A DELIVERABLE OF GOVERNMENT'S CIRCULAR ECONOMY
SCIENCE, TECHNOLOGY AND INNOVATION STRATEGY

BUILDING CIRCULARITY INTO NATIONALLY DETERMINED CONTRIBUTIONS

Piloting the UN Toolbox in South Africa

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EXECUTIVE SUMMARY

Introduction

This report presents the first application of the United Nations' Toolbox for *Building Circularity into Nationally Determined Contributions (NDCs)* in the South African context. The study aimed to explore the potential for circular economy interventions to reduce greenhouse gas (GHG) emissions, thereby supporting future updates to South Africa's NDCs.

South Africa is the 12th largest contributor to GHG emissions, accounting for 1% of global emissions. In 2022, South Africa emitted 435.12 Megatonnes of CO_2 equivalent ($MtCO_2$-eq) (DFFE, 2024).

Through more efficient and circular use of just a few key materials (including cement, steel, plastics and aluminium), **circular economy strategies can help reduce global GHG emissions by up to 50%** (EMF, 2021). The transition to a circular economy is therefore critical for mitigating climate change.

Methodology

The UN's NDC Toolbox offers a structured repository of online tools to assist policy-makers in identifying and assessing relevant circular economy opportunities for reducing GHG emissions. It aims to support countries to identify, prioritize, implement and track circular economy interventions for increased ambition and implementation of their NDCs. Specifically, it provides policy-makers with a methodology, resources, and tools to:

1. Assess and identify GHG emission hotspots from material use and establish entry points in their NDCs
2. Assess and select circular economy interventions, and adjust targets for the NDCs
3. Identify policy instruments and indicators for implementation
4. Track and report progress in the Biennial Transparency Report.

The Toolbox is organised into four stages associated with these four objectives. This study focused on piloting the initial stages of the Toolbox: Stage 1, which involves identifying hotpots of GHG emissions and material use, and Stage 2, which supports the preliminary selection and assessment of circular economy interventions. Subsequent steps, relating to policy options, financial instruments, and implementation; should be addressed in future work.

Key findings and conclusions

The study finds that the **greatest opportunities for material circularity to contribute towards reducing greenhouse gas emissions** are likely to lie in the **mining-fabricated metals and quarrying-construction value chains**.

Based on a more detailed analysis of hotspots of raw material use and GHG emissions within these two value chains, **building construction and civil engineering construction were identified as priority sub-sectors for circular economy interventions to reduce GHG emissions**.

Emissions in these sub-sectors are largely driven by the use of carbon-intensive construction materials, such as cement (particularly in concrete) and steel.

A detailed assessment identified **eight viable circular economy interventions that, if implemented, could reduce sectoral GHG emissions by 12.3 $MtCO_2$-eq, or 52% of current emissions in the building construction and civil engineering construction sub-sectors** (see Table 1 and Figure 1).

Table 1: Summary of potential greenhouse emission reductions associated with eight circular economy interventions, ranked as a % of current emissions in the building construction and civil engineering construction sub-sectors.

Intervention	Reduction in GHG emissions (ktCO$_2$-eq)	Emission reduction as a % of current emissions in construction
Fly ash and bottom ash to replace clinker in cement production	3 198	13.42
Fuel switch to low-carbon fuels for cement production	3 190	13.39
Cement made from calcined clay instead of limestone clinker	1 950	8.19
Recycling and re-use of concrete and cement	1 740	7.30
Cement and concrete with intentionally introduced air voids	1 064	4.47
Cement substitution with wood waste	699	2.93
Ground granulated blast furnace slag to replace clinker in cement	468	1.96
Plastic waste as a partial replacement for bitumen in asphalt	4	0.01
Total	**12 313**	**51.69**

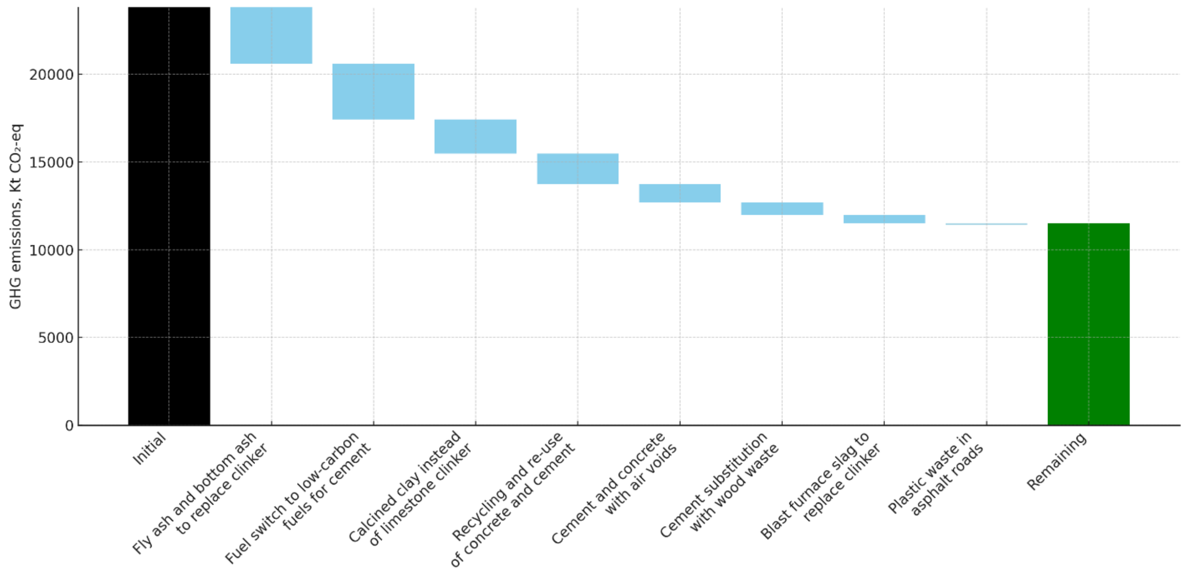

Figure 1: Potential reduction in greenhouse gas emissions in the building construction and civil engineering construction sub-sectors associated with implementing eight circular economy interventions.

Two interventions, namely **substituting clinker with fly ash and bottom ash** and **switching to lower carbon fuels**, can be seen as providing the highest potential emission reductions; with **each reducing emissions by approximately 3.2 Mt, or 13.4% of total emissions in the building and civil engineering construction sub-sectors.** These are followed by replacing clinker with calcined clay and limestone; and recycling and re-use of concrete and cement.

If implemented in combination, **the eight circular economy interventions could reduce GHG emissions by 12.3 MtCO$_2$-eq, or 52% of current emissions** from building and civil engineering construction.

Beyond emissions reduction, these interventions offer potential socio-economic benefits; including waste diversion, cost savings, and job creation; as well as adaptation co-benefits, by increasing the resilience and adaptive capacity of buildings and infrastructure to climate-related hazards and natural disasters. Integrating these interventions into future NDC updates can therefore strengthen national climate ambition, while delivering socio-economic and adaptation co-benefits.

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Abbreviations

Abbreviation	Full Term
AAC	Autoclaved Aerated Concrete
AFOLU	Agriculture, Forestry and Other Land Use
ASPASA	Aggregate and Sand Producers Association of Southern Africa
BAU	Business-As-Usual
BUR	Biennial Update Report
C&D Waste	Construction and Demolition Waste
CBA	Clay Brick Association
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CE	Circular Economy
CEM	Cement (e.g., CEM I, CEM II)
CIDB	Construction Industry Development Board
CJM	Circular Jobs Monitor
CLT	Cross Laminated Timber
CO_2-eq	Carbon Dioxide Equivalent
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry and Fisheries
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DPWI	Department of Public Works and Infrastructure
DSTI	Department of Science, Technology and Innovation
EIA	Environmental Impact Assessment
EMF	Ellen MacArthur Foundation
EUI	Energy Use Intensity
GABC	Global Alliance for Buildings and Construction
GAIN	Green Jobs Assessment Institutions Network
GBCSA	Green Building Council of South Africa
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLAD	Global LCA Data Access Network
GJ	Gigajoule
GJAM	Green Jobs Assessment Model
IAP	Invasive Alien Plant
IEA	International Energy Agency
IDC	Industrial Development Corporation
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LC^3	Limestone Calcined Clay Cement
LEDS	Low Emission Development Strategy
LULUCF	Land Use, Land-Use Change and Forestry
MAC	Marginal Abatement Cost

MBSA	Master Builders South Africa
Mt	Megatonnes
NBR	National Building Regulations
NDC(s)	Nationally Determined Contribution(s)
NID	National Inventory Document
NIR	National Inventory Report
NUM	National Union of Mineworkers
NUMSA	National Union of Metalworkers of South Africa
OPC	Ordinary Portland Cement
PE	Polyethylene
PJ	Petajoules
PP	Polypropylene
PS	Polystyrene
RDP	Reconstruction and Development Programme
RSA	Republic of South Africa
SABS	South African Bureau of Standards
SAFCEC	South African Forum of Civil Engineering Contractors
SAIA	South African Institute of Architects
SAM	Social Accounting Matrix
SANRAL	South African National Roads Agency Limited
SARMA	South African Ready-Mix Association
SAICE	South African Institution of Civil Engineering
SAPOA	South African Property Owners Association
SCP-HAT	Sustainable Consumption and Production Hotspot Analysis Tool
SDG	Sustainable Development Goal
SET	Sectoral Emission Target
S-LCA	Social Life Cycle Assessment
SMME	Small, Medium and Micro Enterprises
t	Tonnes (metric)
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compound
WOM	Without Measures

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Introduction and context

South Africa's climate-related emissions and commitments

South Africa is a rapidly industrialising country, and one of the largest greenhouse gas emitters globally. It is ranked as the 12th largest contributor to global greenhouse gas (GHG) emissions, accounting for 1% of global emissions (Khan et al., 2021). The country's GHG emissions in 2022 were estimated at 435.12 Megatonnes of CO_2 equivalent ($MtCO_2$-eq), based on South Africa's 2022 National Inventory Document (NID)[1] (DFFE, 2024).

In a reference scenario which assumes no policy or measures to mitigate climate change (Without Measures, WOM), national GHG emissions are set to rise to 1 692 $MtCO_2$-eq by 2050, with energy contributing 1 043 $MtCO_2$-eq; industry 410 $MtCO_2$-eq; transport 137 $MtCO_2$-eq; Agriculture, Forestry and Other Land Use (AFOLU) 52 $MtCO_2$-eq; and Waste 52 $MtCO_2$-eq (DEA, 2014).

South Africa submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in September 2015, which became the country's first Nationally Determined Contribution (NDC) following South Africa's ratification of the Paris Agreement on 1 November 2016. The NDC committed South Africa to keeping its annual emissions within the range of 398 – 614 $MtCO_2$-eq for 2025, as defined in national policy (RSA, 2016). South Africa shifted from business-as-usual (BAU)-based targets for 2020 and 2025 in terms of the Cancun Agreement under the UNFCCC, to a fixed level target range under the Paris Agreement.

In South Africa's updated NDC (RSA, 2021), the country's GHG emission target is in the 398 – 510 $MtCO_2$-eq range for 2025, and in the 350 – 420 $MtCO_2$-eq range for 2030 (RSA, 2021). This represents a significant reduction as compared to the first NDC submitted in 2016, which had upper limits of 614 $MtCO_2$-eq for both 2025 and 2030. The upper end of the target range for 2025 has been reduced by 17%, while the upper end of the target range for 2030 has been reduced by 32%.

South Africa has also developed a Low Emission Development Strategy (LEDS) (2050), submitted to the UNFCCC in 2020 (RSA, 2020), which provides an overarching framework for achieving the country's mitigation ambition under the Paris Agreement, in line with the NDC commitment. The LEDS sets out a long-term decarbonisation trajectory for key economic sectors, and identifies actions required to achieve this. According to the LEDS, the country aims to reach net zero by 2050 (RSA, 2020). South Africa's national emissions trajectory is aligned with Sectoral Emission Targets (SETs), which are quantitative GHG emission targets allocated to an emitting sector or sub-sector, over a defined period. Targets are reviewed every five years and revised based on monitoring results, technological advances, and international commitments.

The role of the circular economy

South Africa's economy is very linear in nature, characterised by a high reliance on raw material extraction and exports, a lack of local value adding, and significant inefficiencies in terms of material losses. Material cycling is only 7%, with 5% coming from ecological processes such as biomass cycling,

[1] According to South Africa's National Inventory Document for 2022 (DFFE, 2024), which is compiled in accordance with IPPC Guidelines, GHG emissions in 2022 were 478.30 Mt CO_2-eq (excluding Land Use, Land-Use Change and Forestry (LULUCF)), and 435.12 Mt CO_2-eq (including LULUCF). Emissions including LULUCF can be lower than emissions excluding LULUCF due to carbon sequestration, afforestation/reforestation, etc.

and a mere 2% from socio-economic recycling and re-use (von Blottnitz et al., 2022). This low circularity underscores the unsustainable nature of the current economic model, posing a significant risk to future economic growth and environmental resilience.

Globally, the linear economic model has driven natural resource depletion, land and soil degradation, biodiversity loss, pollution, and climate change. International studies show that resource extraction and processing contribute to 50% of climate impacts, 90% of water stress, and 90% of biodiversity loss due to land use (International Resource Panel, 2019).

The circular economy is recognized as an opportunity to reframe economic development and unlock new opportunities for growth and employment; while achieving global commitments relating to climate change and sustainable development, and reducing the negative impacts associated with both resource extraction and waste. In contrast to the linear economic model, a circular economy "entails keeping materials and products in circulation for as long as possible, through practices such as re-use of products, sharing of underused assets, repairing, recycling and remanufacturing" (Schröder, 2020).

A circular economy therefore minimises the need for extraction of primary resources, while also reducing waste. It provides opportunities for improved resource efficiency and resource security, reduced energy and materials consumption, and reduced climate impacts; while offering new sources of economic growth and job creation. The circular economy is based on three principles, driven by design (Ellen MacArthur Foundation (EMF), 2024):

1. Eliminate waste and pollution
2. Circulate products and materials (at their highest value)
3. Regenerate nature.

International studies have shown that, through more efficient and circular use of just 4 key materials (cement, steel, plastics and aluminium), circular economy strategies can help reduce global emissions by 40%, or by 50% if circular approaches within the food system are included (EMF, 2021).

The transition to a more circular economy is therefore essential to mitigate economic and environmental risks, and to align with climate goals (Godfrey et al., 2021). A circular economy can help South Africa meet its NDCs through increased material circularity; which would lower the demand for virgin raw materials, add value from extracted raw materials, and reduce the emissions from carbon-intensive activities such as resource extraction, production, and transportation.

This study aims to identify the opportunities for reducing GHG emissions through increasing material circularity in the South African context, and thereby to assess how the transition to a circular economy could help South Africa meet its NDC targets for mitigating climate change. This was done by applying the United Nations' (UN's) Toolbox for Building Circularity into National Determined Contributions (UNEP et al., 2023a), which is described in the following section.

The UN Toolbox for Building Circularity into Nationally Determined Contributions

In October 2023, a coalition of three UN organisations launched an online Toolbox (UNEP et al., 2023a) to support countries in identifying, prioritizing, implementing and tracking circular economy interventions for increased ambition and implementation of their NDCs. The Toolbox is designed to assist policy-makers in selecting the most appropriate tools to identify and assess relevant circular economy opportunities for reducing GHG emissions. The tools are selected for their ability to identify the most suitable circular economy policies to support reductions in GHG emissions and enhance climate resilience. The "Building Circularity into Nationally Determined Contributions (NDCs) - A Practical Toolbox" is a structured repository of 33 online tools, complemented by a range of resources.

The Toolbox aims to support countries to identify, prioritize, implement and track circular economy interventions for increased ambition and implementation of their NDCs. It provides policy-makers with a methodology, resources, and tools to:

1. Assess and identify GHG emissions hotspots from material use and establish entry points in their NDCs
2. Assess and select circular economy interventions, and adjust targets for the NDCs
3. Identify policy instruments and indicators for implementation
4. Track and report progress in the Biennial Transparency Report.

The Toolbox is organised into four stages associated with these four objectives, as shown in Figure 2.

Each Stage of the Toolbox consists of a series of steps, with questions to be addressed at each stage. For each of the questions to be answered, the Toolbox recommends a number of tools and resources to be used.

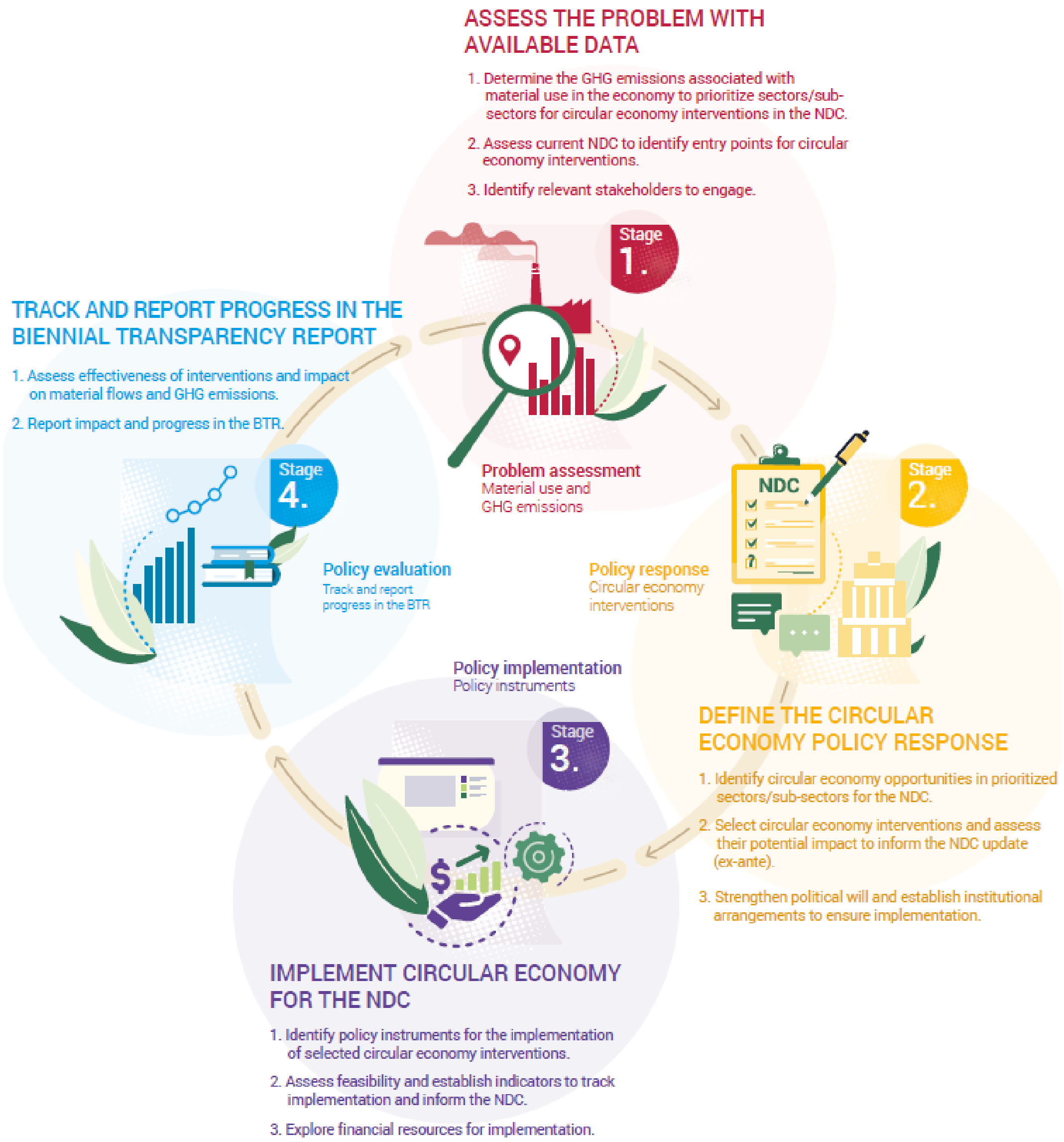


Figure 2: Four stage overview of the UN NDC Toolbox (Source: UNEP et al., 2023b).

1.1 Determine GHG emissions associated with material use in the economy to prioritize sectors/sub-sectors for circular economy interventions in the NDC

Which sectors/sub-sectors are major contributors to GHG emissions according to national inventories?
- National GHG inventories

What are the main consumption and production material flows associated with the GHG emissions and where are the hotspots?
- SCP-HAT modules 1 and 2
- Life cycle inventory database

Which sectors/sub-sectors should be prioritized for the interventions?
- Develop a short-list of priority sectors/sub-sectors from using the tools in this step

What is the socio-economic context of the identified priority sectors/sub-sectors?
- SCP-HAT (indicators on jobs and GDP)
- Social life cycle assessment

1.2 Assess current NDC to identify entry points for circular economy interventions

Which circular economy measures and associated targets are included in your current NDC? How does this compare to other countries' NDCs?
- Climate watch explorer
- NDC registry

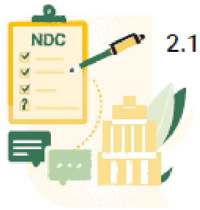
Which new prioritized sectors/sub-sectors/GHG emissions need to be included in the NDC?
- Compare list of prioritized sectors/sub-sectors from step 1.1 against existing measures in the NDC

1.3 Identify relevant stakeholders to engage

Who are the key stakeholders linked to the identified priority sectors/sub-sectors and their value chains?
- ICAT stakeholder participation methodology
- Value chain approach

Tool/resource

Figure 3: Key steps, questions and tools for Stage 1 (Source: UNEP et al., 2023b).



2.1 Identify circular economy opportunities in prioritized sectors/sub-sectors for the NDC

What are the current policies and practices in the value chain of the prioritized sectors/sub-sector?
- Value chain approach (including stakeholder consultations and desktop research)

What are the challenges/barriers to circularity?
- Value chain approach (integrating climate resilience and gender responsiveness)

What circular economy opportunities exist across the value chain?
- List of knowledge hubs to find case studies and best practices

What has worked well in a similar country context and can be learned from other NDCs?
- Climate watch explorer

2.2 Select circular economy interventions and assess their potential impact to inform the NDC update (ex-ante)

What is the GHG mitigation potential (and costs) of interventions to inform the NDC update with targets and indicators?
- IPCC GHG inventory guidelines
- CDM methodologies
- Life cycle inventory database
- GHG protocol and policy action standard
- ICAT policy assessment guides
- Circular indicators for governments

What are the potential socio-economic and environmental impacts of the interventions?
- Life cycle inventory database
- SDG Climate Action Nexus (SCAN) tool

How to assess job creation based on the identified interventions?
- Green jobs assessment model
- Circular economy jobs tool

Figure 4: Key steps, questions and tools for Stage 2; up until Step 2.2 (Source: UNEP et al., 2023b).

Scope of the study and outline of the report

This study applies the UN's NDC Toolbox in the South African context, in order to identify the opportunities for reducing GHG emissions through increasing material circularity, and thereby to assess how the transition to a circular economy could help South Africa meet its NDC targets.

In doing so, the objectives were to (1) test the Toolbox in a developing country context, (2) build on the initial circular economy climate mitigation work undertaken by the CSIR for the DSTI (Padayachi et al., 2023), and (3) provide evidence to support the Department of Forestry, Fisheries and the Environment (DFFE) in considering the inclusion of circular economy interventions in future updates of the NDCs.

The current scope of work is confined to piloting Stage 1 and Stage 2 (Steps 2.1 and 2.2) of the Toolbox only (see Figures 2, 3 and 4). Step 2.3, as well as Stages 3 and 4, which relate to policy options, financial instruments, and implementation; were beyond the scope of this study. Future work should focus on undertaking these remaining steps (from Step 2.3 onwards); in collaboration with DFFE, who are responsible for drafting and updating South Africa's NDCs, and other relevant stakeholders.

Figures 3 and 4 summarise the steps, questions to be addressed, and recommended tools/resources for Stage 1 and Stage 2 (up until Step 2.2) respectively.

This report follows the structure of the Toolbox, providing the findings associated with each of the stages, steps and questions to be addressed.

Box 1: Links to main resources and tools used in the study

The main resources and tools used for this study are available online:

- **Building Circularity into Nationally Determined Contributions: A Practical Toolbox** (UNEP et al., 2023a): https://www.undp.org/publications/building-circularity-nationally-determined-contributions-practical-toolbox
- **Building Circularity into Nationally Determined Contributions: User Guide** (UNEP et al., 2023b): https://www.undp.org/sites/g/files/zskgke326/files/2023-10/undp-unep-uncc-building-circularity-into-ndcs.pdf
- **National GHG inventory and associated data sources**: https://www.dffe.gov.za/sites/default/files/reports/8nationalgreenhousegasreport2022.pdf
- **Sustainable Consumption and Production Hotspot Analysis Tool (SCP-HAT):** https://scp-hat.org/. This tool provides key information on a country's environmental and socio-economic performance in the context of relevant policy areas (UNEP, 2024b). SCP-HAT is a web-based analytical platform that uses extended input–output life cycle assessment (EIO-LCA) and global databases (EXIOBASE) to trace environmental impacts across global supply chains. This approach incorporates both production-based and consumption-based GHG emissions and, unlike standard production-based territorial emissions under the Paris Agreement, accounts for GHG emissions embodied in traded goods. This approach offers a more complete value chain assessment of the climate impacts of domestic consumption, and supports the identification of material intensive sectors for circular economy interventions.

Step 1.1: Determine GHG emissions associated with material use in the economy to prioritize sectors/sub-sectors for circular economy interventions in the NDC

1.1.1: Which sectors are major contributors to GHG emissions according to national inventories?

Combustion of solid, liquid and gaseous fuels for energy usage is the primary driver of GHG emissions in South Africa, accounting for 74% of total emissions (DFFE, 2022; DMRE, 2023). The major contributing sectors to GHG emissions in South Africa are as follows (see Figure 5):

- The **energy** sector accounts for 59% of total emissions; covering energy production, fuel production, and processes within energy industries, including fugitive emissions.
- The **manufacturing** sector follows with 13%, stemming from fuel use and direct manufacturing processes.
- The **mobility** sector contributes 10%, mainly from fuel combustion in transportation.
- **Agriculture** accounts for 9%, with emissions mainly arising from farming operations, livestock, and soil management.
- The **human settlements** sector is responsible for 8%, including from fuel use and waste management activities.
- The **water** and **mining** sectors each contribute 1%, with emissions arising mainly from wastewater treatment and mining operations, respectively (DFFE, 2022; DMRE, 2023).

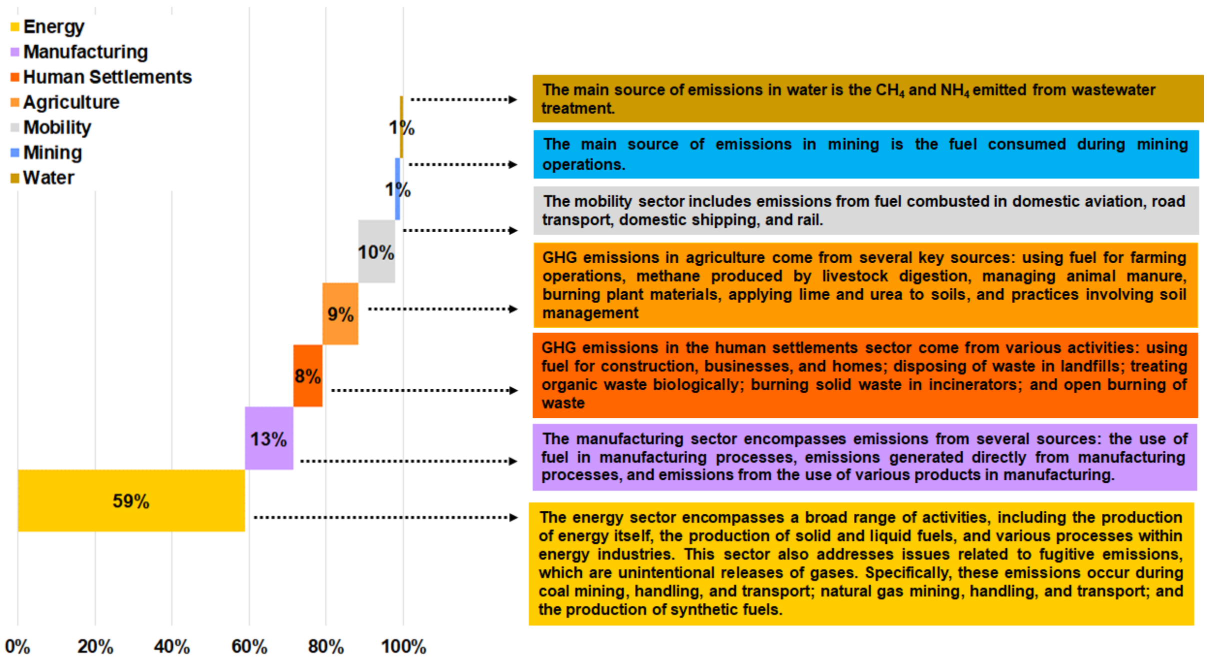


Figure 5: Main sectors contributing to South Africa's GHG emissions (DFFE, 2022; DMRE, 2023).

Sixty nine percent of South Africa's direct GHG emissions come from burning fossil fuels in the energy (71%) and mobility sectors (13%), as well as in manufacturing (7%), human settlements (6%), and mining (1%) (DFFE, 2022; DMRE, 2023).

The share of non-combustion GHG emissions is distributed mainly amongst agriculture (32.9%), processing and product use in manufacturing (27.8%), and fugitive emissions in the energy sector (24.1%) (DFFE, 2022; DMRE, 2023). Appendix 1 provides further details.

1.1.2: What are the main consumption and production material flows associated with the GHG emissions and where are the hotspots?

Many developed nations externalize the environmental impacts of their production and consumption by being net importers, particularly of raw materials; such that their consumption footprint tends to exceed their production footprint. In contrast, in developing nations such as South Africa, the production footprint tends to exceed the consumption footprint, indicating that the country is a net exporter of raw materials. According to the SCP-HAT tool (UNEP, 2024b), **South Africa's production-related emissions are currently 420 $MtCO_2$-eq, while consumption-related emissions are only 320 $MtCO_2$-eq.**. This indicates that approximately 100 $MtCO_2$-eq of South Africa's annual domestic GHG emissions (Figure 6) are for goods exported to and consumed in other countries (UNEP, 2024a).

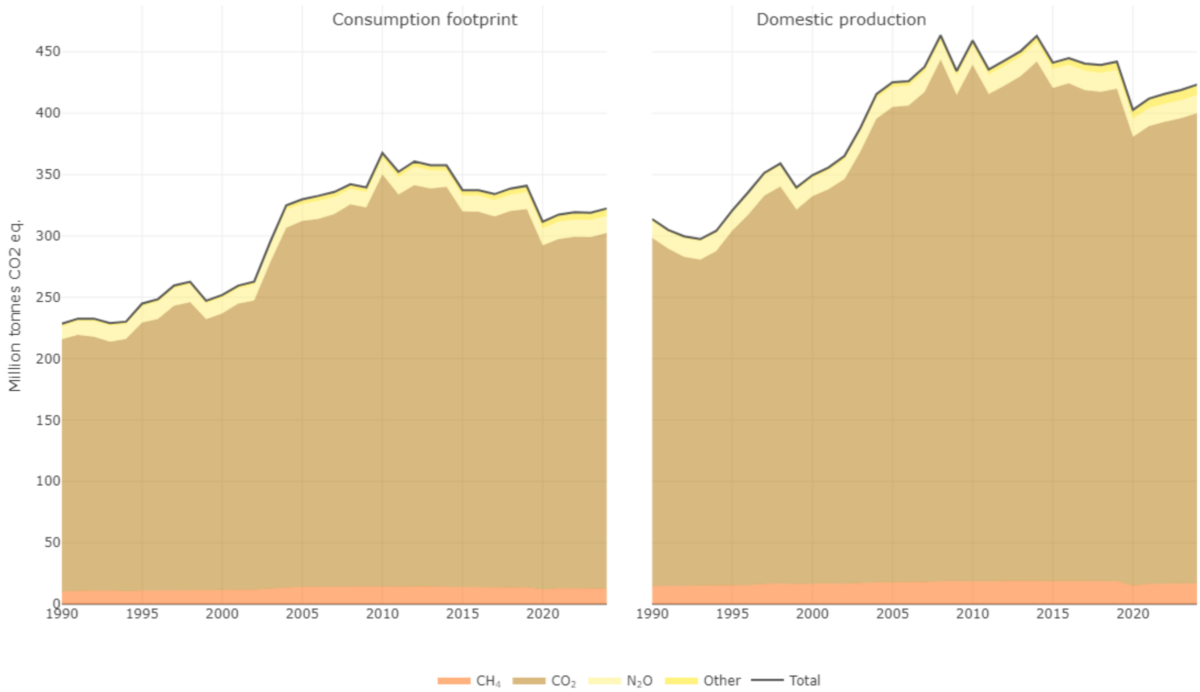


Figure 6: Consumption- and production-related greenhouse gas emissions in South Africa, 1990-2024 (Source: UNEP, 2024a).

In addition to GHG emissions, the combustion of fossil fuels also contributes towards depletion of fossil fuel resources. In 2024, fossil fuel depletion associated with South Africa's consumption was 40 Mt of oil equivalent, while the production footprint was 101 Mt of oil equivalent (Figure 7) (UNEP, 2024b).

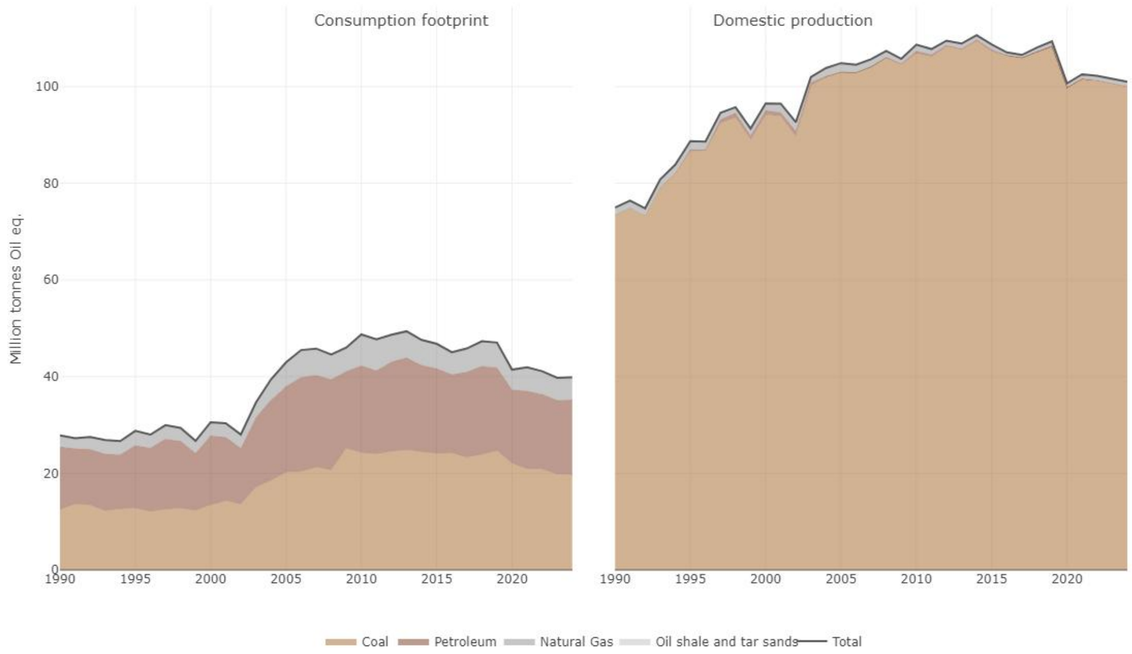


Figure 7: Fossil fuel depletion associated with consumption and production in South Africa, 1990-2024 (Source: UNEP, 2024b).

This pattern is also reflected in the use of raw materials more broadly. In 2024, raw material use associated with domestic production amounted to 868 Mt; dominated by metallic minerals (255 Mt) and fossil fuels (239 Mt). However, the consumption footprint is 363 Mt of raw material use per annum, of which fossil fuels account for 68 Mt, and metallic minerals 34 Mt (Figure 8) (UNEP, 2024a). This highlights that a substantial proportion of raw materials are exported.

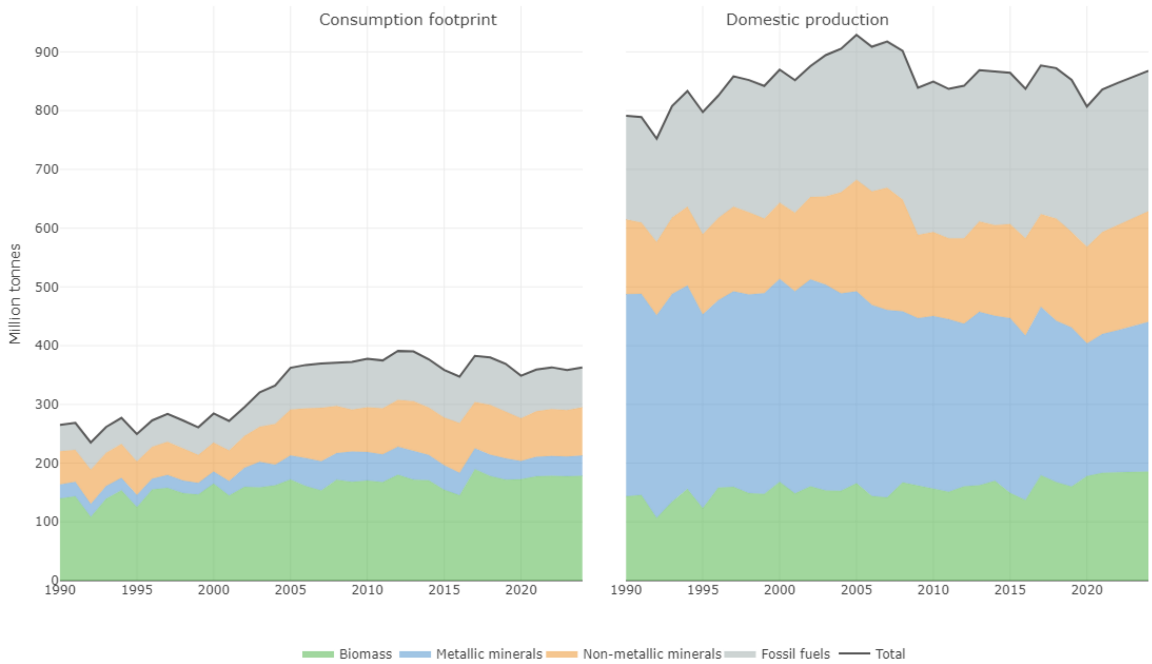


Figure 8: Consumption and production footprint of raw material use in South Africa, 1990-2024 (Source: UNEP, 2024a).

This **raw material use also results in minerals depletion.** In 2024, mineral depletion associated with domestic production amounted to 372 Mt Cu-eq, with 190 Mt of mineral depletion associated with the consumption footprint (Figure 9) (UNEP, 2024b).

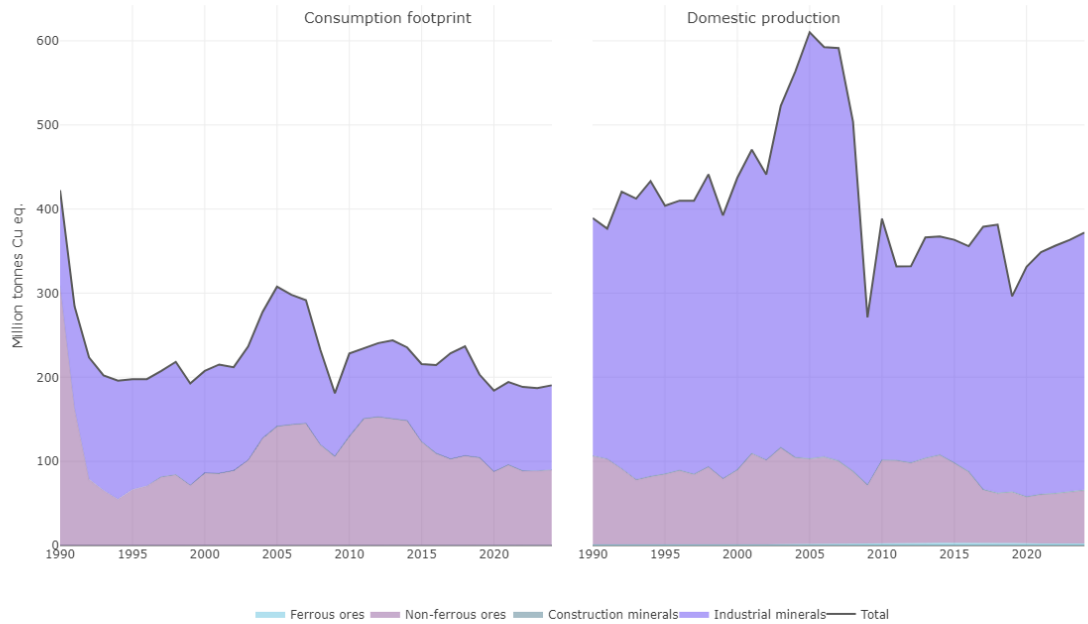


Figure 9: South Africa's consumption and production footprint for mineral depletion, 1990-2024 (Source: UNEP, 2024b).

Overall, the development picture reflects the fact that South Africa is a net exporter of raw materials, with net exports of raw materials (exports less imports) amounting to 504 Mt per annum (Figure 10) (UNEP, 2024a).

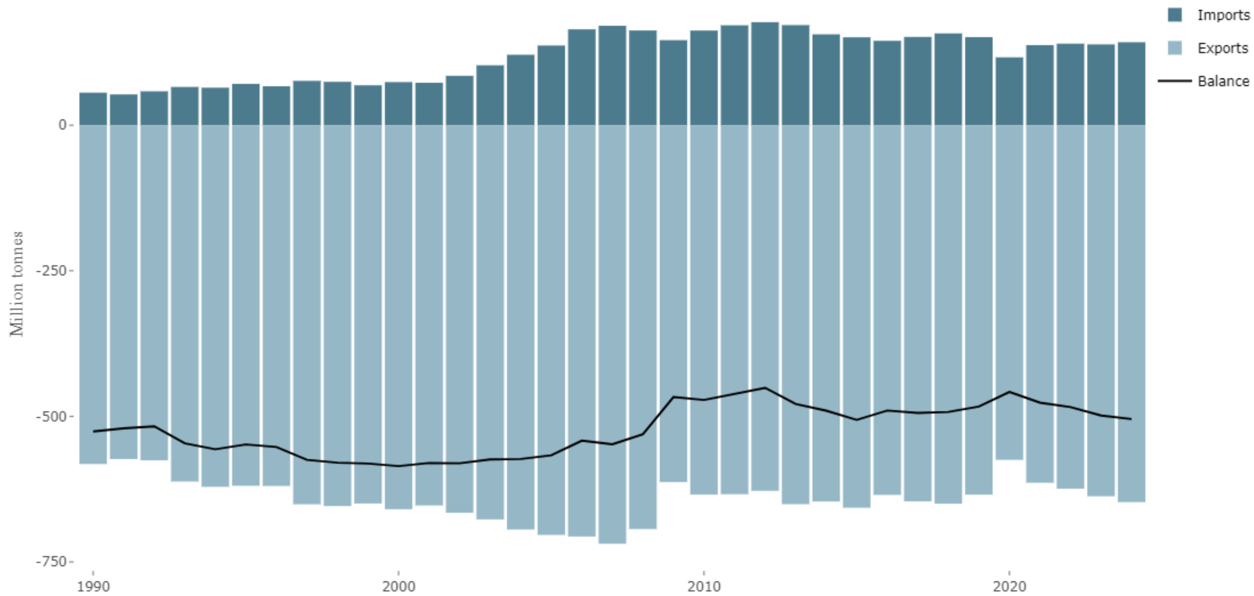


Figure 10: South Africa's raw material imports and exports, 1990-2024 (Source: UNEP, 2024a).

Raw materials are predominately exported to China, followed by Japan and India (UNEP, 2024b). Figure 11 provides a Sankey diagram illustrating global supply chains for South Africa's raw material exports by destination country, as well as consumption of finished products by country of end-use.

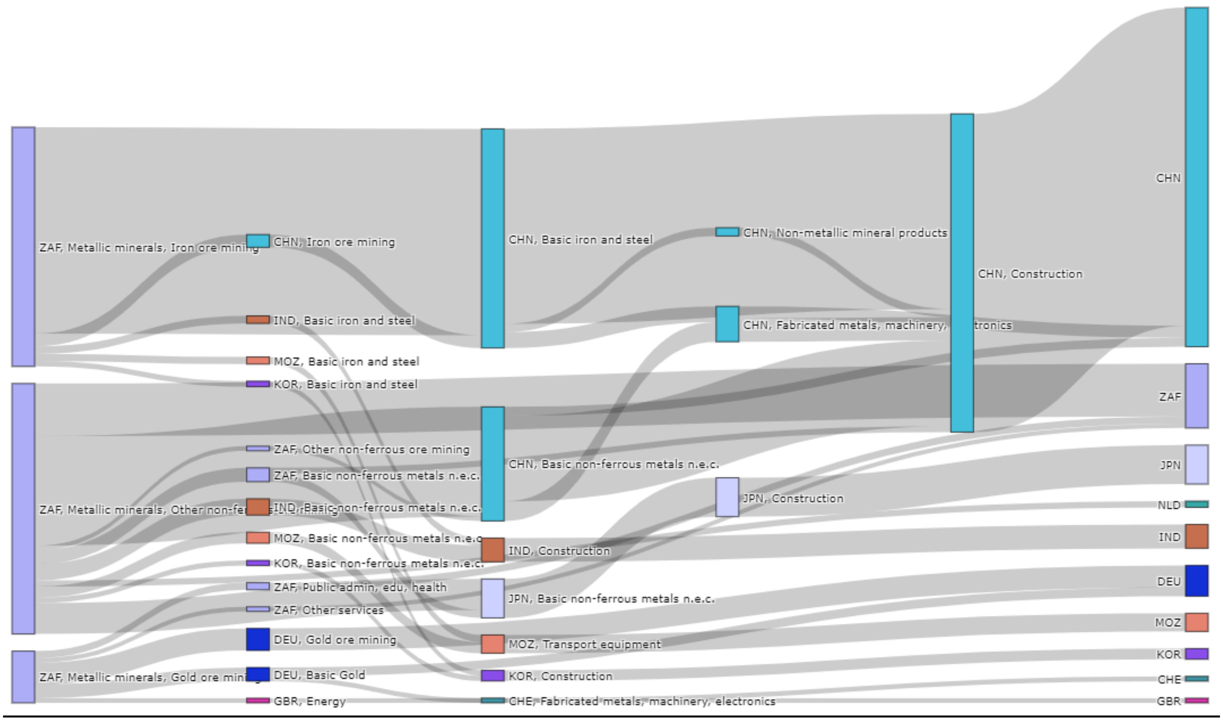


Figure 11: South Africa's raw material trade flows, 1990-2024 (CHN = China, ZAF = South Africa, JPN = Japan; NLD = Netherlands, DEU = Germany, IND = India, MOZ = Mozambique, KOR = South Korea, CHE = Switzerland, GBR = Great Britain). (Source: UNEP, 2024b).

South Africa's reliance on exports of raw materials implies that the developmental potential of South Africa is being undermined by a lack of local stock building and value-adding (Von Blottnitz et al., 2022). In addition, the intensity of South Africa's resource use, particularly finite raw materials such as fossil fuels and metal ores, results in resource depletion, which creates a business and developmental risk. The transition toward a more circular economy in South Africa, underpinned by a reduced reliance on raw material extraction and exports, developing local stocks of infrastructure, and localising production of higher value-added products, is critical to addressing these risks (Nahman et al., 2021).

1.1.3: Which sectors/sub-sectors should be prioritized for the interventions?

1.1.3.1: Greenhouse gas emissions and raw material use per sector

Sectors that contribute significantly towards both greenhouse gas emissions *and* the consumption of raw materials, could offer "win-win" opportunities for circular interventions to contribute towards reducing both GHG emissions and resource use.

Figure 12 and Figure 13 show, respectively, South Africa's production and consumption footprint in terms of raw material use and GHG emissions, per economic sector (see Appendix 2 for tabulated data). This data enables the identification of sectors with both high material use *and* high greenhouse gas emissions.

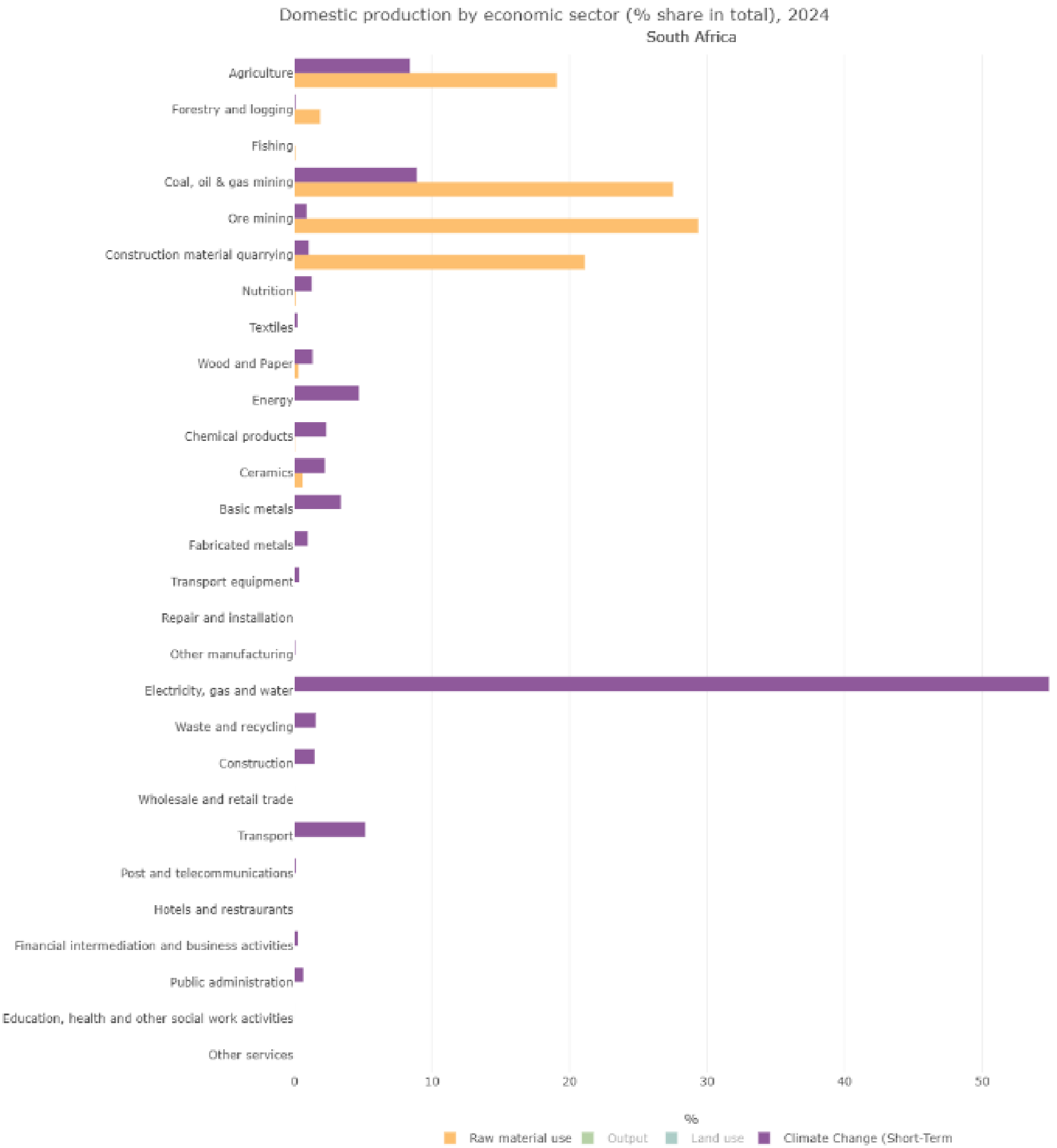


Figure 12: Raw material use and greenhouse gas emissions associated with domestic production in South Africa, per sector (2024) (Source: UNEP, 2024b).

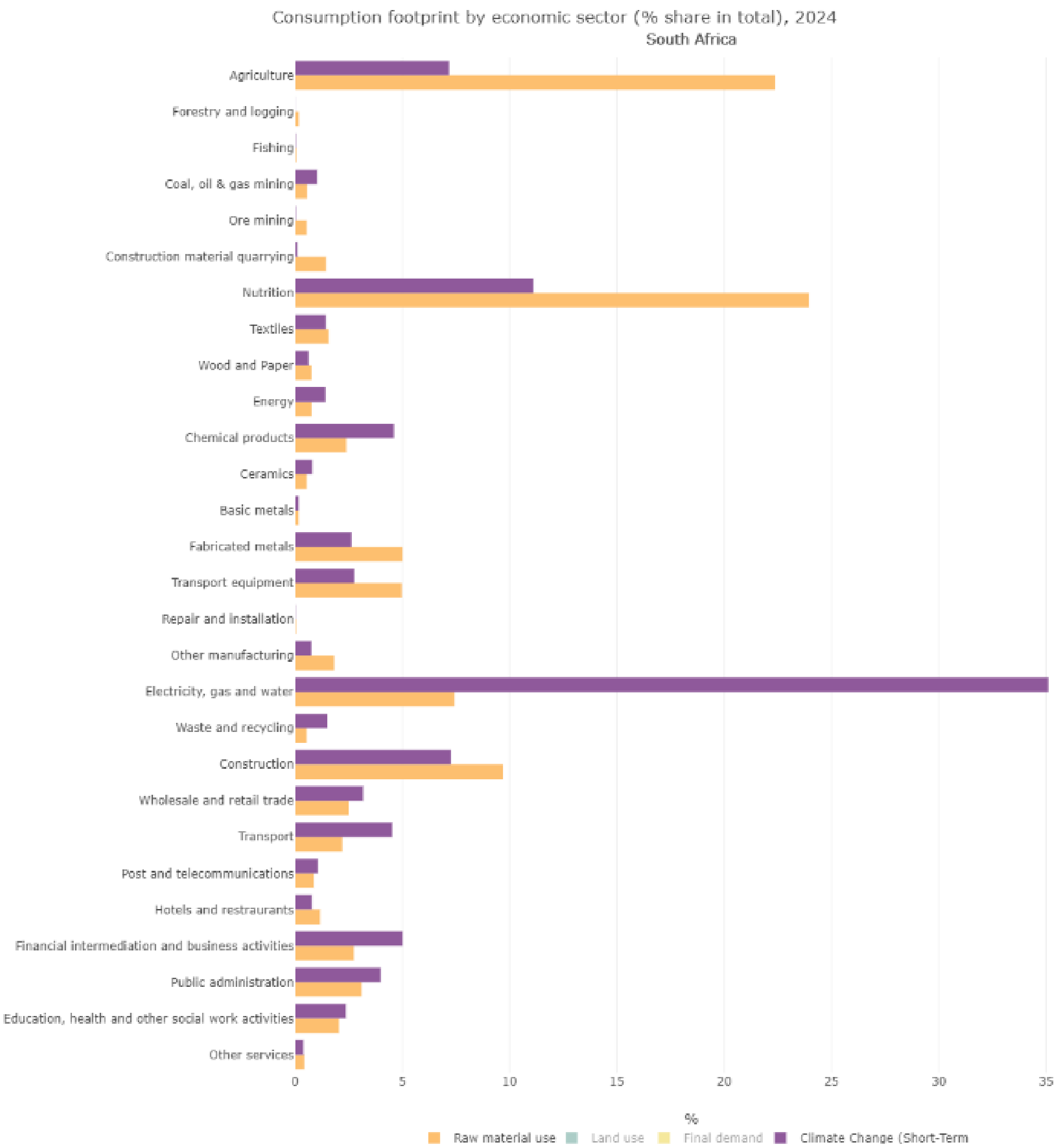


Figure 13: South Africa's consumption footprint in terms of raw material use and greenhouse gas emissions, per sector (2024) (Source: UNEP, 2024b).

Specifically, by looking at both the production (Figure 12) and consumption footprint (Figure 13), and by adopting a full value chain approach (i.e. considering the full product life cycle, from raw material extraction through to consumption), **the following value chains can be identified as having both high GHG emissions and high material use:**

- *Agriculture – Nutrition*
- *Coal, oil and gas mining – Electricity, gas and water*
- *Ore mining – Fabricated metals*
- *Construction material quarrying – Construction*
- *Transport equipment – Transport*

However, **in some cases, GHG emissions from these value chains could best be addressed through other types of interventions, rather than specifically through enhanced material circularity**. Below, we briefly discuss the opportunities specifically for circular economy interventions within each of these value chains, to address both GHG emissions and raw material use:

- *Agriculture – Nutrition* contributes to approximately 10% of domestic production-related GHG emissions (see combined contributions of agriculture and nutrition in Figure 12 and Appendix 2), and 18% of the consumption related emissions (Figure 13). It further contributes to approximately 19% of production-related raw material use, and 46% of material use on the consumption side (for agriculture and nutrition combined, as per Figure 13) (UNEP, 2024b). However, these impacts are predominately related to land use; the intensive use of chemical fertilizers and irrigation; the energy and carbon intensity of food production, processing and storage methods; food losses and waste; and dietary choices (e.g. methane emissions arising from enteric fermentation in cattle). This indicates relatively little opportunity specifically for material circularity, since GHG mitigation opportunities predominately relate to changes in agricultural production methods, reducing land use and energy intensity, switching from chemical to organic fertilisers, switching toward more plant-based diets, etc. This suggests that increasing material circularity does not present as significant an opportunity for reducing GHG emissions in the Agriculture – Nutrition value chain as other types of interventions[2].
- *Coal, oil and gas mining – Electricity, gas and water:* This value chain is the greatest contributor to climate change, contributing to approximately 64% of emissions on the production side and over 36% on the consumption side. The contribution toward raw material use is approximately 28% on the production side and 8% on the consumption side (UNEP, 2024b). However, similarly to Agriculture, there is relatively little opportunity for material circularity to contribute toward reduced emissions associated with the combustion of fuels for energy; where the major opportunities lie instead in energy efficiency and fuel switching (from fossil fuels towards renewable, low-carbon energy sources). The provision of water services is also carbon-intensive, and largely a result of the energy intensity of water supply and treatment. Again, the use of low-carbon, renewable energy sources is critical for reducing these embodied carbon emissions.

[2] There are various circular economy opportunities in agriculture that would contribute towards regenerating natural systems, which is also one of the principles of a circular economy. These include recycling and reusing agricultural materials (e.g. mulch and packaging), keeping agricultural machinery in use through repair and remanufacturing, improving soil health through composting and sustainable farming practices, etc. However, these are not seen as significant contributors to reducing GHG emissions as compared to interventions within some of the other value chains identified in this report.

- *Ore mining – Fabricated metals*. The ore mining – fabricated metals value chain contributes less than 1% to production-related GHG emissions, and approximately 3% to consumption-related emissions. However, it contributes to 29% of production-related material use, and 6% in terms of consumption (UNEP, 2024b). This relatively large material footprint suggests that reducing raw material consumption through increased circularity may offer an opportunity to also reduce GHG emissions, through increasing the lifetime and enabling increased recovery of valuable metals and materials, as well as adding value and reducing the energy intensity and carbon emissions associated with production. Since a large proportion of metal ores are exported, there is a lost opportunity to add value and deliver greater economic and social benefits within the local economy.
- *Construction material quarrying – Construction*. This value chain contributes to approximately 3% of production-related GHG emissions, and 7% of consumption-related emissions. In terms of raw material use, it contributes 21% to the total on the production side, and 11% on the consumption side (UNEP, 2024b). Similarly to the ore mining – fabricated metals value chain, this relatively large material footprint suggests that reducing material use through increased circularity may offer an opportunity to also reduce GHG emissions; for example, through extending the lifetime of buildings and infrastructure, or switching toward bio-based and recycled building materials.
- *Transport equipment – Transport.* Finally, the transport equipment – transport value chain contributes 5% to GHG emissions on the production side, and 7% on the consumption side. Production-related material use contributes <1% to the total, while on the consumption side, this value chain contributes approximately 7% to the total (UNEP, 2024b). However, similarly to the agriculture –nutrition and coal – electricity value chains, increased circularity may not offer significant opportunities for reducing transport-related GHG emissions, as the strongest opportunities are likely to be related to transport modality (e.g. public transport) and fuel use. In particular, a large portion of the transport-related emissions are for fuel combustion, which offers little opportunity for material circularity. Instead, opportunities for reducing transport-related emissions include switching to clean and low-carbon transport systems driven by electricity, e-fuels and/or biofuels; and improving the efficiency of transportation through improved spatial planning and multi-modal transport network optimisation.

In summary, the **greatest opportunities for material circularity to contribute towards reducing greenhouse gas emissions are likely to lie in the (1) ore mining – fabricated metals and (2) construction material quarrying – construction value chains**.

In the following sub-section, these value chains are explored in more detail, in order to identify "hotspots" of high GHG emissions and raw material use within each sector.

1.1.3.2: Identifying hotspots in the mining-fabricated metals and quarrying-construction value chains

Addressing both the consumption and production side of the value chain is crucial in reducing GHG emissions through circular economy interventions. However, the focus can vary depending on specific goals and contexts. South Africa for example produces more raw material products than it consumes, with a significant portion of these products being exported. It is therefore important to analyse the full product value chains, from production to consumption. This section provides greater insight into the mining-fabricated metals and quarrying-construction value chains, and aims to identify hotspots of high GHG emissions and raw material use.

As shown in Figure 14, gold ore (140.8 Mt) has the highest production-related raw material use among the sub-sectors within the two value chains, followed by quarrying of stone, sand, and clay (109.5 Mt), other non-ferrous ores (94.5 Mt), and iron ores (50 Mt). However, the domestic consumption footprint associated with these sub-sectors is much lower, since most of the domestically produced raw materials in South Africa are exported (UNEP, 2024b).

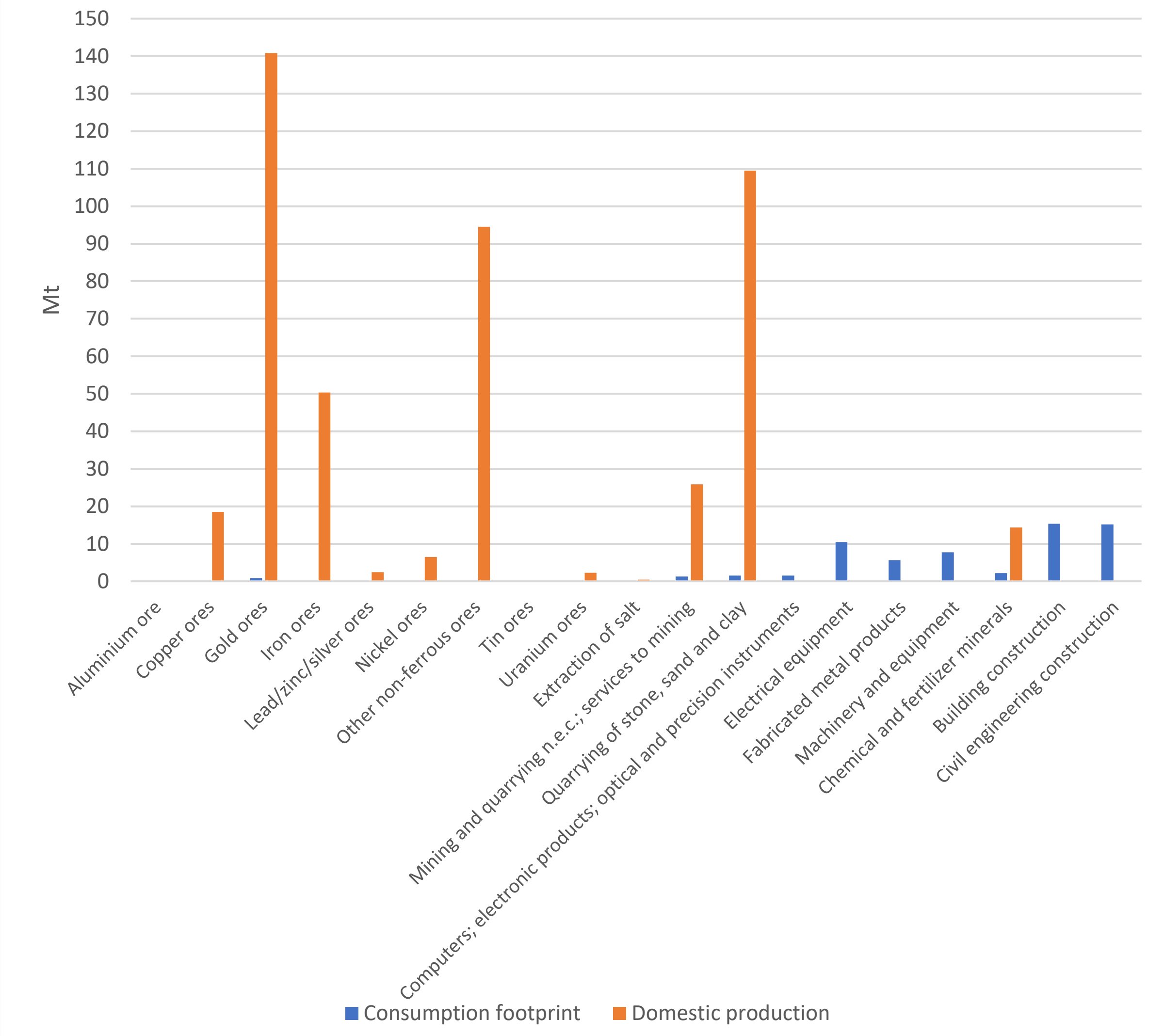


Figure 14: Hotspots of raw material use (in domestic production and consumption) in the mining-fabricated metals and quarrying-construction value chains in South Africa (Source: UNEP, 2024b).

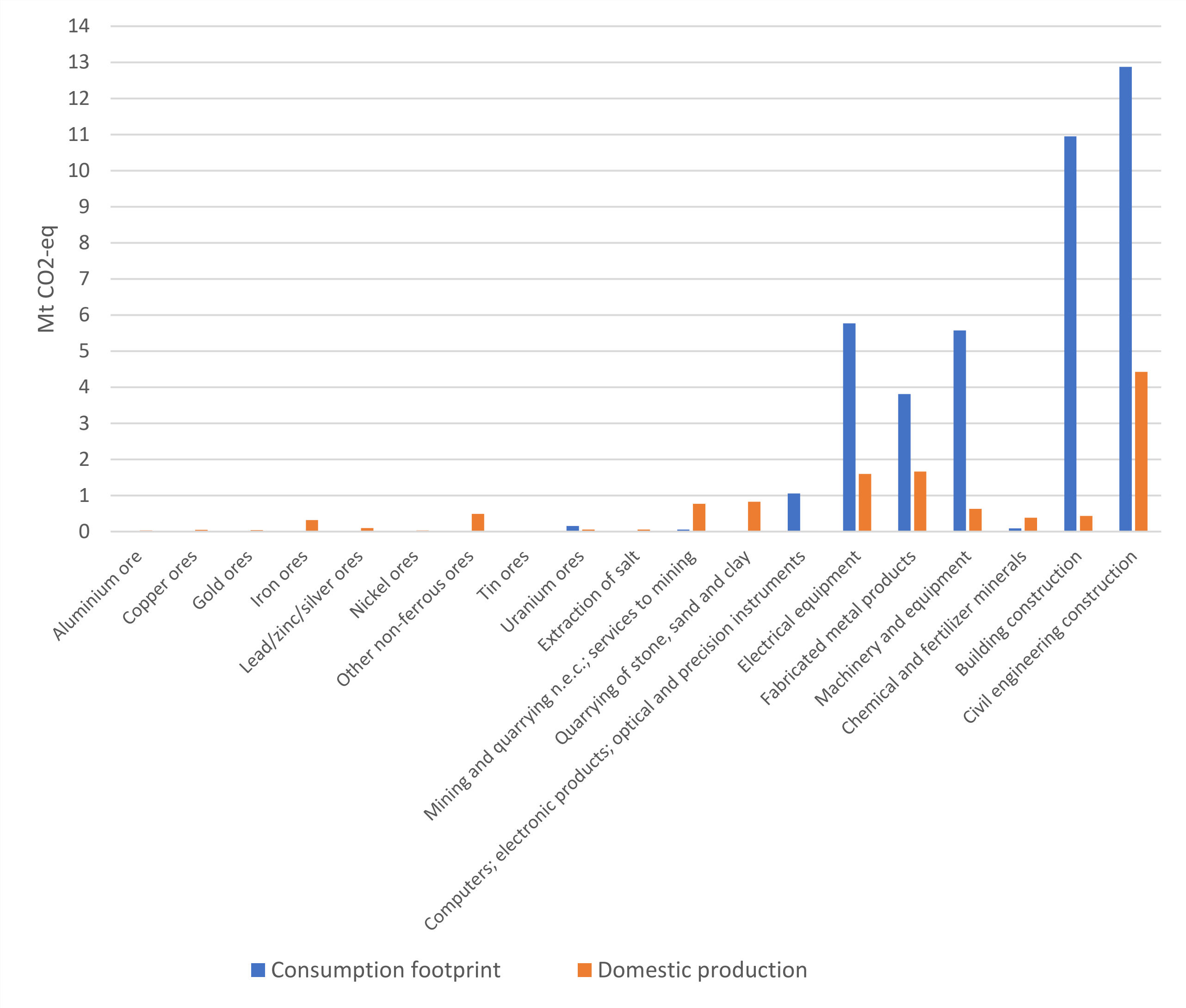


Figure 15: Hotspots of greenhouse gas emissions use (in domestic production and consumption) in the mining-fabricated metals and quarrying-construction value chains in South Africa (Source: UNEP, 2024b).

On the other hand, while the production-related raw material consumption of metal ores is substantial (UNEP, 2024b); Figure 15 shows that the corresponding climate change impact associated with these sub-sectors is relatively low.

Many of the ores and quarrying products are in turn used for the manufacturing of various other products, and are therefore part of the value chain of other sub-sectors; such as electrical equipment, fabricated metal products, building construction and civil engineering construction; which in turn have a high consumption-related climate change impact (Figure 15).

It can be seen from Figure 14 and Figure 15 that the sub-sectors with a relatively high consumption-related raw material use *and* climate change footprint are:

- building construction (15.4 Mt material use, 10.951 $MtCO_2$-eq emissions)
- civil engineering construction (15.2 Mt material use, 12.871 $MtCO_2$-eq emissions)
- electrical equipment (10.5 Mt material use, 5.770 $MtCO_2$-eq emissions)
- machinery and equipment (7.7 Mt material use, 5.569 $MtCO_2$-eq emissions)
- fabricated metal products (5.7 Mt material use, 3.813 $MtCO_2$-eq emissions)

In particular, in terms of the consumption footprint, the **building construction** and **civil engineering construction** sub-sectors can be seen as having both the highest material use and the highest GHG emissions.

1.1.3.3: Selection of priority sub-sectors for further analysis in this report

Based on the above analysis, **the building construction and civil engineering construction sub-sectors** within the quarrying-construction value chain **can be identified as priority sub-sectors for circular economy interventions to contribute towards reduced GHG emissions**.

While the sub-sectors within the ore mining – fabricated metals value chain also present opportunities for circular economy interventions to reduce emissions; **the building construction and civil engineering construction sub-sectors were selected for further analysis in this report**. The rationale for this selection is as follows:

- As seen in Section 1.1.1, the human settlements sector contributes 8% to South Africa's GHG emissions, while the mining sector contributes only 1%.
- Cement, which is used as a binder in concrete; as well as other materials often used in construction, such as steel, plastic and aluminium; were identified as the key materials for which circularity strategies can give rise to significant reductions in global GHG emissions (EMF, 2021).
- Mining and quarrying of the various materials used in construction gives rise to substantial production-related raw material use (as per Figure 14), and relatively high production-related GHG emissions (Figure 15).
- The building construction and civil engineering construction sub-sectors have relatively high production-related GHG emissions; with the latter having the highest production-related emissions among the sub-sectors shown in Figure 15.
- These two sub-sectors also have substantial consumption-related raw material use and GHG emissions; the highest among the sub-sectors shown in both Figure 14 (raw material use) and Figure 15 (emissions).
- Since the intention of this report is to identify circular economy interventions to address GHG emissions in priority sub-sectors, it would make sense to focus on sub-sectors where the full value chain (from production to consumption) occurs primarily within South Africa, as this is where we would be best able to implement and monitor the effectiveness of circular economy interventions across the full value chain.

As such, the remainder of this report focuses on identifying and assessing circular economy interventions to reduce GHG emissions within the quarrying-construction value chain; specifically within the building construction and civil engineering construction sub-sectors.

1.1.4: What is the socio-economic context of the identified priority sectors/sub-sectors?

South Africa is a net exporter of quarry products. In 2020, export of quarry products amounted to USD 54 million, while in the same year South Africa imported USD 18 million worth of quarry products. Dimension stones and clay are the major trade drivers, accounting for 71% and 25% of total trade respectively (Thwala, 2021). Dimension stones are divided into calcareous materials (marbles, taverines, limestone etc), siliceous materials (granites, quartzites and sandstone) and slate (Ashmole and Motloung, 2008).

The construction sector contributes approximately 3% to South Africa's GDP, with an income of R436,7 billion in 2020 (Gibberd et al., 2025). It also contributes significantly to employment; employing over 1.2 million people in 2021 (Bekker, 2024). It accounts for around 8% of total formal employment, and 17% of total informal employment (Gibberd et al., 2025). According to SCP-HAT, the quarrying-construction value chain[3] contributes 1% of South Africa's overall monetary output, 9% of the overall labour footprint, and 9% of final demand (UNEP, 2024b).

The construction sector also has a significant job creation multiplier effect; with approximately 4.2 formal jobs and 2.3 informal jobs created for every million rand invested. This increases further to around 9 jobs created per million rand invested if manufacturing and distribution of materials are included (Gibberd et al., 2025).

For example, the clay brick industry provides 20,000 direct and 160,000 indirect jobs (UNEP, 2025); with approximately 4 jobs created per 1 million bricks produced, particularly in rural communities (Clay Brick Association, 2017). The industry also contributes toward community development programmes; as well as being a significant supporter of SMMEs (R6.50 spent on community development per 1000 bricks produced) (Clay Brick Association, 2017).

Step 1.2: Assess current NDC to identify entry points for circular economy interventions

1.2.1: Which circular economy measures and associated targets are included in your current NDC? How does this compare to other countries' NDCs?

Intended Nationally Determined Contributions (INDCs) were the initial pledges made by countries prior to the formal adoption of the Paris Agreement, which later transitioned into Nationally Determined Contributions (NDCs) once the agreement was ratified. South Africa's INDC, submitted in 2015, laid out its commitment to peak, plateau, and decline emissions, which evolved into its NDC (RSA, 2016). South Africa ratified the Paris agreement in November 2016 and submitted its NDC, which committed South Africa to keeping its annual GHG emissions within the range of 398-614 $MtCO_2$-eq for 2025.

The NDC was subsequently updated in 2021 (RSA, 2021). The updated NDC has targets for 2030 in a range of 350-420 $MtCO_2$-eq, which represents a significant reduction compared to the first NDC submitted in 2016. Furthermore, according to South Africa's Low Emission Development Strategy (RSA, 2020), submitted to the UNFCCC in 2020, the country aims to reach net zero by 2050. South Africa's mitigation efforts in the NDC are focussed on four priority sectors, which align with South Africa's

[3] Sectors considered as per SCP-HAT were Construction material quarrying and Construction

fourth Biennial Update Report (BUR) as well as the National Inventory Report (NIR): Energy, Industrial Processes and Product Use (IPPU), AFOLU, and Waste.

The current NDC (RSA, 2021) highlights decarbonisation targets for South Africa for 2025 and 2030, focusing primarily on emission reduction in the energy sector in the 2020s; whereas from 2030 onwards, a deeper transition will take place in the electricity sector, coupled with a transition in the transport sector towards low emission vehicles. There are no sectoral targets in the current NDC, and no reference to circular economy interventions[4].

1.2.2: Which new prioritized sectors/sub-sectors/GHG emissions need to be included in the NDC?

In this step of the Toolbox, the prioritized sectors/sub-sectors as identified in Step 1.1 (building construction and civil engineering construction) should be compared against existing measures in the NDC, to identify which of these priority sectors/sub-sectors should be included in subsequent updates.

The current NDC (RSA, 2021) does not establish binding sector-specific emission reduction targets. As such, it does not include emission reduction targets for the quarrying-construction value chain or for the building construction / civil engineering construction sub-sectors. Nevertheless, these sectors are integral to the broader strategies aimed at achieving national emission reduction goals, and have both direct and indirect links to the current NDC in terms of emissions reductions. For example, the quarrying-construction value chain contributes to emissions associated with both energy usage as well as fossil-fuel based transportation. While the NDC prioritizes mitigation in the energy sector—responsible for over 78% of national emissions—it does not explicitly include fuel switching to renewable biomass as a defined strategy. Instead, it focuses on expanding renewable electricity generation (e.g. solar and wind), phasing out coal, improving energy efficiency, and electrifying transport.

The current NDC does, however, mention human settlements as one of the priority sectors for adaptation. The NDC explains that urban planning and building standards must incorporate climate science and risk considerations to enable climate-resilient human settlements. Section 2.2.2 of this report provides an indication of mitigation and adaptation co-benefits associated with the circular economy interventions identified for the building construction and civil engineering construction sub-sectors.

Sector-specific emission reduction targets are expected to be introduced in future updates to the NDC, through the recent Climate Change Act (RSA, 2024), which has the aim of strengthening co-ordination between national sector departments for policy setting and decision-making to enable South Africa to

[4] Searching the NDC with key terms that could refer to Circular Economy interventions did not yield any results. Keywords were searched as per the GIZ 'Guidance on Increasing NDC Ambitions through Circular Action', available at https://www.giz.de/de/downloads/giz2024-en-study-circular-action-ndc-ambitions.pdf. The keywords include Circularity, Material efficiency, Design, Repair / maintenance instructions, Product label, Digital Product Passport, Eco-modulation, Single use, Extraction, Sustainable soil management, Organic fertiliser, Regenerative agriculture, Bio-based, Sustainable soil management, Manufacturing Wood-based construction products, Composite materials, Material efficiency, Material content, Assembly / Dis-assembly, Reducing raw material usage, Process losses, Process yield, Cover crops, Crop rotation, Distribution and Retail Deposit Refund, Reverse Logistic, Consumption/Use Reuse, Up-cycling, Multiple use, Sharing economy, Maintenance, Diet change (Meat, Plant-based food), Collecting and Sorting Separate waste collection, Waste flow, Waste sorting, Recycling and waste management Recycling, Anaerobic Digestion, Composting, Waste management, Waste water/wastewater treatment, Agriculture biowaste, Digestate, and Extended Producer Responsibility.

meet the commitments in the NDC. The Climate Change Act mandates the minister of Forestry, Fisheries and the Environment to identify activities causing GHG emissions, with the assignment of carbon budgets or Sectoral Emissions Targets (SETs) to align with national climate goals (Colegrave, 2024). This provides an opportunity for circular economy interventions in the building construction and civil engineering construction sub-sectors to be incorporated in future updates to the NDC.

Step 1.3: Identify relevant stakeholders to engage

1.3.1: Who are the key stakeholders linked to the identified priority sectors/sub-sectors and their value chains?

The South African quarrying sector is made up of many players, including international cement producers such as Lafarge and Dangote, local companies like PPC and AfriSam, and many small, medium and micro enterprises involved in the production of quarry products (Thwala, 2021). In 2020, there were 888 operating quarries in South Africa. The number of quarries by province is indicated in Table 2.

Table 2: Number of quarries by province (Thwala, 2021).

Province	Number of active quarries in 2020
Eastern Cape	173
Free State	45
Gauteng	127
KwaZulu Natal	112
Limpopo	77
Mpumalanga	55
Northern Cape	47
Northwest	86
Western Cape	166
Total for South Africa	888

A basic flow diagram of the sand and aggregate industry value chain is provided in Figure 16, followed by an illustration of the industry and company structure in Figure 17.

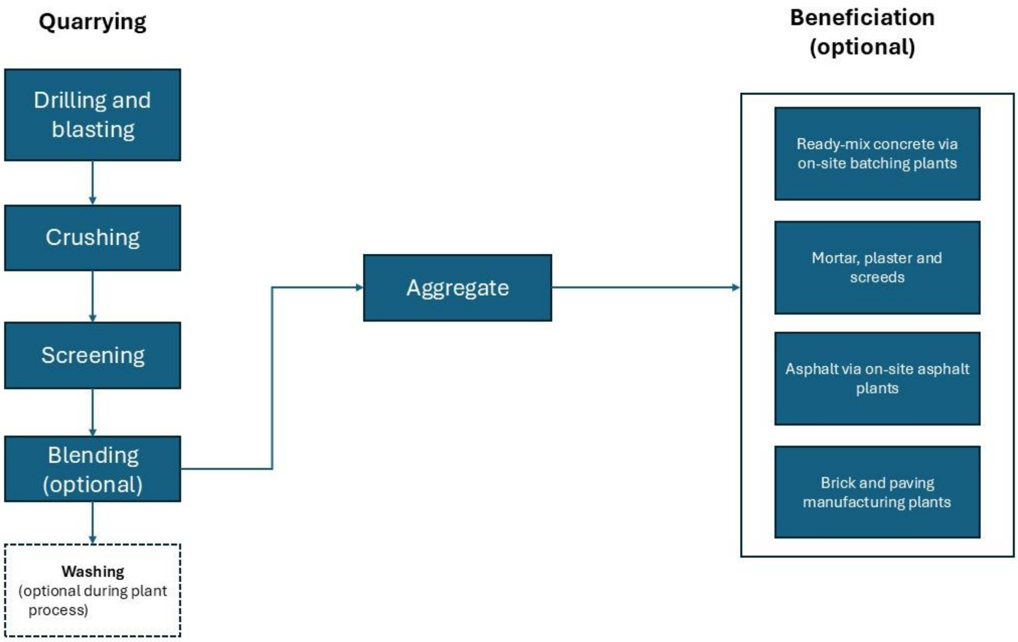


Figure 16: Basic flow diagram of the sand and aggregate industry value chain (DMR, 2012).

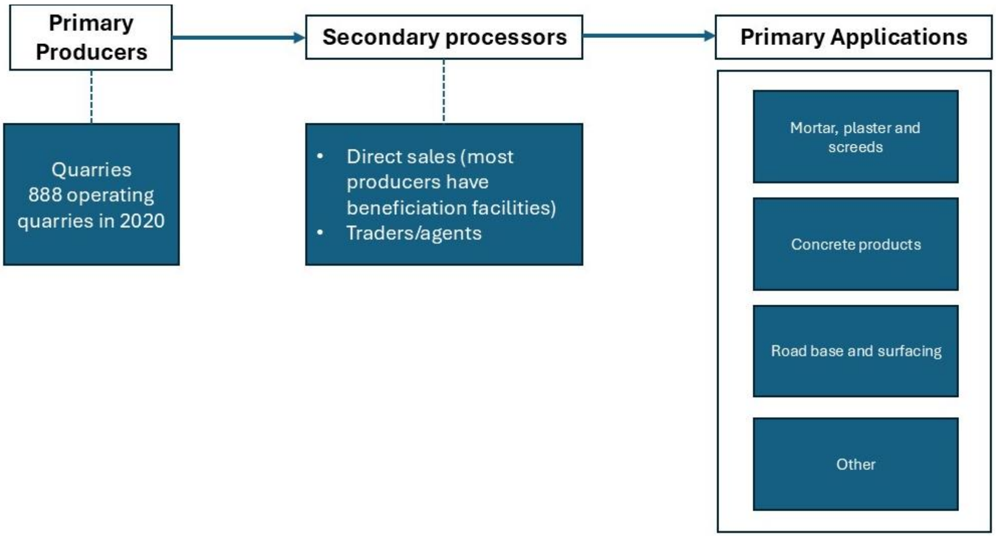


Figure 17: Industry and company structure for the sand and aggregate industry (DMR, 2012).

Table 3 provides an overview (non-exhaustive) of some of the key stakeholders in the quarrying-construction value chain.

Table 3: Key stakeholders in the quarrying-construction value chain (Source: Zonke Dumani, pers comm).

Category	Organisation/Entity	Role in Value Chain
Mining and Quarrying Companies	AfriSam, PPC Cement, Lafarge South Africa, Sephaku Cement, Afrimat, NPC-Cimpor, Mamba Cement	Major suppliers of cement, aggregates, and ready-mix concrete
	Various independent sand, stone, and gravel quarry operators.	Smaller quarries serving local construction markets
Construction and Infrastructure Companies	Murray and Roberts, WBHO Construction, Stefanutti Stocks, Group Five, Raubex, Aveng	Large construction and infrastructure firms.
	Smaller and emerging contractors engaged in residential, commercial, and civil works.	
Industry Associations	Aggregate and Sand Producers Association of Southern Africa (ASPASA)	Represents quarrying and aggregate suppliers.
	Cement and Concrete SA (CCSA)	Represents the cement and concrete industry, promoting standards and sustainability (CLOSED)
	South African Forum of Civil Engineering Contractors (SAFCEC)	Represents civil engineering contractors.
	South African Institution of Civil Engineering (SAICE)	Professional body for civil engineers.
	South African Ready-Mix Association (SARMA)	Represents ready-mix concrete producers.
	National Home Builders Registration Council (NHBRC)	Regulates residential construction and ensures quality compliance.
	Master Builders South Africa (MBSA)	Represents the building and construction industry.
	South African Institute of Architects (SAIA)	Represents architects involved in the built environment.
	South African Property Owners Association (SAPOA)	Represents commercial property developers
	Clay Brick Association of South Africa	Represents brick manufacturers
Civil Society and Environmental Organisations	Green Building Council of South Africa (GBCSA)	Promotes sustainable and green construction practices
	Groundwork, Centre for Environmental Rights (CER)	Advocacy groups focusing on environmental and social impacts of mining and construction.
	Mining Affected Communities United in Action (MACUA)	Represents communities affected by mining and quarrying
	National Union of Mineworkers (NUM)	Represents quarry workers
	National Union of Metalworkers of South Africa (NUMSA)	Various construction workers
Financial and Funding Institutions	Development Bank of Southern Africa (DBSA)	Funds infrastructure and construction projects.
	Industrial Development Corporation (IDC)	Provides funding for local manufacturing and industrialisation, including construction materials.
	Commercial banks (ABSA, Standard Bank, Nedbank, FNB, Investec, etc.)	Provide financing for construction projects and companies
	Infrastructure Fund	Public-private partnership funding
Government Departments and Regulatory Bodies	Department of Mineral Resources and Energy (DMRE)	Regulates mining and quarrying activities, issues mining permits.
	Department of Public Works and Infrastructure (DPWI)	Oversees infrastructure projects and construction regulations.

Category	Organisation/Entity	Role in Value Chain
	Department of Human Settlements (DHS)	The mission of the DHS is "to facilitate the creation of sustainable Human Settlements and improved quality of household life."
	Department of Trade, Industry and Competition (the dtic)	Supports industrialization and local manufacturing of construction materials.
	Department of Forestry, Fisheries and the Environment (DFFE)	Responsible for environmental regulations, including Environmental Impact Assessments (EIAs) and compliance with the National Environmental Management Act (NEMA).
	South African Bureau of Standards (SABS)	Develops standards for construction materials and products.
	Municipal and Provincial Governments	Responsible for zoning, land use, and issuing permits for quarrying and construction activities at the local level.
	South African National Roads Agency (SANRAL)	Manages national road infrastructure projects, often requiring construction materials from quarries.
	Construction Industry Development Board (CIDB)	Registers and grades contractors, promotes industry development, and ensures compliance with construction standards.
	National Treasury	Manages public procurement and infrastructure funding.

Step 2.1: Identify circular economy opportunities in prioritized sectors/sub-sectors for the NDC

2.1.1: What are the current policies and practices in the value chain of the prioritized sectors/sub-sector?

Government policies and regulations play a crucial role in promoting circular economy principles in the construction industry. Incentives for using recycled materials, regulations for waste management, and support for research and development of sustainable construction technologies are essential for driving the transition to a circular economy. However, in South Africa, there are few policies or regulations in place to govern these aspects. In particular, there are currently no legislative requirements to use low carbon, recycled or waste materials in construction. **There is therefore a need to strengthen the regulatory environment to drive construction waste management and the use of low carbon materials in construction.**

Carbon tax requirements are driving changes in certain construction material industries, while energy efficiency in buildings is being driven by revisions to the National Building Regulations (NBR) (RSA, 2008), implemented through SANS 10400 (SABS, 2011a). This prescribes the allowable energy use intensity (EUI) for different building types. The South African new buildings industry is achieving these requirements, but effort and policy is required to improve the efficiency of existing buildings that were constructed prior to the introduction of energy efficiency requirements in the NBR.

In summary, relevant policies, regulations and other initiatives in the construction sector include:

- The National Building Regulations and Standards Act (RSA, 2008)
- SANS 10400, Part A: General principles and requirements (SABS, 2011a)
- SATS 1286: Local Goods, Services and Works – Measurement and Verification of Local Content, (SABS, 2011b).

- SANS 3088 (2019): Water Efficiency in Buildings, (SABS,2019).
- SANS 10400, Part XA: Energy Usage in Buildings, edition 2. (SABS,2021).
- Agrément Certificates (Agrément, 2025).
- Energy Performance Certificates to monitor energy efficiency of existing buildings.
- Government efforts, such as the government-developed ecolabel scheme for certain building materials, and the Department of Public Works (DPW) Green Building Policy.
- Voluntary schemes, especially in upmarket private sector: Green Building South Africa (GBCSA) Green Star rating system.
- National Environmental Management: Waste Act: Regulations and notices regarding Extended Producer Responsibility (DFFE, 2021).
- Industrial Procurement - The Department of Trade Industry and Competition (the dtic, 2024).

2.1.2: What are the challenges/barriers to circularity?

Despite the potential benefits, there are challenges to implementing circular economy principles in the construction industry. These include

- Regulatory barriers and the lack of standardized practices can hinder the widespread adoption of circular economy principles; while there is limited supportive policy (e.g. procurement regulations).
- Ensuring compliance of alternative materials (including secondary and bio-based materials) with national building standards (NBR and SANS 10400); and the high costs for certification, e.g. for new bio-based materials.
- In some cases, there may be constraints associated with limited local availability of alternative materials.
- Recycling and reuse of building materials is difficult to monitor and manage. Metrics and methods for measuring waste are not clear or standardised, and different initiatives use different metrics. Voluntary initiatives, such as the Green Building Council of South Africa's (GBCSA) rating systems and the City of Tshwane Green Building Policy, promote the diversion of waste from landfill, quantified as a percentage; however, it is not clear if this is a percentage by volume or by weight. These initiatives require a waste management plan and should promote separation on site. However, these are niche initiatives; with diversion from landfill for re-use or recycling not part of mainstream practices. There is also limited control of the value chain/chain of custody, and once waste has left the site, the designer/construction manager/building owner has no way of monitoring the impact. Finally, there is a very limited and niche market for reusing construction materials, and challenges with matching available waste material to needs. There is a need to establish robust markets for secondary materials.
- Lack of knowledge and poor information management. Very few building products have LCAs or ecolabels; while very few product manufacturers quantify embodied carbon, making it difficult to select low carbon materials and products.
- Lack of awareness. For example, modular construction systems have seen a slow uptake in South Africa. Many industry professionals are hesitant to use systems that are not conventional and that require additional work to ensure compliance with the National Building Regulations (RSA, 2008), although the NBR does allow for such alternative systems. There is also a hesitancy from the building user/owner perspective, as modular

systems are historically viewed as inferior. Further training and awareness is required to support a transition in the industry.

- Other barriers to the adoption and upscaling of circular economy opportunities in the construction and building sector include limited technical capacity in built environment professionals; insufficient technical training; and negative and inaccurate public perceptions (Gibberd *et al.*, 2025). There is a need for greater collaboration among stakeholders, and the development of new skills and knowledge.

2.1.3: What circular economy opportunities exist across the value chain?

Greenhouse gas emissions from the buildings and construction sector in South Africa are primarily due to the use of emissions-intensive materials such as cement and steel; suggesting significant opportunities for enhanced circularity to contribute to GHG mitigation.

Based on available literature (Dixit, 2017; Pomponi and Moncaster, 2017; Churkina et al., 2020; Habert et al., 2020a; Hoogzaad et al., 2021; GABC, 2021; IEA, 2023; Gibberd et al., 2025); circular economy interventions with the potentially to significantly reduce GHG emissions in the design and construction of buildings and infrastructure include:

- **Circular design:** Implementing circular design principles can significantly reduce GHG emissions particularly in the operational phase of buildings. These include:
  - Modular and prefabricated construction: Modular and prefabricated construction methods align with circular economy principles by allowing for the production of building components off-site in controlled environments (Hoogzaad et al., 2021). This approach reduces waste during construction, improves quality control, enhances the efficiency of the construction process, and facilitates re-use. Modular buildings can be easily disassembled and reconfigured, making them ideal for adaptable and reusable structures.
  - Designing buildings for adaptability, disassembly, and re-use allows for material recovery at end-of-life, mitigating future emissions (Pomponi & Moncaster, 2017).
  - Designing for Longevity and Adaptability: Buildings designed with longevity in mind are constructed to last, reducing the need for frequent repairs, renovations, or demolitions. This is achieved through the use of durable materials, high-quality craftsmanship, and thoughtful architectural design that anticipates future needs and uses. Adaptability in design allows buildings to be easily modified to suit changing requirements, thereby extending their useful life and reducing the demand for new construction. Challenges in this regard lie in selecting materials that are durable (typically brick and concrete) and materials that facilitate adaptability (typically lightweight and potentially less durable).
  - Designing buildings for improved energy efficiency (including passive design, which makes use of natural elements such as sunlight, ventilation and shading to maintain comfortable indoor temperatures and reduce reliance on heating and cooling systems). Energy-efficient designs, including passive solar heating, natural ventilation, and high-performance insulation, contribute to the sustainability and resilience of buildings.
  - Integration of renewable energy sources: The incorporation of renewable energy sources such as solar panels, wind turbines, and geothermal systems in building design

reduces the reliance on fossil fuels and decreases the carbon footprint of buildings during the operational phase.

- **Substitution with low-carbon materials:** Substitution of conventional materials used in building products with materials that are lower in embodied carbon, including recycled and bio-based materials. For example,
    - using alternative types of cement (e.g., geopolymers, blended cements with low clinker content) or recycled aggregates significantly reduces the carbon intensity of concrete, a major source of embodied emissions (Habert et al., 2020a).
    - Increasing recycled content in steel and aluminium used for structural elements cuts emissions by up to 70% (IEA, 2023).
    - Cross-laminated timber and other engineered timber products can also potentially replace more carbon-intensive materials such as steel and concrete, offering additional carbon storage benefits (Churkina et al., 2020).
    - The use of agricultural and forest residues to produce bio-based construction materials can also be considered (Hoogzaad et al., 2021).
- **Lightweighting and dematerialisation:** Dematerialisation in the context of the circular economy in buildings focuses on minimizing the use of physical materials during the design and construction phases. This approach not only reduces the environmental impact by conserving resources, but also enhances the efficiency and sustainability of buildings. By employing innovative design strategies, such as modular construction, lightweight materials, and digital fabrication techniques, architects and builders can create structures that require fewer raw materials. This reduction in material usage leads to lower carbon emissions, less waste, and a more sustainable lifecycle for the building. Ultimately, dematerialisation supports the broader goals of the circular economy by promoting resource efficiency, reducing environmental footprints, and fostering a more sustainable built environment.
- **Switching to lower carbon fuels in the production of construction materials:** In addition to substituting towards lower carbon materials, switching from the use of fossil fuels towards lower carbon fuels in the production of construction materials and products can also contribute towards reduced GHG emissions. For example, substituting coal with biomass in cement clinker production can decarbonise a highly carbon-intensive industrial process.
- **Recycling and re-use of construction and demolition waste (C&D waste):** Closed-loop systems aim to eliminate waste by ensuring that materials remain in use for as long as possible and are continually cycled back into the production process. This can be achieved through strategies such as material recovery and recycling, and the integration of urban mining practices to reclaim materials from existing structures. These systems not only reduce waste, but also create new economic opportunities by turning waste into valuable resources. The re-use and recycling of builders' rubble offers a sustainable pathway for reducing C&D waste, conserving natural resources, and lowering the environmental footprint of new construction materials. Intact elements such as bricks, concrete blocks, tiles, lintels, timber beams, and steel sections can often be directly re-used on site or in nearby projects after inspection and cleaning; which reduces the demand for virgin materials and retains the embodied energy of processed components (Tam and Tam, 2006; GABC, 2021). Where direct re-use is not feasible, builders' rubble – particularly concrete and masonry debris – can be crushed and processed into recycled aggregates. These are increasingly used in low- to moderate-strength concrete, road bases, backfill, and drainage layers (Poon et al., 2004).

Step 2.2: Select circular economy interventions and assess their potential impact to inform the NDC update

2.2.1: What is the GHG mitigation potential of interventions to inform the NDC update with targets and indicators?

The built environment includes building and civil engineering construction; as well as the spatial design, planning and operation of buildings throughout their lifetime. In the context of the built environment, environmental impacts are determined by the design, construction, and operation of human settlements. Globally, the built environment accounts for approximately 37% of global energy-related GHG emissions (IEA, 2023; UNEP, 2022). Building and civil engineering construction contributes approximately 40% of the built environment's total lifecycle GHG emissions, while operational emissions account for the remaining 60% (Wang et al., 2024).

GHG emission reductions in the operational phase of buildings are best achieved through practices such as passive design, renewable energy integration (in both retrofit and Greenfield developments), and smart building systems. For human settlements more broadly, operational emissions can also be addressed through urban planning strategies such as densification and transit-oriented development. These approaches reduce energy demand, improve land-use efficiency, and support low-carbon mobility.

However, as indicated in Section 1.1.3, this report focuses on **circular economy interventions within building construction and civil engineering construction**; as these sub-sectors were found to contribute significantly both to material use and GHG emissions, and therefore to hold potential for material circularity interventions to address both material use and emissions.

As per Section 1.1.3.2, current annual consumption-related material use and GHG emissions within these sub-sectors in South Africa (as per SCP-HAT (UNEP, 2024b)) are as follows:

- Building construction: 15.4 Mt material use, 10.95 $MtCO_2$-eq emissions
- Civil engineering construction: 15.2 Mt material use, 12.87 $MtCO_2$-eq) emissions.

Total annual consumption-related material use associated with construction in South Africa therefore amounts to 30.6 Mt, while consumption-related GHG emissions are 23.82 $MtCO_2$-eq across the two sub-sectors.

Cement (predominantly in concrete) contributes the highest share of embodied emissions in building and civil engineering construction, followed by steel (structural framing and reinforcement), aluminium, glass, and insulation materials (IEA, 2023; RMI, 2022). Cement makes up 10–15% by mass of concrete, but contributes 80–90% of its GHG emissions, due to the energy-intensive production process (Scrivener et al., 2018). Globally, cement contributes 7.7 $GtCO_2$-eq or 36% of the construction-phase emissions for buildings and civil engineering (Habert et al., 2020a). In typical mid-rise concrete-framed buildings, cement-related emissions contribute between 25–40% of total embodied CO_2-eq, depending on building type, material mix, and design choices (Pomponi and Moncaster, 2017; Röck et al., 2020; De Wolf et al., 2017. In particular, due to the energy intensity and associated carbon emissions from the use of limestone for clinker, it has been estimated that 70% to 90% of the theoretical decarbonisation of the cement industry can be achieved through clinker substitution (Scrivener et al., 2018) (Lowitt, 2020; Lehne and Preston, 2018).

The following **circular economy interventions with the potential for reducing emissions specifically in building construction and civil engineering construction** were identified in the literature:

- Substitution with low carbon materials:
  - *Ground granulated blast furnace slag to replace clinker in cement production.*
  - *Fly ash and bottom ash to replace clinker in cement production.*
  - *Cement made from calcined clay instead of limestone clinker.*
  - *Cement substitution with wood waste.*
  - *Plastic waste as a partial replacement for bitumen in asphalt.*
- Lightweighting and dematerialisation:
  - *Cement and concrete with intentionally introduced air voids*
- Switching to lower carbon fuels in the production of construction materials:
  - *Fuel switch to low-carbon fuels for cement production.*
- Recycling and reuse of C&D waste:
  - *Recycling and re-use of concrete and cement.*

The specific interventions within each of these categories are described in more detail below:

1. ***Ground granulated blast furnace slag to replace clinker in cement production***. Replacing 30% of clinker in cement with ground granulated blast furnace slag (GGBFS) can significantly reduce CO_2 emissions associated with cement production, as clinker accounts for up to 90% of the industry's carbon footprint (Scrivener et al., 2018; Schneider et al 2011). GGBFS, a by-product of the steel industry, contains reactive glassy phases that hydrate in the presence of calcium hydroxide to form calcium silicate hydrate (C-S-H), enhancing long-term strength and durability (Juenger et al., 2011). This substitution reduces the heat of hydration, improves sulphate and chloride resistance, and decreases permeability, which is critical for infrastructure exposed to aggressive environments (Thomas, 2007).
2. ***Fly ash and bottom ash to replace clinker in cement production***. Substituting up to 30% of clinker in cement with fly ash and bottom ash reduces CO_2 emissions through the use of by-products from coal combustion (Juenger et al., 2011; Schneider et al., 2011). Fly ash, particularly Class F, contributes pozzolanic reactivity by reacting with calcium hydroxide to form additional C-S-H, enhancing long-term strength and durability (Thomas, 2007). Bottom ash, while less reactive, can improve particle packing and reduce water demand if finely ground (Chen et al., 2009). However, the combined use of fly and bottom ash affects setting time, workability, and early strength development; requiring adjustments in curing regimes and activator content to ensure performance parity with conventional cements (Lee et al., 2015).
3. ***Cement made from calcined clay instead of limestone clinker***. Limestone Calcined Clay Cement (LC^3) replaces a significant portion of clinker with a blend of calcined clay and limestone, reducing CO_2 emissions by up to 40%, while maintaining comparable mechanical properties and durability (Scrivener et al., 2018). The reactivity of calcined clay in LC^3 can enhance strength and reduce the porosity of cement (Habert et al., 2020b). Optimal performance is achieved with approximately 30% calcined clay and 15% limestone, requiring minimal adaptation of conventional production processes and raw materials (Avet et al., 2016). The success of LC^3 depends on the kaolinite content in clay and precise control of calcination temperature, typically between 700–850°C (Habert et al., 2020b).
4. ***Cement substitution with wood waste***. Partial substitution of cement in CEM II formulations with wood waste (e.g. wood shavings and sawdust) presents a viable pathway for reducing

embodied carbon, while promoting circular use of lignocellulosic waste[5]. Wood content can vary; with up to 30% replacement of cement with wood waste maintaining acceptable mechanical properties (Berger et al 2020; Sotomayor-Castillo 2019). Cement composites incorporating wood waste are more lightweight and can maintain acceptable compressive strength for non-load-bearing applications, such as internal partition walls and acoustic panels (Sotomayor-Castillo, 2019). There are established wood-cement composites products; such as Wood Wool Cement Boards (WWCBs), which contain 30–50% wood and are widely used in ceilings due to their sound absorption and thermal insulation properties (Nazerian et al., 2015); as well as cement bonded particle board, containing 30% wood, and fibre-cement board containing 15% wood, which are used in flooring, partitions, dry-walling and siding (Wong et al., 2000; Gutiérrez, 2020). Due to the organic nature of wood, its inclusion in cement mixtures requires careful formulation to address potential issues such as reduced matrix alkalinity, slower setting times, and susceptibility to biological degradation. These challenges can be mitigated through pre-treatment of wood particles and the use of chemical admixtures to ensure stable and durable composite performance (Lowitt 2020, Leskinen et al., 2018).

5. ***Plastic waste as a partial replacement for bitumen in asphalt***. The incorporation of 3–6% plastic waste as a partial replacement for bitumen in asphalt mixtures has been shown to improve pavement performance, while reducing environmental impacts associated with both plastic disposal and bitumen use. Research by CSIR (2020) and the Asphalt Institute (2009) confirms that plastic-modified bitumen enhances resistance to rutting, fatigue, and moisture damage, particularly under high-temperature conditions. Plastics such as polyethylene (PE), polypropylene (PP) and polystyrene (PS) – either virgin or waste-derived – are typically shredded or pelletized before being blended into the hot mix asphalt, where they act as modifiers that stiffen the binder and improve elasticity. At substitution levels up to 6%, studies have reported no significant compromise in workability or adhesion, provided the plastic content is well-dispersed and compatible with the base binder (Asphalt Institute, 2009). Beyond this threshold, excessive stiffness may lead to brittleness and cracking under low

[5] There are also opportunities to use wood waste (wood offcuts and sawdust) in various engineered wood products for non-structural elements, such Orient Strand board, Laminated Veneer Lumber and Fibre-board; which are lower-carbon alternatives to conventional building materials, and can substitute some of the cement, concrete, steel and lumber structural materials used in conventional building construction. The use of engineered wood for structural applications (mass timber) using Cross Laminated Timber (CLT) and Glue laminated timber (Glulam) is also an option, but requires larger pieces of wood that are cross laminated.

This would contribute to lightweight, low-carbon design and reduced GHG emissions. For example, in mass timber buildings (e.g. CLT and glulam), embodied GHG emissions can be reduced by 30–60% compared to conventional reinforced concrete buildings (Peñaloza et al., 2016; Leskinen et al., 2018; Röck et al., 2020).

However, this opportunity is deemed infeasible in South Africa currently, as it is constrained by the supply of woody biomass feedstock. The current supply of wood from the forestry sector is used for timber and paper production, while the wood waste has application in wood-cement composites (e.g. particle board - see above); and is less suitable for engineered wood. In addition, there is little opportunity for additional afforestation in South Africa due to water constraints and water license requirements. Use of forestry biomass for engineered wood would therefore require a diversification away from paper and timber. Alternatively, Invasive Alien Plants (167 million tonnes dry woody biomass in SA) could provide 11.3 million tonnes per annum for 20 years (Bioenergy Atlas 2016). However, suitability, accessibility, cost and sustainability of supply are risks to the use of this resource.

temperatures. Moreover, using plastic in asphalt aligns with circular economy principles by diverting waste from landfills and reducing the reliance on bitumen.

6. ***Cement and concrete with intentionally introduced air voids*** – such as Autoclaved Aerated Concrete (AAC) – serve as lightweight, insulating materials suitable for non-load-bearing applications in building construction. AAC is produced by mixing cement, lime, sand, water, and an expansion agent (typically aluminium powder), which reacts with calcium hydroxide to release hydrogen gas. This gas forms a finely distributed pore structure that is stabilized during autoclaving at high pressure and temperature, creating a cellular matrix with a density of 400–800 kg/m³ (Narayanan and Ramamurthy, 2000). Due to its low density and thermal conductivity, AAC is well-suited for internal partitions, underfloor insulation, and other non-structural components. However, its lower compressive strength – typically in the range of 2–6 MPa – limits its use to non-load-bearing roles, unless supplemented by structural framing. The production of AAC contributes to reduced embodied energy per unit of thermal insulation compared to denser concrete, although the autoclaving process adds energy demand. Alternatives like non-autoclaved aerated concrete or foamed concrete are under development for further energy savings, although these often show lower strength and durability without the controlled curing provided by autoclaving (Kearsley and Wainwright, 2001).
7. ***Fuel switch to low-carbon fuels for cement production***. Substituting fossil fuels (coal) with biomass in cement clinker production can decarbonise a highly carbon-intensive industrial process. Biomass can replace 20–30% of fossil fuels in cement kilns without major retro-fits, and up to 100% with appropriate biomass pre-treatment or fuel upgrading through drying, size reduction, or densification (CEMBUREAU, 2020; Rahman et al., 2015). The use of biomass (or biogenic waste) is considered carbon-neutral at the source, due to the carbon dioxide emissions being captured in biomass regrowth (IPCC, 2014), and when carbon capture and storage has the potential to deliver net-negative emissions (Habert et al., 2020a; Lehne and Preston, 2018). The main techno-economic constraints include ensuring consistent biomass quality, managing feedstock logistics, maintaining kiln combustion stability, and being cost-competitive with current fossil fuels.
8. ***Recycling and re-use of concrete and cement****.* Recycled concrete aggregate, when properly graded and washed, can replace up to 30% of natural coarse aggregate in structural concrete without significantly affecting mechanical performance; and contributes to carbon savings, not only by reducing quarrying and transport of virgin aggregates, but also by reusing remnants of unhydrated cement particles that may still contribute to strength development (Kou and Poon, 2009). However, issues such as contamination (e.g. with gypsum, asphalt, or paint), inconsistency in material quality, and higher water demand due to porous surfaces require careful quality control, appropriate mix adjustments and adherence to building material performance standards, as per the National Building Regulations (RSA, 2008) and SANS 10400 (SABS, 2011a).

To estimate the potential GHG emission reductions associated with these interventions, we:

1. analysed production-consumption data from the SCP-HAT tool (UNEP 2024b); to establish the baseline emissions associated with current practices (based on the quantity of materials used and their carbon intensity); and then
2. estimated the reduction in emissions associated with the alternative scenarios, based on relevant South African life cycle emission factors, as per LCA databases (GLAD and Ecoinvent) and LCA literature.

Emission factors for different cement types in South Africa were based on Lowitt, 2020 (see Appendix 3).

For the interventions involving material substitution, constraints associated with the local availability of the alternative materials were also taken into account. The emission reductions were estimated as the difference between the current emissions using conventional building and construction materials, and those associated with the alternative materials.

The analysis and results are provided in Table 4.

Table 4: Analysis of greenhouse gas emission reductions associated with circular economy interventions in the building construction and civil engineering construction sub-sectors.

CE Intervention	**Business as usual practice**	**Current material use** (per annum)	**Current annual GHG emissions** (based on current material use and carbon intensity)	**Description of intervention**	**Material availability in SA**	**Potential reduction in GHG emissions** (per annum)	**Notes**
Ground granulated blast furnace slag to replace clinker in cement production	Ordinary Portland Cement (OPC / CEM I); consisting mainly of clinker (over 95%) and up to 5% minor additional constituents.	13 Mt of cement is produced annually in South Africa (Lowitt, 2020).	13Mt * 818 kgCO_2-eq/t cement = 10 634 ktCO_2-eq	Substitution of clinker in cement with 30% ground granulated blast furnace slag (Portland slag - CEM II-BS). Carbon intensity for CEM II-BS = 588 kg CO_2-eq/t.	30% substitution for 13 Mt of cement would require 3.9 Mt ground granulated furnace slag; however, blast furnace slag availability is limited to 612 kt (GLAD 2019).	Only 2040 kt cement (CEMII-BS) can be made with the 612 kt of slag available for 30% substitution. <u>CEM I:</u> 2040 * 818 kgCO_2-eq/t = 1668 ktCO_2-eq <u>CEM II-BS:</u> 612kt slag + 1428 CEM1 2040 * 588 kgCO_2-eq/t = 1200 ktCO_2-eq <u>Therefore emission reduction</u> = 1668 - 1200 = **468 ktCO_2-eq**	Ground granulated blast furnace slag is a by-product of refining iron ore in a blast furnace. Future supplies are limited, as blast furnaces are being replaced by arc furnaces (Lowittt, 2020).
Fly ash and bottom ash to replace clinker in cement production	OPC (CEM I)	13 Mt	13Mt * 818 kgCO_2-eq/t cement = 10 634 ktCO_2-eq	Substitution of clinker in cement with up to 30% fly and bottom ash (Portland fly ash cement - CEM II-BV). Carbon intensity for CEM II-BV = 572 kg CO_2-eq /t.	Requires 3.9 Mt fly/bottom ash. South Africa produces 40 Mt of ash per annum, with Eskom producing 31.5 Mt of fly ash and 3.5 Mt of bottom ash, and Sasol producing five Mt of gasification ash.	Sufficient ash to displace up to 30% of total cement production. <u>CEM I:</u> 13Mt * 818 kgCO_2-eq/t = 10 634 ktCO_2-eq <u>CEM II-BV:</u> 13Mt * 572 kg CO_2-eq/t = 7346 ktCO_2-eq. <u>Therefore emission reduction</u> = 10 634 – 7346 = **3198 ktCO_2-eq**	Theoretical availability of 40 Mt exceeds requirements for 30% substitution. However, some fly ash has existing use in Eskom water purification and recycling. Thus only ~19% (6Mt) of the 31.5 Mt fly ash produced by Eskom is available (Reynolds-Clausen and Singh, 2016). Nevertheless, this is still sufficient for 30% fly ash in cement, which requires 3.9Mt. However, coal ash resources will become limited in future as SA decarbonises and moves away from coal (IRP2).

CE Intervention	Business as usual practice	Current material use (per annum)	Current annual GHG emissions (based on current material use and carbon intensity)	Description of intervention	Material availability in SA	Potential reduction in GHG emissions (per annum)	Notes
Cement made from calcined clay instead of limestone clinker	OPC (CEM I)	13 Mt	13Mt * 818 kgCO_2-eq/t cement = 10 634 ktCO_2-eq	Limestone Calcined Clay Cement (LC3) made from calcined clay instead of clinker, with up to 50% clinker substitution in cement. Carbon intensity for LC3 = 668 kgCO_2-eq/t (Dumani and Mapiravana, 2024).	Adequate supply of clay in South Africa, but not evenly distributed or a renewable resource.	CEM I: 13Mt * 818 kgCO_2-eq/t =10 634 ktCO_2-eq LC3: 13Mt * 668 kgCO_2-eq/t = 8684 ktCO_2-eq Therefore emission reduction = 10 634 – 8684 = **1950 ktCO_2-eq**	Producing LC3 instead of CEM I would reduce the GHG emissions associated with cement production by 18%
Cement substitution with wood waste	OPC (CEM I)	13 Mt; of which ~ 20% (2.6 Mt) is for non-load bearing applications	2.6Mt * 818 kgCO_2-eq/t = 2126 ktCO_2-eq	CEM II Cement substitution with 30% wood shavings or sawdust in non-loadbearing applications (combining wood waste with cement to produce 2.6 Mt of wood-cement composite). Wood-cement composite products include WWCBs, Fibre cement board and Cement-Bonded Particle Board. Carbon intensity for wood waste = 119 kgCO_2-eq/t (Ecoinvent, 2024).	30% substitution would require 0.8 Mt wood waste. South Africa produces 5.4 Mt of sawlogs annually, predominantly from pine plantations, and generates approximately 1 Mt wood waste (sawdust, shavings and offcuts).	CEM-I: 2.6 Mt * 818 kgCO_2-eq/t = 2126 ktCO_2 CEM-II with 30% wood-waste: 1.8 * 818 kgCO_2-eq/t + 0.8 * 119kg CO_2-eq/t = 1427 ktCO_2-eq Therefore emission reduction = 2126 - 1427= **699 ktCO_2-eq**	On average, 6% of round-wood processed becomes sawdust, and 14% becomes other wood waste (off-cuts). Total wood waste can therefore be calculated as 5.4 Mt * 6% = 324 kt sawdust + 5.4 Mt × 14% = 756 kt other wood waste = 1 Mt total. There are competing uses for wood shavings and sawdust in energy and other applications. Additional biomass resources may come from Invasive Alien Plants (IAPs), but this is more suited for fuel in cement production (see below).

CE Intervention	**Business as usual practice**	**Current material use** (per annum)	**Current annual GHG emissions** (based on current material use and carbon intensity)	**Description of intervention**	**Material availability in SA**	**Potential reduction in GHG emissions** (per annum)	**Notes**
Plastic waste as a partial replacement for bitumen in asphalt	Bitumen in asphalt roads	Bitumen at 4-6% of asphalt mix, as a binding agent for the aggregates	320 kt bitumen used in SA annually (CSIR 2020); with a carbon intensity of 233 kgCO_2-eq/t bitumen (Maseko, 2020) = 58 ktCO_2-eq.	Plastic (PE and PP) can replace 3-6% of bitumen (CSIR, 2020; Asphalt Institute, 2009). Assuming 6% replacement of the 320 kt bitumen used annually, 19 kt of plastic would be required.	Plastic consumption = 1984 kt per year (of which PE and PP account for 37% and 22% respectively (Plastics SA, 2023)), and only 369 kt is recycled. There is therefore sufficient PE and PP material to substitute 6% bitumen in asphalt.	Assuming that 19 kt of bitumen is replaced by plastic waste, which is assumed to be "burden-free" in terms of emissions, the emission reduction can be calculated as: 0.019Mt * 233 kgCO_2-eq/t = **4 ktCO_2-eq**	
Cement and concrete with intentionally introduced air voids	OPC (CEM I)	13 Mt; of which ~ 20% (2.6 Mt) is for non-load bearing applications	2.6Mt * 818 kgCO_2-eq/t = 2126 ktCO_2-eq	Lightweight (aerated) cement. Cement and concrete with air bubbles (aerated, such as in Autoclaved Aerated Concrete (AAC)) can be used in non-load bearing parts of building (internal wall, underfloor). Using AAC can reduce cement consumption by 50–70% per m³ compared to conventional concrete blocks or cast-in-place walls, due to its lower density and aerated matrix (Narayanan and Ramamurthy, 2000; Karthikeyan et al., 2023).		<u>CEM I:</u> 2.6 Mt * 818 kgCO_2-eq/t = 2127 ktCO_2-eq <u>AAC</u> (assuming a 50% reduction in cement consumption for non-loadbearing applications): 2.6Mt * 0.5 * 818 kgCO_2-eq/t =1063 KtCO_2-eq <u>Therefore emission reduction</u> = 2127 – 1063 = **1064 ktCO_2-eq**	

CE Intervention	Business as usual practice	Current material use (per annum)	Current annual GHG emissions (based on current material use and carbon intensity)	Description of intervention	Material availability in SA	Potential reduction in GHG emissions (per annum)	Notes
Fuel switch to low-carbon fuels for cement production	Fossil fuels used in clinker production for cement	13 Mt of cement produced annually in South Africa. ~ 3 GJ fuel needed per tonne of cement = 39 PJ for the 13 Mt of cement.	Approximately 30% of emissions from clinker production arise from fuel used in the clinker production process. 13Mt * 818 kgCO_2-eq/t * 0.3 = 3190 ktCO_2-eq from fuel use.	Substitute fossil fuel used in clinker production (coal) with low-carbon, renewable fuels.	Achieving 3190 ktCO_2-eq reduction with 39 PJ of low-carbon renewable fuels requires approximately 2 Mt of biomass annually (oven dry biomass with lower heating value of 19 GJ/t), which could be supplied from forestry residues and/or Invasive Alien Plant stock. An estimated 11.3 Mt of IAP stock is available per annum for 20 years (Hugo, 2016).	Assuming 100% substitution of fossil fuels with IAP stock, which is available "burden free", the emission reduction can be calculated based on the current 30% of emissions in clinker production which arise from fuel use: 13Mt * 818 kgCO_2-eq/t * 0.3 = **3190 ktCO_2-eq**.	Use of IAPs for energy may complete with other uses (particle board, engineered wood etc). However, there are large resources (167 Mt dry woody biomass in SA) which must be used/depleted; while these resources also consist of mixed species and ages, which are less suitable for products (particle board, engineered wood etc), and are therefore potentially available for bioenergy.
Recycling and re-use of concrete and cement	Disposal of builders' rubble (C&D waste) and use of virgin materials in new buildings	13 Mt of cement produced annually in South Africa	13Mt * 818 kgCO_2-eq/t cement = 10 634 ktCO_2-eq	Re-use of C&D waste and recycling of cement rubble for aggregate in cement and concrete. This scenario considers only the cement and concrete components of buildings.	C&D waste estimated at 10.8 - 20.2 Mt per year (Berge and von Blottnitz, 2022). Only 56% of builders' rubble can be re-used / recycled according to best practice. Further, the cement and concrete component of rubble constitutes 38%. (DEADP, 2018). Therefore assuming 10 Mt generated per year: 10 * 0.38 * 0.56 = 2128 kt available.	Current: 13Mt * 818 kgCO_2-eq/t cement = 10 634 ktCO_2-eq Re-using 2128 kt of rubble: (13Mt - 2.1Mt) * 818 kgCO_2-eq/t = 8893 ktCO_2-eq Therefore emission reduction = 10634 – 8893 = **1740 ktCO_2-eq**	The reported estimate of 4.48 Mt C&D waste (DEA, 2018) is likely to be a significant underestimate, as it is based primarily on recorded landfill data and excludes informal or unreported disposal. However, C&D waste is also used as landfill cover and so not all builders' rubble is available and recoverable. Increasing design for re-use and modularity of building materials can increase the amount available for future re-use.

The results are summarised in Table 5, which ranks the interventions in terms of the potential reduction in annual GHG emissions, as a % of current total emissions in the building construction and civil engineering construction sub-sectors (23.8 MtCO_2-eq).

Two interventions, namely **substituting clinker with fly ash and bottom ash** and **switching to lower carbon fuels**, can be seen as providing the highest potential emission reductions; with **each reducing emissions by approximately 3.2 Mt, or 13.4% of total emissions in the building and civil engineering construction sub-sectors.** These are followed by replacing clinker with calcined clay and limestone (1 950 ktCO_2-eq, or 8.2% of current emissions from construction), and recycling and re-use of concrete and cement (1 740 ktCO_2-eq (7.3%)).

If implemented in combination, the eight circular economy interventions could reduce GHG emissions by 12.3 MtCO_2-eq, or 52% of current emissions in the building and civil engineering construction sub-sectors.

Table 5 also indicates the potential reduction in virgin raw material use. When implemented together, the eight circular economy interventions can reduce virgin raw material use by 10.9 Mt, equivalent to 35% of total material use in the building and civil engineering construction sub-sectors (30.6 Mt).

Table 5: Summary of potential greenhouse emission reductions associated with eight circular economy interventions, ranked as a % of current emissions in the building construction and civil engineering construction sub-sectors.

Intervention	Reduction in virgin raw material use (kt)	Reduction in GHG emissions (ktCO_2-eq)	Emission reduction as a % of current GHG emissions in the building and civil engineering construction sub-sectors[1]
Fly ash and bottom ash to replace clinker in cement production	3 900	3 198	13.42
Fuel switch to low-carbon fuels for cement production	2 050[2]	3 190	13.39
Cement made from calcined clay instead of limestone clinker	0[3]	1 950	8.19
Recycling and re-use of concrete and cement	2 128	1 740	7.30
Cement and concrete with intentionally introduced air voids	1 300	1 064	4.47
Cement substitution with wood waste	800	699	2.93
Ground granulated blast furnace slag to replace clinker in cement production.	612	468	1.96
Plastic waste as a partial replacement for bitumen in asphalt	19	4	0.01
Total	**10 809**	**12 313**	**51.69**

[1] GHG emission reductions associated with each intervention as a percentage of current total annual emissions in the building construction and civil engineering construction sub-sectors of 23.822 MtCO_2-eq (as calculated in this study using SCP-HAT (UNEP, 2024b)).
[2] The cement industry requires 39 PJ of fuel per annum, and can potentially switch from coal (2.05 Mt, based on coal's heating value of 19GJ/t) to renewable biomass (2.59 Mt wood waste, based on wood's heating value of 15GJ/t at 20% moisture).
[3] No reduction in materials, since clay is partly used instead of limestone for clinker in cement production. Calcined clay is more readily available, and its calcination is less energy intensive and carbon emitting, compared to calcined limestone.

Figure 18 shows the current total GHG emissions for the building construction and civil engineering construction sub-sectors (23.8 MtCO_2-eq, shown as "Initial"); and how implementing the eight circular economy interventions can reduce GHG emissions by 12.3 MtCO_2-eq (52% of current emissions).

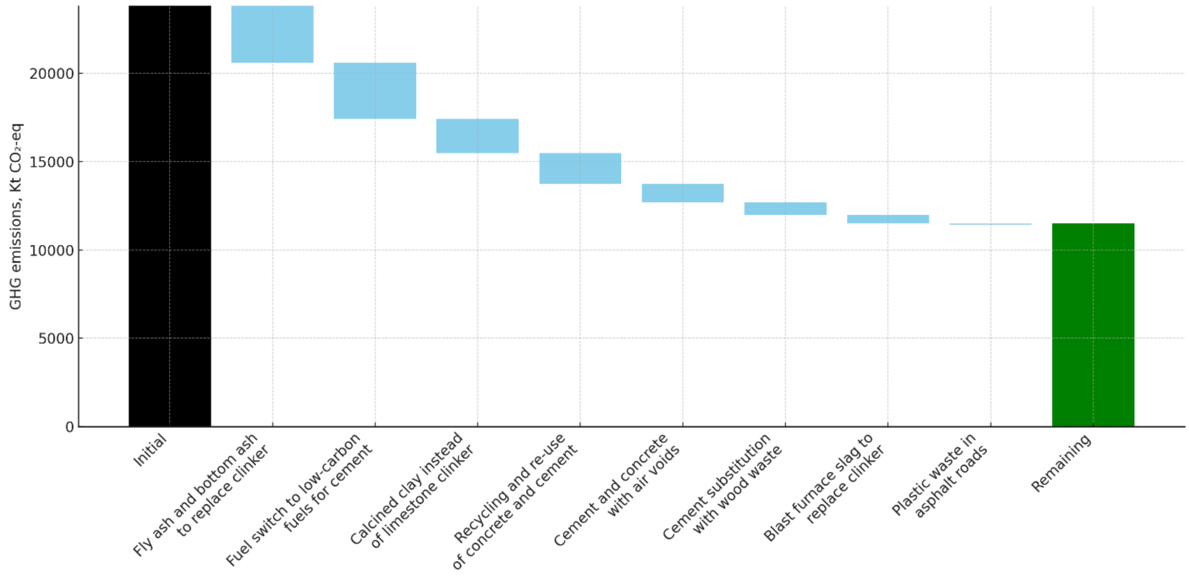


Figure 18: Potential reduction in greenhouse gas emissions in the building construction and civil engineering construction sub-sectors associated with implementing eight circular economy interventions.

2.2.2: What are the potential socio-economic impacts of the interventions? How to assess job creation based on the identified interventions?

In addition to quantifying potential GHG emission reductions associated with the identified circular economy interventions, Step 2.2 of the Toolbox also requires an assessment of the potential socio-economic impacts, including potential impacts on job creation.

Effectively addressing climate change is not only about mitigation, but also strengthening adaptation measures to improve resilience to climate risks, with a particular focus on vulnerable groups such as rural communities, the poor, women, children, and the disabled. It is therefore important to align mitigation measures with adaptation strategies, and with broader economic and social imperatives.

Furthermore, when considering socio-economic impacts, job creation (in term of quantity) is just one element. For example, aspects around decent work (quality and longevity of jobs, origin of the workforce, working conditions etc.) should also be considered. In addition, circular economy interventions could potentially have broader socio-economic impacts, such as revitalising local economies and fostering overall economic growth.

In the South African context, addressing the housing backlog, managing rapid urbanisation, and curbing urban sprawl are urgent priorities. Equitable access to employment, education, and public services is constrained by spatial fragmentation and infrastructure deficits. The development of Smart Cities or '15 minute neighbourhoods' (Gibberd et al., 2025) offers a pathway to simultaneously improve service delivery, reduce emissions, and enhance resource efficiency. By integrating digital infrastructure, data-driven urban planning, and efficient mobility and energy systems, Smart Cities can support compact, connected, and low-carbon urban growth; enabling both climate resilience and inclusive development. For South Africa, adapting Smart City principles within its socio-economic and spatial realities could offer transformative solutions to address urban sprawl, service delivery deficits, and the need for equitable, climate-resilient development.

In South Africa, the urgent need for housing is being addressed though low-income housing programmes such as social housing and the Reconstruction and Development Programme (RDP). By integrating the circularity interventions discussed in Section 2.2.1 into these programmes, it is possible to reduce the material use and GHG emissions associated with construction, while delivering socio-economic benefits in terms of fulfilling basic needs to poorer members of society. Additionally, optimising building performance through passive design strategies and embedding social housing and RDP housing developments within compact, mixed-use, and transit-accessible urban areas lowers operational emissions, while also supporting equitable access to work opportunities and public services. Integrating both Smart City and circular economy principles into the design and construction of human settlements will contribute to significant reductions in lifetime emissions per person associated with housing, while advancing the goals of inclusive and climate-resilient urban development.

The NDC Toolbox lists a number of tools that can be used for assessing potential socio-economic impacts (including job creation) associated with circular economy interventions:

- Life cycle inventory databases
- The SDG Climate Action Nexus (SCAN) tool
- Green jobs assessment model
- Circular economy jobs tool

Life Cycle Inventory Databases predominately contain environmental LCA data. Complementary LCA tools such as Social LCA (S-LCA) and Life Cycle Costing (LCC)[6] have been developed for assessing socio-economic impacts associated with products and materials. However, it was beyond the scope of this study to conduct S-LCA or LCC assessments for the specific interventions identified in Section 2.2.1; given the lack of existing data relating to socio-economic impacts for these interventions in life cycle inventory databases. However, the following relevant information can be drawn from existing studies:

- Akintayo et al. (2024) conducted an LCA of Portland Cement production in South Africa. Impacts on human health (in terms of Disability-Adjusted Life Years, DALYs) were quantified at approximately 55,404 lives potentially endangered due to damage associated with annual cement production requirements in South Africa. Substances contributing to the human health damage category include CO_2 (56%), Sulphur dioxide (SO_2) (18%), Nitrogen oxides (NOx) (10%), fine particulate matter (PM2.5) (5%), arsenic (2%), ammonia (NH_3) (1%), and others (8%). As such, substituting toward the use of alternative materials in cement production could potentially reduce some of these impacts.
- Blaauw et al. (2020 and 2021) have found that bitumen used in asphalt is one of the most environmentally and socially burdensome materials used for pavement development. Emissions from pavement infrastructure development which predominantly affect human health include SO_2, NOx, PM and Volatile Organic Compounds (VOCs). As such, switching toward alternative materials to bitumen could result in improved environmental and human health outcomes.

[6] LCC is a method used to assess the total cost of ownership of a product, asset, or system over its entire life cycle, from acquisition to disposal. S-LCA is a method to assess the actual and potential positive and negative social impacts of products along their life cycle. S-LCA makes use of generic and site-specific data and can be quantitative, semi-quantitative or qualitative. It can either be applied on its own or in combination with other techniques. As an S-LCA is a broader analysis that considers the social impacts across a product's life cycle, it differs from a social risk assessment, which is more targeted to a specific project or situation.

The SDG Climate Action Nexus tool (SCAN-tool) is designed to provide high-level guidance on how climate actions can impact achievement of the Sustainable Development Goals (SDGs). The tool is high level in nature, making it difficult to apply to the specific CE interventions identified in Section 2.2.1. However, the following broad linkages can be made between the types of interventions considered in this report and specific SDG targets related to socio-economic development:

- **SDG 8 (Decent work and economic growth):**
  - Switching away from fossil fuels can reduce unsafe jobs associated with mining (e.g. for coal) (Target 8.8: Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment).
  - Creating demand for lower carbon construction methods and building products can contribute to:
    - Target 8.2 (higher levels of economic productivity through diversification, technological upgrading and innovation)
    - Target 8.5 (full and productive employment and decent work for all women and men).
- **SDG 9 (Industry, Innovation and Infrastructure):** Creating demand for lower carbon construction methods and building products can:
  - support sustainable industrialisation (Target 9.2: Promote inclusive and sustainable industrialization)
  - support R&D, innovation and upgrading of industrial capabilities (Target 9.5: Enhance scientific research, upgrade the technological capabilities of industrial sectors, and encourage innovation).
- **SDG 11 (Sustainable Cities and Communities):** The circular economy interventions identified in this report for building construction; as well as broader application of circular economy principles (including Smart Cities / 15 minute neighbourhoods) within human settlements, can contribute to a number of Targets under SDG 11, which focuses on making cities and human settlements inclusive, safe, resilient and sustainable.
- **SDG 13 (Climate Action):** A number of the circular economy interventions identified in Section 2.2.1 for reducing GHG emissions, can also help strengthen resilience and adaptive capacity to climate-related hazards and natural disasters (Target 13.1). These mitigation measures can therefore be seen as providing **co-benefits for adaptation**. For example:
  - Calcined clay and fly ash can reduce water demand in concrete and reduce drying shrinkage, making structures more resilient to drought-induced cracking (Habert et al., 2020a; Antoni et al., 2012).
  - Blended cements, particularly those with slag or fly ash, improve thermal stability of concrete under high ambient temperatures or wildfires (Siddique, 2011; Antoni et al., 2012).
  - Aerated autoclaved concrete is non-combustible and withstands high temperatures (Ahmed and Kamua, 2017). This can protect the building shell from being burnt down in wildfire-prone or extreme heat environments.
  - A switch to carbon neutral feedstocks in cement production using local resources reduces exposure to fossil supply disruptions (IEA, 2019; IRENA, 2021).
  - Recycling local C&D waste reduces reliance on imported materials, the supply of which can be vulnerable to climate disruptions and extreme weather events (Tam et al., 2009; UNEP, 2023).

- Some recycled aggregates in concrete can enhance fire resistance and thermal mass (Kadir et al., 2016; Medina et al., 2012).
- Bricks with recycled aggregates often have lighter colours and higher albedo, reflecting solar radiation and lowering localized heat (C40 Cities, 2022; Siddique, 2011).

The Green Jobs Assessment Model (GJAM) is a macro-economic modelling framework based on Input-Output Tables or a Social Accounting Matrix (SAM) to assess and guide policy making. Alternative policy scenarios can be modelled to compare effects on jobs, skills, gender, growth, income distribution, household groups and other job characteristics of interest. It was developed to provide a methodology which countries can use to answer multi-dimensional policy questions related to multiple social, economic and environmental goals. The model is well suited to informing climate policies and NDCs.

However, the GJAM is not a prepackaged model which is readily available for "plug and play" use. The GJAM modelling framework must be adapted to the country's needs and policy questions, and users must be guided through the process (2-3 years) by the Green Jobs Assessment Institutions Network (GAIN). Following this process, a GJAM can be built for ownership and use by the specific country.

Finally, the **Circular Jobs methodology** was developed by Circle Economy and UNEP with the aim of assessing employment related to circular economy. It combines the Key Element Framework created by Circle Economy and the Spatial Microsimulation Urban Metabolism model developed by UNEP. The methodology processes employment, economic and environmental data. The results of the methodology are displayed on the Circular Jobs Monitor (CJM), a digital tool that maps the number and range of jobs that drive circular strategies in different geographies. The Circular Jobs methodology provides the framework to assess circular jobs at a national or sectoral level, or for a specific economic activity.

Potential socio-economic impacts associated with the circular economy interventions identified in Section 2.2.1 are summarised in Table 6. The interventions are listed in order of the magnitude of potential GHG emission reductions, as per Table 5.

Table 6: Potential socio-economic impacts associated with the circular economy interventions identified for reducing greenhouse gas emissions in the building construction and civil engineering construction sub-sectors.

CE intervention	Potential socio-economic impacts
Fly ash and bottom ash to replace clinker in cement production	Diverts waste from landfill; supports industrial symbiosis; creates jobs in waste management and beneficiation (ash handling and processing); lowers cement input costs.
Fuel switch to low-carbon fuels for cement production	Enables local fuel diversification using waste-derived fuels; creates waste fuel supply chains; reduces GHG liabilities and air pollutant health burdens; aligns with Just Energy Transition objectives.
Cement made from calcined clay instead of clinker	Reduces dependence on limestone; utilises abundant clays; creates mining and clay processing jobs; avoids high energy clinker production costs.
Recycling and re-use of concrete and cement	Reduces virgin aggregate extraction; lowers demolition waste disposal costs; boosts the local recycling sector; creates green jobs in collecting and sorting of C&D waste.
Cement and concrete with intentionally introduced air voids	Reduces total cement use and transport loads; avoids raw material extraction and emissions; minor capital shift towards design and R&D jobs for lightweight formulations.
Cement substitution with wood waste	Creates rural forestry jobs; supports biomass valorisation; enables engineered wood product manufacturing; diverts organic waste from landfills.
Ground granulated blast furnace slag to replace clinker in cement production	Diverts slag waste from landfill; enhances durability; enables steel sector waste valorisation; creates local processing jobs in cement blending near steel hubs.
Plastic waste as a partial replacement for bitumen in asphalt	Diverts plastic waste from landfill; reduces bitumen demand and import costs; reduces environmental and human health impacts associated with bitumen; supports polymer processing jobs; avoids plastic waste treatment costs; reduces public costs of waste collection and treatment (landfill); creates green jobs in collecting and sorting plastic waste.

Conclusions and next steps

This study made a first attempt at applying the UN's Toolbox for Building Circularity into National Determined Contributions (UNEP et al., 2023a) in the South African context. The current scope of work was confined to piloting Stage 1 (Steps 1.1 to 1.3) and Stage 2 (Steps 2.1 and 2.2) of the Toolbox only. It is proposed that a future phase of work should focus on the remaining stages within the Toolbox (from Step 2.3 onwards).

The aim of the study was to identify opportunities for reducing greenhouse gas emissions through circular economy interventions; and thereby to inform future updates of South Africa's NDCs.

South Africa's GHG emissions in 2022 were estimated at 435.12 MtCO_2-eq (DFFE, 2024). A full value chain analysis of South Africa's production and consumption footprints identifies five major value chains with significant contributions to both GHG emissions and material use:

- *Agriculture – Nutrition*
- *Coal, oil and gas mining – Electricity, gas and water*
- *Ore mining – Fabricated metals*
- *Construction material quarrying – Construction*
- *Transport equipment – Transport*

However, in the *agriculture – nutrition* value chain; as well as the *coal, oil and gas mining – electricity, gas and water* value chain; emissions are primarily associated with biological processes, land use, energy inputs, and fuel combustion. This suggests that these emissions are largely not materially driven, providing limited scope for material circularity strategies. Similarly, emissions in the *transport equipment – transport value* chain are largely energy-related, with the greatest mitigation potential lying in fuel switching and modal shifts, rather than through material circularity interventions.

By contrast, in the *ore mining – fabricated metals* and *construction material quarrying – construction* value chains, GHG emissions are strongly linked to material intensity. Circular economy interventions within these value chains can therefore reduce both material throughput and the associated GHG emissions.

As such, this study finds that **the greatest opportunities for material circularity to contribute towards reducing greenhouse gas emissions are likely to lie in the mining-fabricated metals and quarrying-construction value chains**.

Based on a more detailed analysis of hotspots of raw material use and GHG emissions within these two value chains, the **building construction and civil engineering construction sub-sectors were identified as priority sub-sectors for circular economy interventions to reduce GHG emissions**.

Cement, particularly in concrete, constitutes the highest share of embodied emissions among the materials used in construction (IEA, 2023; RMI, 2022). In typical mid-rise concrete-framed buildings, cement-related emissions contribute between 25–40% of total embodied CO_2-eq, depending on building type, material mix, and design choices (Pomponi and Moncaster, 2017; Röck et al., 2020; De Wolf et al., 2017. Due to the energy intensity and associated carbon emissions from the use of limestone for clinker, it has been estimated that 70% to 90% of the theoretical decarbonisation of the cement industry can be achieved through clinker substitution (Scrivener et al., 2018) (Lowitt, 2020; Lehne and Preston, 2018).

Eight circular economy interventions with the potential for reducing emissions in building construction and civil engineering construction were identified in the literature. Potential GHG emission reductions associated with these interventions were estimated as follows (listed in order of the magnitude of the potential reductions):

- **Replacing clinker in cement production with up to 30% fly and bottom ash** (CEMII-BV) results in a GHG emission reduction of 3 198 ktCO_2-eq, equivalent to 13.42% of total emissions from the building construction and civil engineering construction sub-sectors.
- **Fuel switching to low-carbon alternatives in cement production** yields a GHG emission reduction of 3 190 ktCO_2-eq (13.39%).
- **Replacing clinker with calcined clay and limestone** (LC^3) results in a reduction of 1 950 ktCO_2-eq (8.19%).
- **Recycling and re-use of concrete and cement** accounts for a GHG emission reduction of 1 740 ktCO_2-eq (7.30%).
- **The use of lightweight (aerated) cement** reduces emissions by 1 064 ktCO_2-eq (4.47%).
- **Cement with 30% wood shavings or sawdust** achieves a GHG emission reduction of 699 ktCO_2-eq (2.93%).
- **Cement with 30% ground granulated blast furnace slag** (CEMIII-BS) is constrained by the availability of blast furnace slag, but based on the current availability of material, GHG emission reductions of 468 kt CO_2-eq (1.96%) are possible.
- **Bitumen substitution with plastic in asphalt roads** provides a negligible GHG emission reduction of 4 ktCO_2-eq (0.01%). This intervention is not constrained by the availability of plastic waste; but rather by the amount of asphalt used in roads, as well as the current 6% blending limit of plastic with bitumen so as to maintain the performance requirements of asphalt (CSIR, 2020).

Two interventions, namely **substituting clinker with fly ash and bottom ash** and **switching to lower carbon fuels**, can be seen as providing the highest potential emission reductions; with **each reducing emissions by approximately 3.2 Mt, or 13.4% of total emissions in the building and civil engineering construction sub-sectors.** These are followed by replacing clinker with calcined clay and limestone (1 950 ktCO_2-eq (8.2%)), and recycling and re-use of concrete and cement (1 740 ktCO_2-eq (7.3%)).

If implemented in combination, the eight circular economy interventions could reduce GHG emissions by 12.3 MtCO_2-eq, or 52% of current emissions in the building and civil engineering construction sub-sectors; while also reducing virgin raw material use by 10.9 Mt.

These mitigation potentials can be used to inform sectoral GHG emission reduction targets in future updates of the NDCs. South Africa's current NDC does not establish binding sector-specific emission reduction targets. However, such targets are expected to be introduced in future through the recent Climate Change Act (RSA, 2024), which aims to strengthen co-ordination between national sector departments for policy setting and decision-making to enable South Africa to meet its NDCs. The Climate Change Act mandates the Minister of Forestry, Fisheries and the Environment to identify activities causing GHG emissions, with the assignment of carbon budgets or Sectoral Emissions Targets (SETs) to align with national climate goals (Colegrave, 2024). The Act therefore introduces a legal mechanism for setting SETs, and offers an opportunity to incorporate the circular economy interventions identified in this report into the national climate policy framework. Given that the current NDC (RSA, 2021) does not include specific measures relating to the building construction / civil engineering construction sub-sectors; there is an opportunity for the identified circular economy interventions to be incorporated in future updates.

Beyond emissions reduction, these interventions also offer potential socio-economic benefits; including waste diversion, cost savings, and job creation in sectors such as ash beneficiation, clay processing, and construction waste recycling. They also provide potential adaptation co-benefits, by increasing the resilience and adaptive capacity of buildings and infrastructure to climate-related hazards and natural disasters. Integrating these interventions into future NDC updates can therefore strengthen national climate ambition, while delivering socio-economic and adaptation co-benefits.

However, achieving net-zero emissions by 2050 in the building construction and civil engineering construction sub-sectors will require a comprehensive mix of interventions, beyond those assessed in this report. The remaining GHG emission reductions (11.5 Mt CO_2-eq) that will be needed to reach net-zero carbon emissions are those that persist after implementing currently available circular economy interventions; and represent the shortfall in achieving full decarbonisation of the building construction and civil engineering sub-sectors. Closing this gap to reach net zero may require additional substitution of current materials to lower carbon alternatives, such as the use of novel low-carbon aggregates, engineered wood and bio-based composites; and the switch to low-carbon renewable energy for all parts of the quarrying-construction value chain. For processes inherently difficult to abate, such as those arising from limestone calcination in cement production, the application of carbon capture and storage (CCS) or carbon capture and utilisation (CCU) may be required[7].

Nevertheless, this report demonstrates how material circularity interventions can significantly reduce GHG emissions in the building construction and civil engineering sub-sectors. Using waste materials in construction (such as fly ash, slag, wood waste, and recycled aggregates) can effectively decouple economic output from both GHG emissions and raw material use. By substituting conventional, carbon-intensive virgin materials with lower-emission materials or secondary resources, the construction sector can maintain productivity, while reducing GHG emissions and resource depletion. This resource and impact decoupling demonstrates that a shift towards a resource-efficient, low-carbon and circular economy is possible.

The feasibility of achieving these emission reductions in practice depends on local material availability, availability of infrastructure for recycling and processing, and alignment with building codes and standards. In the case of interventions involving material substitution, many of the substitute materials are by-products from other industrial processes, which can potentially replace both structural and non-structural cement-based components, according to their suitability and compliance with National building standards (RSA, 2008 and SANS 10400).

Furthermore, to prioritise investment in these interventions, an understanding of both technical mitigation potential and of the associated costs is required, particularly where the substitution of conventional materials involves additional costs for collection, processing, and logistics for alternative material inputs.

Future research should therefore focus on assessing the techno-economic feasibility and cost-effectiveness of each of the interventions, taking into account costs as well as the actual local availability of the required materials; in order to derive marginal abatement cost (MAC) curves that can inform least-cost decarbonisation pathways and climate investment decisions in the construction sector. The use of waste materials such as fly ash, slag, or wood residues may result in low or even negative abatement costs, as they displace virgin materials and reduce the need for waste disposal and treatment. However, the use of wastes and bio-materials in buildings must ensure that building standards are met, and that concerns regarding product durability can be addressed (Gibberd et al., 2025).

Finally, the socio-economic impacts associated with the interventions should also be assessed in more detail. These and other issues could be addressed in a future phase of work aimed at applying the remaining stages of the NDC Toolbox; which should include engagement with DFFE and other stakeholders to validate the selection of interventions to be considered for implementation in future updates of the NDCs.

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[7] CCS involves capturing CO_2 at the point of emission (e.g. cement kilns), compressing it and permanently storing it in geological formations such as saline aquifers or depleted oil and gas reservoirs. CCU, captures CO_2 and converts it into usable products such as synthetic aggregates, polymers, or fuels.

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Appendix 1: Greenhouse gas emissions per sector

Table 7: Average of GHG emissions from fuel combustion for the period 2000 to 2018, based on DFFE (2022) and DMRE (2023).

Sector/sub-sector	**GHG emissions in $MtCO_2$-eq**	**Share of emissions %**
Energy	272.0	71%
Energy Industries	252.6	66%
Non-specified stationary (Military and public sector)	19.3	5%
Manufacturing	27.9	7%
Manufacturing industries fuel combustion	27.9	7%
Mining	3.4	1%
Fuel combustion in mining	3.4	1%
Human Settlements	24.5	6%
Fuel combustion in construction	0.8	0%
Fuel combustion in the commercial and institutional sub-sectors	11.9	3%
Fuel combustion in the residential sub-sector	11.8	3%
Agriculture	3.7	1%
Fuel combustion in Agriculture, Forestry Fishing and Fish Farms	3.7	1%
Mobility	50.3	13%
Fuel combustion in domestic aviation	1.6	0%
Fuel combustion in road transportation	47.7	12%
Fuel combustion in railways	0.6	0%
Fuel combustion in domestic water-borne navigation	0.4	0%
Total	381.9	

Table 8: Average of GHG emissions from non-combustion activities for the period 2000 to 2018, based on DFFE (2022).

Sector/sub-sector	**GHG emissions in $MtCO_2$-eq**	Share of emissions %
Energy	31.7	24.1%
Fugitive emissions from all oil and natural gas activities	0.9	0.7%
Fugitive emissions from synfuels and gas-to-liquids/chemicals processes	28.1	21.4%
Fugitive emissions from coal mining	2.7	2.0%
Manufacturing	36.6	27.8%
Cement Production	4.8	3.6%
Lime Production	0.7	0.6%
Glass Production	0.1	0.1%
Other Process Uses of Carbonates	0.1	0.1%
Ammonia Production	0.4	0.3%
Nitric Acid Production	0.9	0.7%
Carbide Production	0.0	0.0%
Titanium Dioxide Production	0.3	0.2%
Soda Ash Production	0.0	0.0%
Petrochemical and Carbon Black Production	0.2	0.2%
Hydrogen Production	0.1	0.0%
Other	0.0	0.0%
Iron and Steel Production	13.8	10.5%
Ferroalloys Production	10.6	8.1%
Aluminium Production	1.9	1.5%
Lead Production	0.0	0.0%
Zinc Production	0.1	0.0%
Lubricant Use	0.5	0.4%
Paraffin Wax Use	0.1	0.1%
Refrigeration and Air Conditioning	1.9	1.4%
Foam Blowing Agents	0.0	0.0%
Fire Protection	0.0	0.0%
Aerosols	0.0	0.0%
Human Settlements	15.6	11.9%
Solid Waste Disposal	15.4	11.7%
Biological Treatment of Solid Waste	0.0	0.0%
Incineration and Open Burning of Waste	0.2	0.2%
Agriculture	43.2	32.9%
Enteric Fermentation	30.7	23.4%
Manure Management	3.6	2.8%
Emissions from biomass burning	2.0	1.5%
Liming	0.7	0.5%
Urea application	0.5	0.4%
Direct N2O Emissions from managed soils	4.8	3.7%
Indirect N2O Emissions from managed soils	0.7	0.6%
Indirect N2O Emissions from manure management	0.2	0.2%
Water	4.2	3.2%
Total	131.4	

Appendix 2: Production and consumption-related GHG emissions and material use, per economic sector

Table 9: Share of total production- and consumption-related GHG emissions and raw material use, per sector (UNEP, 2024b).

Production				Consumption			
Climate Change		Material use		Climate Change		Material use	
Sub-sector	%	sector	%	Sub-sector	%	Sub-sector	%
Electricity, gas and water	54.85	Ore mining	29.36	Electricity, gas and water	35.10	Nutrition	23.93
Coal, oil and gas mining	8.89	Coal, oil and gas mining	27.52	Nutrition	11.11	Agriculture	22.37
Agriculture	8.39	Construction material quarrying	21.10	Construction	7.26	Construction	9.68
Transport	5.14	Agriculture	19.07	Agriculture	7.18	Electricity, gas and water	7.42
Energy	4.69	Forestry and logging	1.87	Financial intermediation and business activities	5.01	Fabricated metals	5.00
Basic metals	3.37	Ceramics	0.58	Chemical products	4.61	Transport equipment	4.97
Chemical products	2.31	Wood and Paper	0.29	Transport	4.54	Public administration	3.11
Ceramics	2.21	Nutrition	0.09	Public administration	3.99	Financial intermediation and business activities	2.75
Waste and recycling	1.55	Fishing	0.07	Wholesale and retail trade	3.18	Wholesale and retail trade	2.51
Construction	1.47	Chemical products	0.04	Transport equipment	2.77	Chemical products	2.40
Wood and Paper	1.32			Fabricated metals	2.64	Transport	2.20
Nutrition	1.26			Education, health and other social work activities	2.38	Education, health and other social work activities	2.04
Construction material quarrying	1.04			Waste and recycling	1.51	Other manufacturing	1.84
				Textiles	1.43	Textiles	1.58
				Energy	1.41	Construction material quarrying	1.45
				Post and telecomms	1.07	Hotels and restaurants	1.17
				Coal, oil and gas mining	1.02	Post and telecomms	0.88
				Ceramics	0.82	Energy	0.78
				Hotels and restaurants	0.79	Wood and Paper	0.77
				Other manufacturing	0.77	Coal, oil and gas mining	0.58
				Wood and Paper	0.63	Ceramics	0.55
				Other services	0.39	Ore mining	0.55
				Basic metals	0.18	Waste and recycling	0.55
				Construction material quarrying	0.11	Other services	0.44
				Ore mining	0.04	Forestry and logging	0.19
				Fishing	0.04	Basic metals	0.17
				Repair and installation	0.03	Fishing	0.06
				Forestry and logging	0.01	Repair and installation	0.05

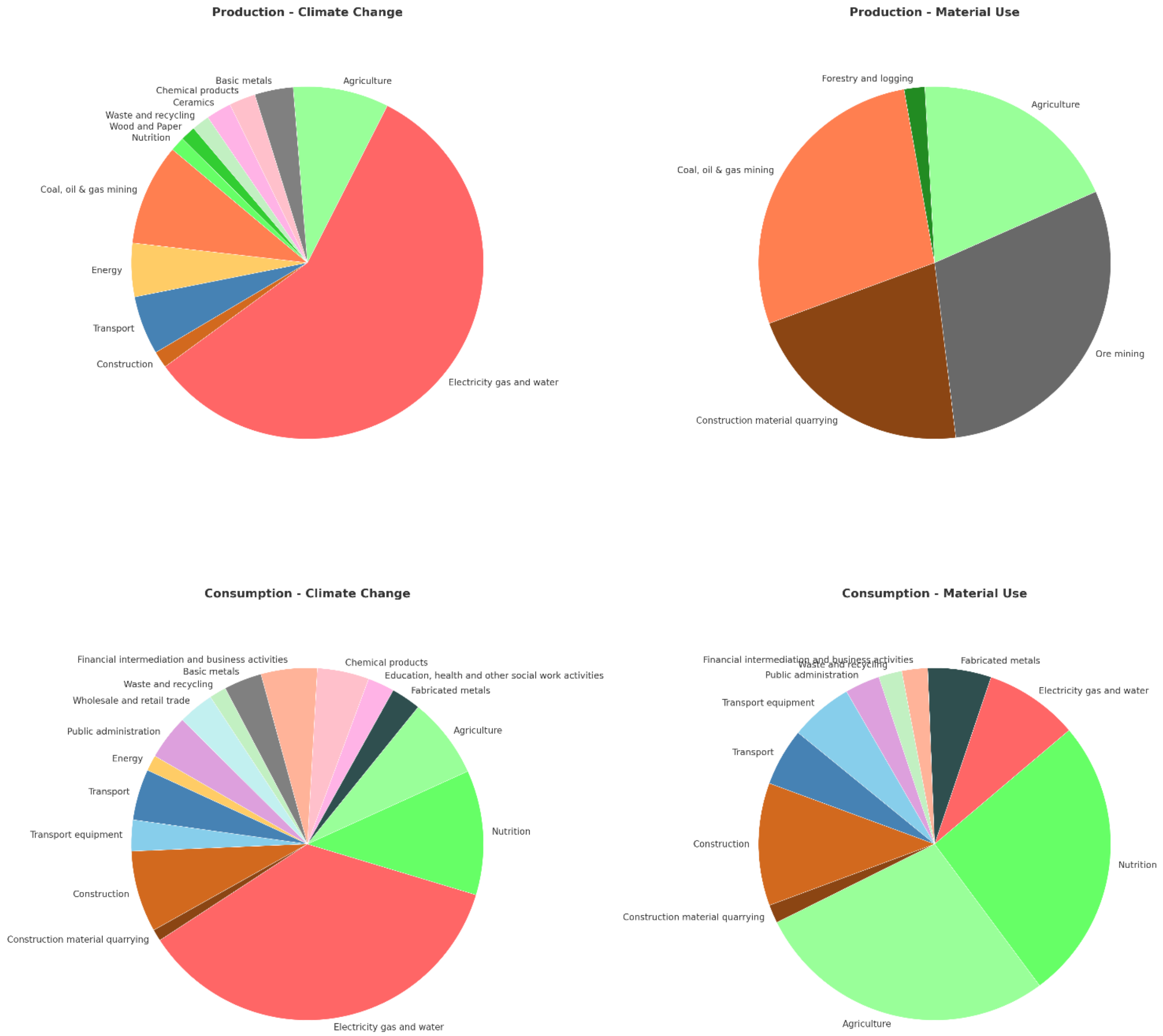

Figure 19: Breakdown of production- and consumption-related GHG emissions and material use by sector (Source: UNEP, 2024b).

Figure 19 shows the breakdown of production- and consumption-related GHG emissions and material use graphically. The top panel highlights the *domestic production* sectors with substantial GHG emissions and raw material use; including energy; agriculture; coal, oil and gas mining; ore mining; construction material quarrying; and transport. The bottom panel indicates the *consumption* sectors with substantial GHG emissions and raw material use as agriculture, nutrition, construction, electricity, gas and water; transport and transport equipment (UNEP, 2024b).

Appendix 3: Cement Types and GHG Emissions

Table 10: GHG emission factors (per tonne) for different cement types in South Africa (Source: Lowitt 2020).

Cement Type	Composition (%)				GHG Emissions (kgCO_2/t)			
	OPC	Fly Ash	GGBS	Limestone	Total	Scope 1	Scope 2	Scope 3
CEM I	100	0	0	0	985	818	145	21
CEM II A-L	85	0	0	15	838	696	124	18
CEM II A-S	80	0	20	0	814	665	131	17
CEM II A-V	80	20	0	0	788	654	116	17
CEM II B-L	73	0	0	27	721	598	107	15
CEM II B-S	70	0	30	0	728	588	124	15
CEM II B-V	70	30	0	0	690	572	102	15
CEM III A	50	0	50	0	557	435	110	10
CEM IV A	65	35	0	0	641	531	95	14
CEM IV B	58	42	0	0	572	474	84	12
CEM V A	57	18	25	0	594	479	102	12
CEM V B	38	31	31	0	414	327	79	8