reducing material consumption, ii) recycling metals, iii) bioeconomy and land use, iv) resourcing renewable energy, v) regenerative agriculture, and vi) nature-based solutions.

The main report presents a synthesis of the six themes (Table 1 in main report), along with four case studies showcasing different practices around regeneration, sharing, nature-based solutions and substitution. It also introduces key 'integration principles' and recommendations for policymakers. In this appendix, we present the literature review underpinning the six themes, as well as our policy review.

3. Findings from literature & policy review

Building on existing resources in the academic and grey literature, we identified six prominent areas of intersection between the circular economy, climate mitigation and biodiversity:

3.1 Reducing material consumption
3.2 Recycling metals
3.3 Bioeconomy and land use
3.4 Resourcing renewable energy: wind, solar and lithium-ion batteries
3,5 Regenerative agriculture
3.6 Nature-based solutions

For each of these sections, we discuss the potential opportunities and challenges they represent for integration. We then discuss how circular economy, climate mitigation and biodiversity are currently integrated in various policies in Australia and abroad.

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.1 Reducing Material consumption

- **Reducing material consumption must be prioritised to minimise trade-offs (e.g., in the bioeconomy)**
- **Built environment, food and mobility sectoral approaches can bring substantial benefits**
- **Circular business models, such as vehicle sharing can reduce transport-related GHG emission and promote reuse**

A UNEP report highlights that "increasing resource use is the main driver of the triple planetary crisis" [15] (p. xiv), which refers to the problems of climate change; nature and biodiversity loss; pollution and waste [15]. As such, reducing the number of resources that are consumed and reducing extraction and processing of natural resources is essential to addressing these crises. However, the strategy of reducing demand has historically received far less attention than supply side solutions.

A report by Material Economics focused on the climate mitigation potential of the circular economy highlights the critical need to address demand side approaches, as they can enable half of the emissions reductions needed to get to net zero at low costs [16]. They argue that achieving the necessary reductions in GHG emissions would be impossible without reducing the overall demand for primary materials.

Synergies

UNEP's report emphasises that lowering resource demand in high consumption contexts is critical. The report refers to reducing consumption of high impact protein for dietary changes, building more compact neighbourhoods, and enabling mobility through shared and active transport [15]. Strategies focusing on food and diets are also emphasised in the UK report by WRAP and University of Leeds. Of the eight priorities for addressing the circular economy and carbon emissions, the top three relate to food and are 1) addressing food waste, 2) reducing caloric intake for health and carbon, 3) reducing the carbon intensity of food production and the food we eat [17]. Other strategies for enabling reductions in both carbon and resource consumption include "the reuse of components; reduction in yield losses; less raw material for the same service; longer-life products and services; remanufacturing" [18] (p. 8).

Critiques of the circular economy cite the potential for rebound effects, particularly where products made of secondary materials do not effectively displace primary production and 'increase the overall pie'. Zink & Geyer's paper concludes that, "what is truly required to reduce environmental impact is less production and less consumption" [19] (p. 600).

Tradeoffs

Simultaneously driving the circular economy, net zero and nature positive agendas involves trade-offs and there are few strategies that enable positive synergies for all three agendas.

For example, energy is required to enact many circular economy activities, including recycling, repair and refurbishing; and renewable energy technologies, notably solar, wind turbines, batteries and electric vehicles, increase demand for resources.

A zero carbon CE increases demand for land through renewable energy infrastructure, as well as for agricultural and forestry products, such as wood, natural fibres, biofuels, and biopolymers [20]. Essentially, a zero-carbon circular economy shifts resource consumption away from fossil resources and towards biotic resources. Given these tradeoffs, the clearest way to achieve positive synergies across all three agendas is to reduce demand for raw materials [20].

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.2 Recycling metals

- **Due to high production impacts of virgin metals, recycling offers clear carbon mitigation benefits**
- **Contamination of secondary steel and aluminium with copper and alloys can limit applications**
- **Redesigning metal products for disassembly & recycling is important to expand recycling opportunities**

Synergies

Recycling metals that are carbon intensive, such as steel and aluminium are repeatedly cited as an important opportunity to enable synergies between carbon mitigation, circular economy and biodiversity by recycling resources and reducing their associated energy and mining requirements [16], [20], [21]. For many materials, recycling can be energy and carbon intensive, and this can reduce the benefit of recycling, but for metals, production impacts from virgin resources are so high, that recycling has clear carbon mitigation benefits. This is the case for heavy industries that require high temperatures, such as in the production of steel [18].

Addressing the embodied energy of materials through resource efficiency is an important means of continuing to decarbonise the economy. In a report investigating strategies to decarbonise hard to abate sectors through the circular economy, the most powerful strategy that was modelled is 'materials recirculation', primarily for steel, aluminium and plastics [16].

In the Canadian Climate Institute report, metals recycling is considered a top sectoral circular economy and decarbonisation opportunity. Steel produced from scrap generates a quarter of the emissions of equivalent virgin steel production, and emissions can be further reduced to 5% of emissions associated with conventional steel by changing processing practices, such using low carbon electricity and not preheating metals [21]. Recycling aluminium also provides significant carbon and resource use benefits, with recycled aluminium using 5% of the energy required in primary production [16].

Tradeoffs

Metals recycling is already an important practice, with steel production globally relying on approx. 30% scrap iron [22]. Further use of recycled steel is limited by the quality of secondary materials. Recycled steel can be contaminated by copper or other alloys if it is not adequately separated before processing. This situation limits the use of recycled steel to lower quality uses, such as construction rebar or construction 'longs', rather than the 'flats' required for car manufacturing [21].

A critical strategy for improving the quality of recycled steel is designing products for disassembly and component separation and limiting the use of alloys [23], as well as introducing certification processes to specify a quality standard and enable trust in recycled materials [21]. To maximise the potential for recycled aluminium, it will be important to reduce aluminium losses at end of life and reduce downcycling from wrought aluminium alloys to casting alloys [16]. Some options to reduce losses include improving collection of aluminium from consumer products, potentially through a deposit system and reducing the scrap aluminium generated in production [16].

While there are clear benefits to recycling steel and aluminium, recycling of some metals can have a marginal decarbonisation benefit due to the energy required to separate compounds in the recycling process [24]. This is the case for some electronics, which are challenging to recycle due to the way the product is assembled and due to the diminishing concentrations of high value metals [25].

Finally, the recycling of metals in some products may need to be conducted under specific conditions, to avoid adverse climatic effects. This is the case for white goods containing refrigerant gases, such as fridges, freezers and air-conditioners. If degassing is not conducted before scrapping, it can lead to the emission of greenhouse gases (transitional generation refrigerants are hydrofluorocarbons, which are greenhouse gases, while previous generations refrigerants, like chlorofluorocarbons, contribute to the depletion of the ozone layer) [26].

In Australia, air conditioners are often managed by licensed technicians who handle the refrigerants appropriately [27]. In contrast, it is estimated 30% of refrigerators are collected by unregulated contractors and scavengers who sell them to metal scrappers without degassing. Metal scrappers themselves are rarely qualified to degas equipment, so refrigerants are released into the atmosphere during shredding. This is in addition to leakages that may occur prior to collection [27]. As such, ensuring safe pathways exist for the recycling of those metals is necessary.

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.3 Bioeconomy & land use

- **Bioeconomy approaches are considered to reduce fossil fuel use and carbon emissions**
- **There are trade-offs from increased land-use for growing bio inputs, often competing with land needed for food production or nature**
- **Specific feedstock e.g. organic waste and approaches e.g. biorefining may generate less trade-offs**

The bioeconomy – which encompasses economic activities involving the use of biomass for a range of applications [28], including energy, packaging and construction, is increasingly considered as a strategy contributing to climate change mitigation as well as the circular economy [29]:

- Bioenergy can present an alternative to fossil-fuels, notably in hard to abate sectors (e.g. industrial heat generation) [30].
- Several types of bioplastics have shown a decrease in CO2 emissions at the construction phase compared to plastic derived from fossil fuels [31], [32].
- Increasingly, wood is considered in policies as a preferable construction material to concrete and steel as it may provide a long-term carbon storage solution and make buildings lighter, which in turn reduces the amount of concrete needed in the foundations [10], [33].

There are assumptions that approaches such as biomimicry or bioeconomy are circular and benefit nature, but this is not always true [28],[29]. Biomimicry refers to innovations that mimic nature in their design. This approach could lead to compostable materials that are less impactful, however, designs mimicking structures in nature could still be made with problematic materials.

The bioeconomy operates a shift away from fossil resources to biological resources. While this shift can provide climate benefits (as described above), it can also increase impacts on land use and biodiversity by increasing agricultural needs and/or enabling the production of polluting wastes - e.g. the use of industrially compostable bioplastics that have no collection system [29].

Specific feedstocks and approaches offer interesting perspectives in terms of circularity, climate mitigation, and reduction of biodiversity impacts (compared to other feedstocks). A report from the European Environment Agency (EEA) identified potentially promising feedstock and production approaches [28]:

- Organic waste, which can be used for high-value products such as clothes or food products or for nutrient and energy generation, notably through anaerobic digestion or composting [3], [28].
- Biorefining can be used to obtain a range of products from the diverse components of a feedstock. Taking the example of sugar refinery from sugar beets, the EEA report explains that the beet tails are used for chemicals, fibres and rare sugars, the beet pulp is used for animal feed and transformed into bio methanol etc. [28].

The climate and biodiversity implications (positive or negative) of those feedstock and approaches are all context dependent and require detailed analysis to understand the implications of their use. This illustrates that circular economy initiatives need to be carefully planned to avoid perverse outcomes and to consciously support climate mitigation and biodiversity [29].

Below, we provide a more in-depth discussion of the climate and biodiversity implications of three bio-based products: timber used in the built environment, bioplastics and bioenergy and biofuels.

3.3 BIOECONOMY & LAND USE

Timber in built environment example

The IRP argues that CO_2 emissions generated by building materials could be reduced by 1 to 8% in the G7 countries and by 5 to 31% in India and China if timber was more readily used [34]. Those climate benefits have been questioned in a World Resources Institute (WRI) report, which argues that a large proportion of the studies that found reductions in CO_2 emissions had the following shortcomings [35]:

- They did not consider the carbon loss that occurs from the proportion of the harvested wood which is not being used in buildings and instead is: burnt, used to make other products that do not store carbon in the long-term (e.g. paper), or decomposes.
- They considered wood harvesting as 'carbon neutral' when the annual harvest corresponds to the growth from the tree during that year. While this means that no forest is lost per se, it does not consider the carbon benefits of not harvesting the forest growth.

The WRI report – in alignment with other research - argues that it would take decades for the use of timber in construction to bring carbon benefits.

Additionally, the use of timber in construction is also likely to have negative impacts on biodiversity by putting pressure on ecosystems through land clearing and deforestation. Recent modelling by SITRA estimated that, while circular production and consumption of timber (i.e. designing buildings that reduce material use, keeping buildings in use longer, and material reuse or recycling) could reduce land clearing (83 million hectares saved), the increase in demand for wood in the building sector by 2050 could still lead to clearing 40 million hectares of native forest [10]. Despite its land clearing implications, the use of wood in the built environment is still considered as a potentially effective strategy by SITRA, due to its carbon sequestration benefits - benefits we already discussed [10].

3.3 BIOECONOMY & LAND USE

Bioplastics example

Since the mid-20s century, the production and use of plastics has increased [36]. The ubiquitous use of plastic in daily life, along with poor management and low circularity of the plastics value chain has led to significant issues of plastic pollution in terrestrial and aquatic ecosystems [36]. Borrelle and colleagues estimated that, in 2016, 11% of the plastic produced globally ended up in the aquatic environment [37].

The use of bioplastics has emerged as a potential pathway to more sustainable plastic. However, the production, use and disposal of bioplastics leads to the emergence of new challenges which have circularity, carbon mitigation and biodiversity implications.

The umbrella term 'bioplastics' includes a diversity of plastics, which can be characterised based on their source material (i.e. bio-based, fossil-based or both) and their end-of-life pathway (i.e. compostable, recyclable, landfill bound). Generally speaking, four broad categories of 'bioplastics' can be identified [32]:

- Bio-based plastics, which are plastics made from plant-based materials (e.g. sugarcane),
- Biodegradable plastics, which are bio or fossil-based plastics that can progressively disintegrate through the action of micro-organisms.
- Fragmentable plastics, which are plastics that contain pro-degradant additives to speed up their breakdown when exposed to light or heat. Instead of fully degrading, fragmentable plastics become microplastics and are therefore not biodegradable - but are often described as such.
- Compostable plastics. which are plastics that will break down when composted. Some compostable plastics can be composted in home compost, while others will require industrial composting.

Bioplastics are often thought to provide environmental benefits. Compared to fossil fuel based plastics, bio-based plastics have often been found to emit less CO_2 during production [31], [32]. Compostable plastics could technically reduce end-of-life issues of environmental pollution and methane emission in landfill, by turning plastics – along with food waste – into compost.

However, several sustainability issues are associated with the production and disposal of bioplastics:

The production of bio-based plastics can lead to an increase in demand for crops (e.g. sugarcane, corn) and the clearing of natural ecosystems to make space for crops, which could have negative impacts both in terms of climate mitigation and biodiversity protection [32]. Brizga and colleagues estimated that 61 million hectares and 388.8 billion m3 of water would be required to replace plastic packaging with bioplastic packaging. Increasingly, the use of other feedstocks is being considered to reduce the potential land impacts of bio-based plastics [38]. For example, a report from the European Environment Agency mentions the use of residues from tomato harvest – leaf and stem – to create packaging [28]. However, the use of residues could have negative impacts on agricultural systems, as they may deprive the soil from essential nutrients [28].

Biodegradable or compostable plastics do not degrade naturally in the environment, but instead need to be exposed to specific conditions to break down. If disposed improperly they may generate environmental pollution, contaminate waste (e.g. home composting system, mechanical recycling systems) and emit CO_2 [32]. To generate some degree of positive climate and biodiversity benefits at end-of-life, biodegradable or compostable plastics should, at a minimum, be disposed of and managed properly. This requires consumers to understand how to properly dispose of bioplastics, which may be rendered difficult by their great diversity [32]. It also requires for adequate collection, sorting and composting processes to be available [28]. In any case, higher-order circular approaches, which facilitate avoidance and reuse, should be prioritised.

The mounting quantities of compostable plastics disposed in organic bins may pose risks to the application of compost on agricultural land. CSIRO investigated the effects of the presence of compostable plastic in Food Waste and Organic Waste (FOGO) bins and found that when 0.5 w/w of compostable forks and films were put into FOGO waste that was then processed in an industrial composting facility, the compost that resulted from this process had a negative effect (after two weeks) on the “growth of earthworms and the root length of wheat” [39] (p. xi). These findings compelled the NSW EPA to forbid the disposal of compostable waste in FOGO bins, with caddy liners as an exception because they meet Australian Standard AS 4736-2006 [40] and significantly improve food waste capture. As such, the benefits of increased food waste capture outweighted the risks of introducing compostable plastics in the system.

3.3 BIOECONOMY & LAND USE

Bioenergy example

There exists a broad range of bioenergy feedstocks, which all have different implications regarding circularity, climate and biodiversity.

The first generation of feedstock for bioenergy are food and feed crops. Similar to bioplastics, the use of food and feed crops for bioenergy production can lead to direct or indirect land-use change with negative climate and biodiversity impacts [41]. This is particularly true if the production of bioenergy leads to the clearing of natural carbon sinks.

Second-generation feedstock - non-food oil crops and lignocellulosic biomass crops – emerged as a way to mitigate the impacts of bioenergy on food security by avoiding competition with food crops and prioritising the use of 'marginal land'. However, the use of marginal land can lead to the clearing of natural ecosystems to make space for bioenergy plantations, noting that those plantations may become invasive and negatively impact surrounding natural ecosystems [41].

Increasingly, feedstock that are less likely to lead to direct or indirect land-use change are being prioritised, such as organic waste from primary industry and urban streams [41]. Additionally, the use of organic waste as bioenergy has also the potential to reduce methane emissions at end-of-life. That does not mean, however, that organic waste does not have potential direct or indirect negative impacts, notably on biodiversity. For example, some studies found that organic waste used for bioenergy was diverted from animal feed, leading to land clearing for animal feed production [42], [43].

As a result, ensuring that the higher-order use is prioritised is essential. It also illustrates that the impacts of various bioenergy feedstock on climate and biodiversity are highly dependent on context and require a tailored approach.

In addition to energy generation, organic waste can be used as a source of nutrient through composting or digestate (which is a by-product of the anaerobic digestion process). While uncertainties remain on the long-term effects of the use of digestate on agricultural soils (notably due to the variability in digestate composition and the diversity of soils) [44], composting has been widely used to make soil healthier and improve its water holding-capacity [45]. In South Australia, 83% of organic waste is recycled, with a large proportion being converted into compost [45]. The recycling of organic waste has led to annual water savings (2,300 ML), as well as avoided CO2 emissions (239 kT per year), and the application of 34,700 tonnes of soil organic carbon on farmlands, which is likely to enhance soil health, reduce the need for fertiliser use and improve the water holding capacity of the soil [45]. Composting of organic waste has direct climate benefits as it reduces GHG emissions by diverting organic waste from landfill. It can also have indirect positive effects on biodiversity, by increasing soil water holding capacity thereby reducing need for irrigation, theoretically leaving more water in aquatic ecosystems.

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.4 Resourcing renewable energy:

Wind, Solar & Lithium-ion batteries

- **Renewable energy is essential to decarbonisation and has increased the demand for critical minerals**
- **Mining and construction can cause water and soil pollution and habitat destruction**
- **At end-of-life renewable energy technologies can release toxic leachate when landfilled**

The decarbonisation of the economy through the broad scale deployment of renewable energy is one of the central tenets of climate mitigation policies the world over. The International Energy Agency (IEA) estimates that to reach net zero, renewable energy should represent 90% of total electricity production worldwide by 2050, with 70% being provided by solar and wind [46]. Australia has set an objective to have 82% of its electricity provided by renewable energy sources by 2030. This will require a dramatic scale up of solar and wind.

Renewable energy has obvious climate mitigation benefits. A UNEP report states that, across their lifecycle, renewable energy sources (wind, solar, hydro, geothermal) emit only 5 to 6% of the GHG emissions of coal and 8-10% of the GHG emissions of gas [47]. While reducing GHG emissions will have benefits for biodiversity that is impacted by the changing climate, the development of renewable energy technologies and infrastructures will also lead to a range of biodiversity impacts [41], [48]:

The manufacture of wind turbines, solar PVs, and lithium-ion batteries require a range of critical minerals. An IEA report stated: in 2023, demand for lithium increased by 30%, while demand for other minerals, including nickel, cobalt, graphite and rare earth elements increased by 8% to 15% [49]. The report highlights that under a Net Zero Emission Scenario the demand for critical minerals is multiplied by three by 2030 and by four by 2040. Mining for critical minerals can lead to a range of negative environmental impacts, including high-water withdrawal, habitat destruction, pollution of soil and waterways [50], [29], [41].

Wind and solar facilities require large tracts of land, contributing to habitat destruction during the construction phase, while birds and bats fatalities remain a concern during the operation phase of wind facilities [29], [41]. At the end-of-life, wind, solar and batteries have the potential to impact ecosystems if disposed in landfill, as toxic components can leach into the environment [41]. This issue is pressing with some renewable energy infrastructures reaching end of life. For example, in Australia, it is projected that by 2035, 100,000 tones of PV panels will reach end-of-life [51].

The circular economy is increasingly considered as a tool to reduce the amount of critical minerals used by renewable energy through a range of strategies. A recent report by Sintef studied seven minerals (lithium, cobalt, nickel, manganese, rare earth elements, platinum and copper) used in solar, wind, EV, fuel cells and electrolysers, batteries and other renewable energy [6]. The study estimates that demand for the minerals studied could be reduced by 58% by 2050 with these approaches [6]:

- 30% reduction could be obtained through the development of new technologies that require less critical minerals.
- 18% reduction could be obtained through the adoption of strategies including demand reduction and lifetime extension. E.g. moving from individual car ownership to other means of transportation including active and public transport.
- 10% reduction could be obtained through recycling. While recycling does not contribute to reducing the overall mineral demand, it can reduce extraction.
- Most minerals required for the energy transition will be provided through recycling by 2050. Recycling is therefore likely to represent 20% of demand, with the remainder being provided by virgin mineral extraction, emphasising the importance of following responsible mining practices [6].

While Sintef states that implementing circular economy measures can reduce the environmental impacts of the energy transition, there is no quantification of how a reduction in mineral demand could reduce impacts on biodiversity [6]. Other measures need to be considered to reduce the impacts of renewable energy infrastructures on biodiversity. Habitat destruction can occur at the construction and operation phases. As a result, it is essential to locate renewable energy facilities in areas where they will have the lowest possible impacts on habitat. This can be done by deploying them in the built environment or on degraded landscapes (e.g. industrial land), but also by setting up hybrid power systems (bringing wind and solar power together) or marrying energy generation with another activity (e.g. agrivoltaics) to reduce land requirements [41].

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.5 Regenerative agriculture

- **A variety of regenerative practices are relevant to circular economy, carbon mitigation and biodiversity conservation**
- **While regenerative agriculture can result in biodiversity improvement and carbon mitigation, the outcomes lack real-world evidence, and the risk exists of overstating the climate and biodiversity benefits of regenerative practices**
- **Solutions need to go beyond stop-gap approaches, towards achieving holistic outcomes that consider the long-term impacts and trade-offs**

The concept of regenerative agriculture (RA) broadly refers to ways "of producing food that, its advocates claim, may have lower – or even net positive – environmental and/or social impacts" [52] (p.1). Interpretations of RA vary widely and a range of 'discourses' exist on what RA is [53]. In an attempt to categorise those interpretations, Newton and colleagues identified a range of outcome spaces prioritised by RA practitioners:

- enhancing soil quality came first (86.4% of definitions), followed by providing carbon sinks (63.6%), delivering social and economic benefits to communities (40.9%) as well as enhancing biodiversity (45.5%) and water quality on farm (45.5%) [52].

In the last decade, RA has been increasingly present in the public discourse and has been harnessed by governments and the private sector, notably with regard to its potential role in climate mitigation through carbon sequestration [54],[55].

More recently, organisations shaping discourses on the circular economy, such as the Ellen MacArthur Foundation, identified RA as an essential tool to meet the third principle of its circular economy framework: 'regenerate nature', while also providing climate benefits. It is interesting to note that, in contrast, the RA community does not appear to have identified the circular economy as one of its central components. Anja Bless - a researcher who conducted a doctorate on the politics of regenerative agriculture and was interviewed for this research - stated "*in the regenerative agriculture literature [...] circular economy is almost never mentioned, there's not a lot of cross pollination happening there*". This point is further illustrated by Newtown and colleagues who found only 4.5% of RA practitioner definitions included circular economy principles' [52].

In the same way that there is no single definition of the outcomes of RA, there is not a determined set of RA practices. However, when discussed in the context of its potential circularity, carbon and biodiversity benefits, RA is often considered as encompassing the following practices: i) avoiding or minimising soil disturbance through the adoption of no-till or reduced-till; ii) using cover crops; iii) reducing or avoiding mineral fertilisers, and when possible, replacing them with biological nutrients (e.g. manure); iv) avoiding pesticide use; v) implementing grazing management, which consists in rotating animals between different portions of the pasture, to avoid over grazing and improve soil health [56], [57].

RA can also involve practices such as agroforestry, which refers to integrating tree growing and agricultural activities into the landscape – the trees can be used as timber, food production but also to enhance biodiversity in agricultural landscapes.

Synergies

According to The Ellen MacArthur Foundation, circular economy practices can contribute to reducing emissions from the food and agriculture sector by 49% in 2050, with RA being the most effective 'circular economy practice' to reach that goal [3]. Using information generated by Indigo Ag, a company enrolling farmers in regenerative agriculture programs in the context of carbon offsetting, the report estimates that RA could reduce annual CO2 emissions by 3.9 billion tonnes, which would roughly represent 70% of the emission reductions possible in the food sector. The remaining 30% would be reached by eliminating food waste and composting [3].

In addition to its potential climate mitigation benefits, The Ellen MacArthur Foundation also argues that RA can 'regenerate nature' by improving soil, air and water quality, reducing the use of synthetic fertilizers and pesticide, and enhancing biodiversity [11]. In an attempt to quantify the benefits of regenerative agriculture for biodiversity, SITRA found that it would contribute to 5% of a circular economy scenario aiming to improve the Biodiversity Intactness Index (BII) of the Earth by 2050, due to a reduction in water use and nitrogen input [10]. The study only considered the impacts on land ecosystems and highlighted that the positive impacts of regenerative agriculture could be higher if aquatic ecosystems had been considered.

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.5 Regenerative agriculture cont.

The same study also estimates that regenerative forestry, which includes practices such as maintaining old trees, continuous tree cover using a diverse range of native tree species, could also contribute to 5% of the circular economy scenario improving the BII of the Earth by 2050.

Limitations

In recent years, the climate mitigation benefits of RA through carbon sequestration have been challenged for several reasons which were discussed and summarised by Popkin [58] and the World Resources Institute [56], [59]:

- **No-till** which is often considered as one of the leading practices in soil carbon sequestration has been shown to be less effective at storing carbon than previously thought.
- **Cover crops** are considered as a potentially more promising avenue by some researchers. However, uncertainties remain on: i) the quantities of carbon they could store, ii) the quantities of nitrous oxide they could emit (which could potentially offset carbon storage), and iii) the likelihood of their wide adoption by farmers as they may affect yield in some circumstances. Similar questions arise for **agroforestry.**
- **Manure** is carbon and nutrient rich. When applied to fields it can increase the amount of soil carbon in a field. However, the manure applied on one farm has been taken from a farm elsewhere. As such, the use of manure is unlikely to increase the overall soil carbon sequestered on the planet.
- **The adoption of regenerative practices may, in some circumstances, lead to a reduction in yield.** If this reduction in productivity is compensated by clearing land for cultivation elsewhere, the potential carbon benefits of regenerative practices would be neutralised, while new impacts on biodiversity would be generated.
- **Nitrogen** is necessary to fix carbon in the soil by transforming it into microbial organic matter. It is argued that this may lead to an increase in the use of nitrogen, which may not be feasible (in terms of availability of nitrogen) or desirable (in terms of the negative environmental impacts of nitrogen on aquatic ecosystems notably). Van Groningen & colleagues comment on an initiative from the COP21, which aims to increase global carbon stocks in soil by 0.4% every year [60].
- They argue reaching this objective would require 'an increase of ~75% of current global N-fertilizer production, or extra symbiotic N2 fixation rates equalling twice the current amount in all agricultural systems' (p. 4738). Van Groningen and colleagues comment on an initiative from the COP21, which aims to increase global carbon stocks in soil by 0.4% every year [60].

They continue by explaining that while this quantity of nitrogen may be present as 'surplus in global agroecosystems'. they are concentrated in specific locations (e.g. China). Additionally, some of the nitrogen applied on field would leach into aquatic ecosystems causing pollution issues, while some may be converted in and emit nitrous oxide.

- **Current models** aiming to quantify soil carbon sequestration still face important uncertainties and are often based on an insufficient amount of data. One such model is DayCent, which provides estimates of carbon sequestration at the field/farm level based on the adoption of a range of practices, such as no till or cover crops. This model is used by companies, such as Indigo Ag mentioned earlier, in the context of their offsets program, despite its limitations.

Limitations related to the role RA could play in 'regenerating nature' have also been raised by Anja Bless, who argued that, in practice, the main focus of RA remains to improve "*soil diversity and soil microbiology and restor[e] and regenerat[e] soil*", rather than to regenerate nature and enhance sustainability in a broader sense. As a result, RA practitioners, do not necessarily prioritise the adoption of circular principles. While some regenerative famers may "*use less nutrients or they might […] use cattle to get manure into soil*", they rarely engage in sourcing their nutrients from circular sources beyond the farm gate (e.g. phosphorus recovered from urine). Indeed, few RA practitioners talk "*about retrieving nutrients from human or food ways […] it's very rarely mentioned because [they are] not really engaging […] beyond the farm gate*".

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.5 Regenerative agriculture cont.

When considering biodiversity enhancement, Anja Bless mentioned that some RA practitioners may choose to fence off areas of their properties solely for ecological restoration, while highlighting the fact that those types of practices are not mainstream in the RA movement. She also mentioned the uptake of activities that are more directly linked to the agricultural system management, such as creating shelter belts or agro-forestry. While those practices may have some biodiversity benefits, they focus more on "regenerating an agri-ecosystem" than on restoring a specific ecological community.

Still according to Anja Bless, one of the main risks of mainstreaming RA as a way to 'regenerate nature' in the circular economy agenda and elsewhere, is to "mak[e] it into something that it's not" and "treat it as a silver bullet". While RA can provide a range of environmental benefits, such as enhancing biodiversity, reducing bushfire risks, improving overall resilience to climate change and storing carbon, there is a risk to overstate those benefits and to enrol RA as the main solution to pressing environmental issues.

The socio-cultural aspects of regenerative agriculture

In recent years, criticisms have emerged that dominant discourses on RA have focused on how RA can help reach climate commitments and increase farm profits [54], while remaining silent on its socio-cultural dimensions [55]. This narrow approach runs the risk of 'd*iluting [its] ability to drive transformation in the agri-food system*' [55] (p. 1380). The potentially more transformative aspects of RA that need further scrutiny and integration include the recognition that [53], [54], [55] [61]:

- Indigenous peoples have been practicing regenerative land stewardship for centuries and Indigenous worldviews, notably around notions of relationality and respect of the environment, are integral to regenerative agriculture
- The food system's inequities need to be addressed for agriculture to be truly regenerative.

When considering regenerative agriculture in the context of the circular economy, it is important to ensure that circular economy proponents harness a regenerative agriculture narrative that integrates those socio-cultural and political dimensions. To do so, circular economy proponents need to ensure that they endorse a definition of regenerative agriculture that:

- Integrates and promotes different forms of knowledge [55]
- Provides spaces for marginalised stakeholders and discourses within the regenerative agriculture movement [55]
- Considers both the quantifiable (e.g. carbon storage) as well as the non-quantifiable aspects a regenerative approach [53].

3. FINDINGS FROM LITERATURE & POLICY REVIEW

3.6 Nature based solutions

- **Nature-based solutions (NbS) can provide a range of co-benefits, including biodiversity enhancement, climate mitigation/adaptation and circularity, especially in urban settings**
- **While circular economy approaches have focused on consumer products, NbS enable a refocusing on natural cycles, such as those for water and nutrients**
- **The effectiveness of NbS is heavily dependent on the solution design and context of where it occurs**

In recent years, nature-based solutions (NbS) have been increasingly promoted by governments and international organisations as an effective approach to tackle a range of social and environmental issues. The IUCN defines NbS as 'actions to protect, sustainably manage, and restore natural and modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' [62] (p.2).

NbS encompass a diversity of activities ranging from enhancing the use of existing ecosystems to the design of new ecosystems. Eggermont and colleagues identified three types of NbS along this spectrum: Type 1 are NbS that enhance the use of existing ecosystems by offering them better protection; Type 2 are NbS that improve the multifunctionality of environments that have been more heavily modified by human activities such as agricultural landscapes and Type 3 refers to the creation of new ecosystems, such as constructed wetlands or green walls on buildings [63].

Additionally, the definition of NbS can also be expanded to integrate processes 'derived from nature', such as biofiltration [64]. While NbS can be implemented on their own, they can also be integrated into grey infrastructures [65] or used along chemical or physical processes [66].

Traditionally, the circular economy has focused its efforts on 'consumer products industry', such as textiles or packaging [66]. The emerging interest for NbS enables the circular economy to focus on aspects that have been overlooked, such as water and nutrient cycles [65].

The discussion on the interconnections between NBS and the circular economy appears to be particularly prominent in the urban context, where NbS are seen as a way to improve non-circular urban systems [65], [66], [67], [68], [69], [70]:

- **Impervious surfaces in urban environments** have disrupted the natural water cycle by preventing infiltration and increasing water run-off. This may lead to untreated run-off water entering waterways, polluting the environment, as well as waterways receiving more water than they can hold, leading to floods.
- **Impervious surfaces in urban environments cont.** With climate change altering rainfall patterns, heavy rainfall episodes are likely to be more frequent, further worsening flood risks.
- **Wastewater in cities** is often carried to water treatment plants before being discharged in the environment while still containing organic by-products, such as phosphorus. The release of those by-products in the environment can have negative impacts on ecosystems and represents a missed opportunity to reuse those nutrients on urban or peri-urban farms for example.
- **Materials used in the built environment** of cities are often landfilled. Opportunities exist to use those materials as part of NbS, e.g. as filter media.

A broad range of NbS has been found to be able to improve the circularity of cities. Langergraber and colleagues categorised them as follows [69]: i) rainwater management, including for example, vegetated grid pavement or tree pits; ii) vertical greening systems or greenroofs, iii) remediation, treatment and recovery (e.g. treatment wetland, composting or ammonia stripping), iv) river restoration; v) soil and water bioengineering, including erosion control or soil improvement; v) green space and vi) food and biomass production (e.g. urban farms or forests, hydroponic).
In addition to addressing circularity challenges, NbS may also provide a range of co-benefits, including biodiversity enhancement (e.g. planting) and climate mitigation and adaptation [67]. NbS can contribute to mitigation directly by absorbing CO2 or indirectly by limiting energy consumption. They can play a role in adaptation by reducing flooding risks.

The effectiveness of NbS in enhancing circularity and providing climate and biodiversity co-benefits is highly dependent on the context where the NbS occurs and the design of the NbS. Monitoring is necessary to evaluate their effectiveness. While it is difficult to provide a full picture of how NbS can contribute to address specific circularity challenges while also providing co-benefits. For an example of NbS, see case study 3 in the main report.

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- **Building materials, plastics and organic waste sectors are prioritised for their potential to mitigate climate change.**
- **Plastic pollution on land and in waterways has implied links between circular economy and biodiversity**
- **While the role of circular economy in reducing environmental impact is acknowledged, biodiversity aspects are not explicit. Regenerating nature is sometimes mentioned as a principle of the circular economy but remains under-explored.**

The section below provides a brief overview of how some of the circular economy regulations and strategies in five Australian states and territories – New South Wales, the Australian Capital Territory, Queensland, South Australia and Victoria.

Since the focus of this research is on the circular economy, the policy review does not cover regulations and strategies focusing on net zero, decarbonisation, climate change and biodiversity (except in the cases of South Australia and Victoria for which an initial snapshot is provided). Future research can provide more qualitative insights on the convergence and divergence of framing of the circular economy-climate-biodiversity nexus in circular economy versus climate and biodiversity policies and strategies. Lastly, sector plans that are being developed to support Australia in reaching its net zero objectives could also be analysed to understand whether and how the circular economy and biodiversity agendas are incorporated.

Australian Capital Territory

- Circular Economy Bill (2023) [71] aims to diminish waste generation while facilitating the adoption of a circular economy with requirements for businesses to reduce waste generation, keep records, prepare plans and report on compliance. The Act aims to minimise waste, improve resource recovery, facilitate the design and manufacturing of resource efficient, “durable, repairable, reusable, recyclable or compostable” products. While the Act refers to reducing harm of waste on the environment, it does not explicitly link the circular economy to carbon mitigation or biodiversity initiatives.
- **Circular Economy Strategy and Action Plan (2023)** [72] highlights many existing CE initiatives in the territory and has three strategic objectives: 1) “grow extended producer responsibility”,

2) “grow markets for recovered materials and goods and circular business models”, 3) “create high-value jobs and attract innovative new enterprises” (p.7). The six focus areas of the plan are: “food and organics”, “built environment”, “consumer goods”, “emerging and problematic waste streams”, “creating space to showcase our commitment to the circular economy” and “procurement, skills, innovation and governance” (p.8).

Reducing carbon emissions are expected benefits associated with actions related to food and organics (notably through food waste avoidance and reduction, as well as composting) and the built environment. Biodiversity and regeneration are mentioned in the introduction with reference to circular economy principles and the Ellen Macarthur Foundation policy goals but are not tied to specific actions

4. Findings

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New South Wales

- **NSW Circular Economy Policy Statement "Too Good to Waste" (2019)** [73] states the key principles for sustainable resource management, designing out waste and pollution, resource productivity and maintaining the value of products and materials (p. 3). While this policy statement refers to the importance of reducing the environmental impacts associated with raw material extraction and processing, and valuing organics is one of the priority focus areas, it does not explicitly mention climate change, carbon emissions, biodiversity, restoration or regeneration.
- **NSW Waste and Sustainable Materials Strategy 2041 (2021)** [74] takes a more integrated view of the need and opportunity to reduce both material consumption and greenhouse gas emissions simultaneously. While regeneration and restoration do not feature as part of the circular economy approach, reducing carbon emissions and protecting the environment are embedded within two of the three focal areas of the strategy, which are: "reducing carbon emissions through better waste and materials management", and "protect[ing] the environment and human health from pollution" (p.18). This strategy is linked with the Net Zero Plan Stage 1: 2020-2030 [75] and the Waste Delivery Plan, which also sets out to reduce carbon emissions from waste [76].
- **NSW Plastics Plan Action plan (2021)** [77] focuses on reducing plastic litter has a clear link with pollution reduction in the natural environment and waterways. The plan has limited mentions of carbon, climate change and greenhouse gas emissions, however, mentions plastics emit GHG at every lifecycle stage. Overall, it focuses on six key actions to address plastic pollution: 1) introducing new legislation to phase out some single use plastics and reduce harmful plastics e.g. microbeads, 2) accelerating the transition to better plastics, including recycled plastics, 3) supporting innovation in recycling and remanufacturing, 4) tackling cigarette butt litter, 5) reducing the risk of nurdles (plastic resin pellets) entering the environment, (6) supporting plastics research.
- **NSW Circular design guidelines for the built environment (2023)** [78] has a strong focus on the co-benefits of material and carbon emission reductions. The guidelines set out to embed circularity into the design of buildings, infrastructure and precincts and complements the NSW Net Zero Plan Stage 1. The four objectives are 1) "reduce embodied carbon", 2) "minimise the generation of waste", 3) "improve materials efficiency", and 4) "increase the circularity of materials" (p. 6). Regeneration is mentioned with reference to the circular economy approach moving from resource extraction to resource regeneration. The reduction of greenhouse gas emissions is expected outcomes of several of the strategies, including for reusing existing assets or materials, selecting products with recycled content and designing for disassembly. Biodiversity is not mentioned, however, one of the circular design strategies "incorporate green infrastructure" seeks to incorporate networks of green spaces including waterways, bushland, tree canopies and open spaces including natural and semi-natural spaces with an intention to maximise co-benefits such as improving habitat, natural drainage, and enabling cooler and healthier urban areas.
- **NSW Plastic reduction and circular economy Act 2021** [79], in addition to "promot[ing] and support[ing] the principles of a circular economy", also aims to "protect the environment and human health". The Act also considers the "ecologically sustainable and regenerative management of resources and systems" as being one of the principles of a circular economy. As such, nature and biodiversity appear to be considered – even though not explicitly. In contrast, the climate impacts and mitigation potential of plastics do not appear to be mentioned.

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Queensland

- **Organics Strategy** [80] **and Action Plan 2022-2032** [81] highlights the role of organic waste recycling in avoiding greenhouse gas emissions to achieve net zero by 2050. Organics and climate mitigation also link to increasing the amount of carbon contained in soil. The strategy also acknowledges the range of environmental benefits from using organics as fertiliser, such as reducing water use, pesticides and herbicides, coupled with a reduction in nutrient leaching.
- **Tackling plastic waste:** Queensland's plastic pollution reduction plan [82] acknowledges that the use of plastics (notably single use plastics) can lead to the overexploitation of virgin resources and relies on the use of fossil fuel in the manufacturing process, without directly discussing how better plastics management can contribute to climate mitigation. The plan also notes that poor management of plastics results in the unintentional release of microfibres, leaching microplastics into land and marine ecosystems, insisting on the need to address environmental harms related to plastics pollution.
- **Waste management and resource recovery strategy** [83] and **Waste reduction and recycling plan 2019-2022** [84] outline waste reduction, recycling and landfill diversion to help Queensland meet climate mitigation targets (net zero emissions by 2050 and reduction by 30% or more, by 2030, in comparison to 2005 levels). The strategy and plan also highlight that landfill can lead to land contamination, while littering can harm aquatic ecosystems. Restoration or regeneration are not discussed.

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South Australia

- **Supporting the circular economy: South Australia's waste strategy 2020-2025** [85] acknowledges the role of waste management in reducing greenhouse gas emissions by contributing to a circular economy. The strategy focuses on the role of different products and materials in climate mitigation (e.g., organics and plastics), and highlights the importance of increasing recyclable products/recycled content in product and enhance waste and resource recovery to reduce GHG emissions. Regarding biodiversity impacts, the strategy draws connections with its 'Australia's National Strategy for Ecologically Sustainable Development' by offering to look at how "new mechanisms for design, use and recovery" reduce environmental harm. The strategy mentions the importance of reducing biocide use, single-use plastics use and of safely managing problematic wastes. It also mentions that the circular economy can encourage the circulation of materials that "regenerate the environment safely" (e.g. compost).
- **Valuing our Food Waste: South Australia's strategy to reduce and divert household and business food waste (2021)** [86] "integrates policy measures, behavioural change actions and support for industry to address the estimated 200,000 tonnes of food waste sent to landfill each year in South Australia" (p.5). Preventing and recovering food waste for regenerating soils (through compost) can support the biological circular economy and contribute to GHG emissions reduction. Composting is also considered as a way to "regenerate the environment safely", while also sequestering carbon in the soil and improving overall soil quality.
- **Circular economy in South Australia's built environment – Action Plan** (2023) [87] summarises "circular economy opportunities in the built environment for South Australia" and outlines "key actions and stakeholders that will need to work collaboratively to drive the transition from linear to circular" (p. 1).

In this plan, climate is acknowledged as a disruptor that poses a threat to the built environment, in the form of damage or destruction and loss embodied emissions, while circular economy is considered to be a "critical climate solution". Regarding nature and biodiversity, 'regenerative design' is presented as an approach "aligns with a circular economy approach" (p. 18), while mitigating climate and enhancing biodiversity

What do climate and biodiversity policies have to say about the circular economy and each other? A glimpse from South Australia

- **South Australia's Net Zero Strategy 2024-2030 (2024)** [88] sets out strategic objectives and policy priorities to reach net zero emissions. Circular economy 'products and practices' are considered to be part of a suite of 'low emissions economic opportunities' along with green hydrogen and critical minerals (p.12). The role of circular economy in reducing emissions is acknowledged with policy priority 12, which focuses on facilitating the uptake of 'innovative waste management, recycling and resource recovery' with the view to reduce emissions (p. 30). Finally, the South Australian government also aims to help businesses reduce their emission by transitioning toward more circular practices, notably by offering 'business sustainability support programs' (p.32).
- The South Australian Government is developing a **Biodiversity Act.** The aim of the Act will be to enhance biodiversity protection and ecosystem restoration and to facilitate transparent and timely decision-making. A **Draft Biodiversity Bill** [89] has been out for public consultation. In the Draft Bill, the importance of integrating climate considerations into decision-making is discussed. This will be done through: i) the Biodiversity Council, which will advise the Minister on various biodiversity related matters, including climate adaptation, and ii) the State Biodiversity Plan, which will set up priorities for the protection and restoration of climate resilient ecosystems. Circular economy, waste and pollution are not discussed in the Draft Bill.

4. Findings

POLICY APPROACHES REVIEW AUSTRALIA & INTERNATIONAL CONT.

Victoria

- Victoria's circular economy policy, **Recycling Victoria: A New Economy** [90], aims to drive fundamental change in Victoria's economy to reduce waste and make more productive use of resources. It identifies organic waste as having a role to play in mitigating greenhouse gas emissions, and mentions the provision of combined food and garden waste services to all households as an important measure. The policy also identifies the role of anaerobic digesters in wastewater facilities. While there is no explicit mention of nature or biodiversity, reducing the environmental impact of resource use, including extraction of resources and greenhouse gas emissions, and the need to reduce harm from waste polluting the environment are central to the goals and initiatives in the policy
- **The Victorian Recycling Infrastructure Plan (VRIP)** [91] guides the development of waste, recycling and resource recovery infrastructure for the next 30 years. The VRIP outlines infrastructure needs and gaps, driving innovation and potential investment where it is needed most. The VRIP provides insights to support investment decisions through:

1. In-depth infrastructure needs analysis that considers capacity and capability
2. Place-based assessments for each material stream
3. Residual waste and waste to energy
4. Regional opportunities
5. Land use planning

The VRIP highlights the need for systems and infrastructure to be able to withstand future climate impacts, while also discussing new and emerging waste streams brought about by the energy transition (e.g. PV panels, wind turbine blades, lithium-ion batteries etc), as well as emerging opportunities to transition away from fossil fuels through bioenergy (e.g. anaerobic digestion). Nature, biodiversity or regeneration are not discussed.

What do climate and biodiversity policies have to say about the circular economy and each other? A glimpse from Victoria

- **Building Victoria's Climate Resilience** (2022) [92] "sets out what Victoria is doing to adapt and build resilience to the changing climate" (p.1). The transition to a circular economy is mentioned in relation to the water cycle, through promoting "innovation to reduce Victoria's water-related emissions across households and businesses", and "build climate resilience" (p. 40). Nature and biodiversity is mentioned, with a focus on developing measures to respond to climate related events and build the resilience of ecosystems. Nature-based solutions are also mentioned, notably planting activities, which can have numerous climate benefits, including reducing flood impacts, reducing temperature. Both circular economy and nature/biodiversity are discussed in relation to climate resilience, but they are discussed in isolation from one another.
- **Water Cycle Climate Change Adaptation Action Plan 2022–2026** [93] recognises that "system thinking across water sector organisations will see greater integration of emission reduction, resource management and resilience" (p, 43). The circular economy, in the water context, is described as contributing to "regenerating natural systems" (in reference to Ellen MacArthur's definition of the circular economy) (p. 35), notably through waste-to-energy activities. Other measures related to nature and biodiversity are the development of integrated plan to manage water and biodiversity and adapt to climate change impacts. In this plan, the circular economy is considered as both a tool for climate resilience and nature regeneration.

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POLICY APPROACHES REVIEW AUSTRALIA & INTERNATIONAL CONT.

- **Victoria's Climate Change Strategy (2021)** [94] includes actions to reach net-zero emissions and enhance the climate resilience of Victoria by 2050. The strategy notes that climate smart businesses and communities will be supported to adopt practices that will reduce waste related emissions and facilitate the transition to a circular economy. The strategy notes that biodiversity must be protected from climate change impacts. In addition, government actions to support resilient farms and forests, such as protecting Victorian forests and restoring natural landscapes and vegetation through the BushBank program, will help to contribute to the achievement of net zero emissions by 2050

- **Protecting Victoria's Environment – Biodiversity 2037 (2017)** [95] presents a long-term vision for Victoria's biodiversity. The document extensively discusses the climate-biodiversity nexus, with one full chapter discussing the question. The plan aims to channel investments to prevention rather than emergency response to climate events affecting biodiversity. It also states that the impacts of climate change will be considered in each decision made on biodiversity management. The circular economy is not mentioned in this document.

4. Findings

POLICY APPROACHES REVIEW AUSTRALIA & INTERNATIONAL CONT.

Policy approaches internationally

- **International policy approaches**
- **An expansive framing of the circular economy is adopted with references to regeneration, planetary boundaries.**
- **Emphasis is put on the forestry sector and the substitution of biomaterials.**
- **Other areas of interest are the food systems and nature-based solutions.**

Finnish roadmap to a circular economy 2016-2025 [96] The roadmap puts forth practical actions and drivers for systems change, noting that communications will be essential to sustain change across the entire value chain. Circular economy is viewed as a catalyst for growth, investment and exports for Finland, providing tangible value in "machinery and equipment and forest industries, food waste reduction, altering the use of real estate, private consumption, second-hand trade, and nutrient recycling". Aspects of nature, in addition to overall material and energy efficiency, recycling and resource recovery:

- **Sustainable food system –** reducing pre- and post-consumer food waste, biowaste recycling, shifting diets with more seasonal and vegetarian foods, use of recycled fertilisers, unfarmed fish, biofuels in agriculture
- **Forest-based loops** – use of natural and renewable materials, developed a biobased local and export economy, leasing equipment and chemicals in forestry, nutrient recovery from wastewater treatment
- **Transport and logistics** – producing vehicle and transport fuels from renewable raw materials, secondary and biomaterials, making Central Finland a model province for transport biogas, use of water transport to reduce burden on land transport

The Netherlands National Circular Economy Program [97] The report refers to the concept of "broad prosperity", which relates to "the quality of life (...) here and now, and the extent to which it is to the detriment of the quality of life of future generations..." (pp. 15). Circular design is identified as the underpinning strategy to achieve the four goals of the program, which are to i) reduce raw material usage; ii) substitute raw materials; iii) extend product lifetimes; and iv) increase high-grade processing to close the materials loop.
CE aspects related to other policies in the Netherlands:

- **Climate change**: Energy and climate policy
- **Realising a cleaner environment and place to live in**: Air, water and soil policy
- **Restoring biodiversity:** Nature policy

Aspects of nature identified in the program:

1. **Substituting raw materials:** Replacing primarily raw materials with secondary materials and biobased raw materials or with materials which have a lower environmental burden
2. **Recognising planetary boundaries** to limit raw material footprint: The plan acknowledges that the planetary boundaries for climate change, biodiversity, land use and biochemical flows of phosphorus and nitrogen have been exceeded, and that the adverse environmental impacts need to be reversed while society tackles how to manage and reduce the environmental impacts of new chemicals and plastics. While the program did not determine the planetary boundaries for the Netherlands, there is an ambition to be climate-neutral, fossil-free and circular by 2050. A qualitative assessment of limits, impacts and targets for the Dutch use of raw materials is underway.
3. **The Dutch Forest strategy (2020)**: The Strategy aims to add 37,000 hectares to the Dutch forest areas, to revitalise and restore existing forests and realise 10% 'networks of blue and green' in rural areas by 2050. The Strategy also aim to create 25,000 hectares of 'agroforestry'.

Roadmap for a circular Chile by 2040 [98]:

- **Vision:** "By 2040, a regenerative circular economy drives Chile to a sustainable, fair and participatory development path that puts people at the centre; this, through the care of nature and its living beings, the responsible and efficient management of our natural resources..." (pp. 37):
- **Circular practices have driven the regeneration of nature**, positively and sustainably impacting the lives of people and the environment
- **Actions - Promote the development of a line of R&D+I projects** that open the field of nature-based solutions

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