Article:

Sithole, Dingane, Tagwireyi, Caroline, Marowa, Tendayi et al. (18 more authors) (2023) Climate change mitigation in Zimbabwe and links to sustainable development. Environmental Development. 100891. ISSN 2211-4645

https://doi.org/10.1016/j.envdev.2023.100891

Environmental Development 47 (2023) 100891

Contents lists available at ScienceDirect

Environmental Development

journal homepage: www.elsevier.com/locate/envdev

Climate change mitigation in Zimbabwe and links to sustainable development

Dingane Sithole [a], Caroline Tagwireyi [a], Tendayi Marowa [a], Fadzai Muwidzi [a], Farai Mapanda [a], Walter Svinurai [a], Tatenda Gotore [a], Sekai Ngarize [a], Anderson Muchawona [a], Samantha Chigoverah [a], Gamuchirai Takavingofa [a], Kudzai Ndidzano [b], Lawrence Mashungu [b], Washington Zhakata [b], Tafadzwa Dhlakama [c], Christopher S. Malley [d,*], Jessica Slater [d], Eve Palmer [d], Amy Molotoks [d], Chris West [d], Jason Veysey [e]

[a] *Bees Consultancy, Harare, Zimbabwe*
[b] *Climate Change Management Department, Zimbabwe Ministry of Environment, Climate, Tourism and Hospitality Industry, Harare, Zimbabwe*
[c] *United Nations Development Programme, Zimbabwe Country Office, Harare, Zimbabwe*
[d] *Stockholm Environment Institute, Department of Environment and Geography, University of York, United Kingdom*
[e] *Stockholm Environment Institute, Somerville, MA, United States*

A R T I C L E I N F O

Keywords:
Climate change mitigation
Zimbabwe
Nationally determined contribution
Greenhouse gas
Sustainable development goals

A B S T R A C T

In 2021, Zimbabwe updated its Greenhouse Gas (GHG) reduction target from a 33% reduction in per capita energy sector GHG emissions to a 40% reduction from all sectors, compared to 2030 baseline emission scenarios. This work aims to demonstrate how the actions identified in Zimbabwe's Nationally Determined Contribution (NDC) can achieve this updated target, and what development benefits could occur in Zimbabwe through the implementation of these actions. The magnitude of GHG emissions in Zimbabwe are modelled historically and to 2030 to quantify GHG emission reduction potentials, and contributions to selected sustainable development goal targets, from implementation of 28 mitigation measures. The estimated ~37 million tonnes CO_2-equivalent emissions emitted by Zimbabwe in 2017 are projected to increase by 109% to ~77 million tonnes without implementation of any mitigation measures. The mitigation measures included in the updated NDC could reduce GHG emissions by 40% in 2030 compared to the baseline, while additional measures included in other plans and strategies in Zimbabwe could achieve a further 23% reduction. Implementing Zimbabwe's NDC could also lead to substantial development benefits locally, including to public health, biodiversity, and sustainable energy use. This assessment therefore provides a clear pathway to achieve Zimbabwe's updated climate change mitigation commitment, as the target is linked to the implementation of specific, concrete mitigation actions. It provides a practical example as to how methods to assess climate mitigation and development priorities can be integrated within climate change mitigation target-setting assessments. The more widespread adoption of prospective, quantitative assessment of development benefits from climate change mitigation actions could provide further motivation for more ambitious climate change action.

* Corresponding author.
E-mail address: chris.malley@york.ac.uk (C.S. Malley).

https://doi.org/10.1016/j.envdev.2023.100891
Received 12 February 2023; Received in revised form 15 June 2023; Accepted 29 June 2023
Available online 8 July 2023

1. Introduction

The Republic of Zimbabwe (hereafter abbreviated to Zimbabwe) is a landlocked country in southern Africa with 14.7 million people. With a GDP per capita of 1,059 USD per person (2010 USD), and 34% of people living on less than 1.9 USD per day, Zimbabwe ranks 150th on the United Nations Development Programme (UNDP) Human Development Index (United Nations Development Programme, 2020). Zimbabwe is vulnerable to climate change with substantial impacts on crop production forecasted, with two-thirds of employment in agriculture (World Bank, 2021). Only 20% of the rural population have electricity access, and the capability of Zimbabwe to increase electricity generation through the deployment of renewable sources such as hydro is compromised by changes in hydrological cycles reducing the generation capacity of hydro projects (Ministry of Environment, Water and Climate of Zimbabwe, 2017). Whilst highly vulnerable to climate change, Zimbabwe has made a negligible contribution to causing it. Zimbabwe was estimated to have emitted 22.0 million tonnes CO_2-equivalent Greenhouse Gas (GHG) emissions in 2006 (excluding Forestry and Other Land Use), or 0.06% of the 38 billion tonnes CO_2-equivalent estimated to have been emitted globally (Ministry of Environment, Water and Climate of Zimbabwe, 2017; World Bank, 2021).

Zimbabwe ratified the Paris Agreement in 2017, which requires Parties to report their Nationally Determined Contribution (NDC), outlining their commitment to mitigate climate change and limit global temperature increases to 'well below 2 °C' (United Nations, 2015). A key challenge for low- and middle-income countries like Zimbabwe when developing their climate change mitigation pledges is how an ambitious commitment to mitigate climate change can be developed that is aligned with and simultaneously addresses key development challenges. Opportunities from developing climate change commitments which contribute to sustainable development include i) building a broader coalition of support within the country for implementation of climate change mitigation actions if they are demonstrated to lead to local benefits, and ii) accessing international climate finance for implementation of projects and measures that achieve local benefits and climate change mitigation (Linnér et al., 2012; Malley et al., 2021b). Specific links between climate change mitigation and sustainable development goals have been identified (Haines et al., 2017), and sustainable development linkages to national climate change commitments have also been analysed (Antwi-Agyei et al., 2018). However, these analyses are usually undertaken retrospectively (i.e. after the climate change commitments had been developed and submitted as an NDC), and qualitatively (Wagner et al., 2022). Other studies that do quantify specific development benefits for particular countries, regions, or globally, do so often for a set of mitigation actions that do not represent the specific measures, or level of ambition, being considered in a country developing its climate change plans (UNEP/WMO, 2011; UNEP, 2019a). There is therefore a need, but few practical examples, to integrate a package of methodologies to quantify climate and development benefits of nationally-determined climate change mitigation actions. Prospective, quantitative assessments of the link between climate change mitigation and development priorities are necessary so that climate change commitments, and the actions identified to achieve them, can be identified, evaluated, and prioritised based not only on their GHG mitigation potential but also based on the broader benefits achieved locally from their implementation. The research question this papers therefore aims to address is 'How can national greenhouse gas mitigation assessments to inform climate change mitigation target-setting incorporate the inclusion of quantitative development benefits?'.

The GHG mitigation assessment that informed the update to Zimbabwe's NDC is used as a case study to provide a practical example of an integrated climate mitigation and development assessment. In September 2021, the Government of Zimbabwe submitted its updated NDC with higher climate change mitigation ambition compared to its previous submission. Zimbabwe's first NDC, submitted in 2015, committed to a 33% reduction in per capita energy sector GHG emissions compared to a baseline scenario (Republic of Zimbabwe, 2017). The updated NDC committed to a 40% reduction in national *total* GHG emissions (on a per capita basis) compared to the baseline scenario (Government of Zimbabwe, 2021). This updated commitment both increased the percentage reduction in GHG emissions, and expanded the scope of GHG emission sources. This reduction applies to all major sources (energy, industrial processes and product use (IPPU), agriculture, forestry and other land use (AFOLU) and waste). A set of mitigation actions to achieve the GHG reduction target were also outlined in the NDC, including those taken from Zimbabwe's National Development Strategy 1 (Republic of Zimbabwe, 2020). The inclusion of specific mitigation actions therefore provides a useful starting point for evaluation of both GHG emission reductions and achievement of development priorities from implementing the NDC.

2. Methods

The GHG mitigation assessment was informed by data, assumptions, insights and other inputs from the Climate Change Management Department of the Ministry of Environment, that coordinated the overall NDC update process, and sectoral Ministries responsible for major GHG emitting source sectors. Section 2.1 describes the how historic and future GHG emissions were quantified in Zimbabwe. Section 2.2 outlines how broader sustainable development benefits from implementation of the mitigation measures were quantified and evaluated.

2.1. Greenhouse gas mitigation assessment

The GHG mitigation assessment undertaken to update Zimbabwe's NDC was typical of those commonly undertaken for climate change mitigation planning. Zimbabwe's first NDC committed to reduce GHG emissions from the energy sector only (Republic of Zimbabwe, 2017). A key goal of the Government of Zimbabwe was the expansion of the NDC to cover all major GHG emitting source sectors. Therefore, emissions from the Energy, IPPU, AFOLU and Waste sectors were modelled. Emissions included GHGs, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs), as well as co-emitted air pollutants, including black carbon (BC), organic carbon (OC), fine particular matter ($PM_{2.5}$), nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOCs), ammonia (NH_3) and carbon monoxide (CO). For non-CO_2 GHGs, global warming potentials (GWP) from the IPCC 5th Assessment Report (with climate feedbacks) were used to aggregate to total GHG emissions (Myhre et al., 2013). The co-emitted air pollutant emissions impact both climate and air quality, allowing air pollutant-associated health impacts to be included within assessment of development benefits (see Section 2.2). Historical emissions were estimated for 2010–2017. For some sectors data was available for years prior to 2010 (extending back to 1990) and after 2017 (up to 2019) to quantify historical emissions. Future projections of GHG emissions were made from 2018 to 2030.

GHG emissions were estimated by multiplying specific activity data by emission factors. In general, activity data were obtained from national sources, including Zimbabwe's 1st Biennial Update Report (Ministry of Environment, Climate, Tourism and Hospitality Industry of Zimbabwe, 2020), and previous national GHG inventories (Ministry of Environment, Water, and Climate of Zimbabwe, 2017). Emission factors were taken from default international (global and region-specific) sources (IPCC, 2006) (Table 1).

For the future projections different scenarios were created to reflect different assumptions about future development and climate change mitigation efforts. A baseline scenario provided a reference to quantify the emission reduction potential and development benefits of mitigation measures, and was designed to reflect socioeconomic development in Zimbabwe without new climate change mitigation policies and measures. The development vision for Zimbabwe reflected in the baseline scenario was taken from the National

Table 1
Summary of data sources used to estimate GHG emissions for each source sector.

Source Sector	Activity Data	Source of Data
1A1a Public Electricity and Heat Production	Historical electricity production Fuel consumption Power Plant Capacity, Efficiency and Availability	Zimbabwe National Energy Balance (MoEPD, 2020)
1A2 Manufacturing Industries and Construction	Fuel Consumption in Industrial sector	Zimbabwe National Energy Balance (MoEPD, 2020)
1A3b Road transportation	Vehicle fleet composition Fuel consumption in road transport sector	OICA data on vehicle population (OICA, 2021) Zimbabwe National Energy Balance (MoEPD, 2020)
1A3c Railways	Fuel consumption in rail sector	Zimbabwe National Energy Balance (MoEPD, 2020)
1A4a Commercial/Institutional	Fuel consumption in services sector	Zimbabwe National Energy Balance (MoEPD, 2020)
1A4b Residential	Fuel Consumption in household sector Number of households Number of households cooking using different fuels and technologies	Zimbabwe National Energy Balance (MoEPD, 2020)
1A4c Agriculture, Forestry, Fishing	Fuel Consumption in agriculture sector	Zimbabwe National Energy Balance (MoEPD, 2020)
2A Mineral Industry	Cement Production Lime Production Glass Production Other Process Uses of Carbonates	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
2B Chemical Industry	Nitric Acid Production	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
2C Metal Industry	Pig Iron Production Ferrochromium Production Lead Smelting Ferrosilicon Production Sinter Production Steel BOF/EAF Production	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
2D Non energy products from fuels and solvent use	Lubricant Use Paraffin Wax Use	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
2F Product Uses as Substitutes for Ozone Depleting Substances	Refrigeration and Air Conditioning	National Ozone Unit
3A Livestock	Number of Animals Manure Management Systems/Practises Nitrogen Excretion Rates	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
3B Land	Land (forest, plantation, crop, grassland, wooded grassland, wetland, settlement) remaining land type Land converted to other land types Land Use parameters (e.g. biomass growth rates)	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
3C Aggregate sources and non-CO2 emission sources on land	Rice Production	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
3D Other		
4A Solid Waste Disposal on Land	Per Capita waste generation rates Waste collection rates Urban population	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
4B Biological Treatment of Solid Waste	Collected Waste and Composted	First Biennial Update Report (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)

Table 2
Assumptions about socioeconomic development in Zimbabwe linked to activity variables in key sectors that informed the development of the baseline scenario.

Source Sector	Variable used for baseline projections	Value	Source of Data
1A1a Public Electricity and Heat Production	New installed capacity for electricity generation	Hwange 7 & 8 coal expansion: 600 MW Gwanda Solar PV Committed Power Plant: 10 MW Mamina Wind Candidate Power Plant: 100 MW Shilands Gas-fired candidate Power Plant: 210 MW	System Development Plan 2017 (Zimbabwe Electricity Transmission and Distribution Company, 2017)
1A2 Manufacturing Industries and Construction	Fuel Consumption in Industrial sector	Industry value added GDP growth: 2020: -10.8% 2021: 6.4% 2022: 6.5% 2023: 8.0% 2024: 6.0% 2025–2030: 6.1%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
1A3b Road transportation	Vehicles per capita Number of LDVs, HDVs and buses:	GDP per capita growth rates Growth based on historic growth rates	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
1A3c Railways	Fuel consumption in rail sector	GDP growth rates 2020: -4.5% 2021: 7.4% 2022: 5.5% 2023: 5.2% 2024: 5.2% 2025–2030: 5.0%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
1A4a Commercial/ Institutional	Fuel consumption in services sector	GDP growth rates 2020: -4.5% 2021: 7.4% 2022: 5.5% 2023: 5.2% 2024: 5.2% 2025–2030: 5.0%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
1A4b Residential	Number of households Electricity access	Population: 1.4% per year increase 75% rural households have access to electricity by 2030 95% of urban households have access to electricity by 2030	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
1A4c Agriculture, Forestry, Fishing	Fuel Consumption in agriculture sector	Agriculture value added GDP growth rates 2020: -0.2% 2021: 11.3% 2022: 8.9% 2023: 7.6% 2024: 9.5% 2025–2030: 10.4%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
2A Mineral Industry	Cement Production	Manufacturing value added GDP growth rates 2020: -10.8% 2021: 6.4% 2022: 6.5% 2023: 8.0% 2024: 6.0% 2025–2030: 6.1%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
2B Chemical Industry	Nitric Acid Production	Manufacturing value added GDP growth rates 2020: -10.8% 2021: 6.4% 2022: 6.5% 2023: 8.0%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)

(*continued on next page*)

Table 2 (*continued*)

Source Sector	Variable used for baseline projections	Value	Source of Data
		2024: 6.0% 2025–2030: 6.1%	
2C Metal Industry	Pig Iron Production Ferrochromium Production Lead Smelting Ferrosilicon Production Sinter Production Steel BOF/EAF Production	Manufacturing value added GDP growth rates 2020: -10.8% 2021: 6.4% 2022: 6.5% 2023: 8.0% 2024: 6.0% 2025–2030: 6.1%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
2D Non energy Products from Fuels and Product Use	Lubricant Use Paraffin Wax Use	Industry value added, GDP growth rates 2020: -10.8% 2021: 6.4% 2022: 6.5% 2023: 8.0% 2024: 6.0% 2025–2030: 6.1%	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
2F Product Uses as Substitutes of Ozone Depleting Substances	Refrigeration and Air Conditioning	GDP Growth	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
3A Livestock	Number of Animals	Dairy Cattle: 9.67% per year increase Other Cattle: 1.83% Sheep: 8.83% Goats: 6.33% Pigs: 4.17%	Zimbabwe Livestock Growth Implementation Plan 2021–2025 (Ministry of Lands Agriculture Water and Rural Resettlement, 2020)
3B Land	Land (forest, plantation, crop, grassland, wooded grassland, wetland, settlement) remaining land type Land converted to other land types		Continuation of historic trends from 1st Biennial Update Report data 1992–2017 (Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020)
3C Aggregate sources and non-CO2 emission sources on land	Rice and other crop Production Amount of fertilisers applied Area burnt in grasslands, forestland, croplands	Population Growth Rate: 1.4% per year increase	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
3D Other			
4A Solid Waste Disposal on Land	Per Capita waste generation rates	GDP per capita growth rates	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)
4B biological Treatment of Solid Waste	Waste collected for composting. Per Capita waste generation rates	Population Growth Rate: 1.4% per year increase	National Development Strategy 1 2021–2025 (Republic of Zimbabwe, 2020)

Development Strategy 1 (Republic of Zimbabwe, 2020), excluding any specific policies and measures to reduce GHG emissions (Table 2).

Secondly, mitigation scenarios representing implementation of individual mitigation measures were modelled to assess their emission reduction potential and development benefits. The policies and measures included in the mitigation assessment were from existing plans in Zimbabwe, and were reviewed and endorsed by key stakeholders. In total 28 specific mitigation measures with targets and timelines were included in the GHG mitigation assessment (Table 3). The individual mitigation scenarios were grouped into two categories of measures, so that the effect of implementing a group of mitigation measures could be assessed, accounting for interactions between different mitigation actions. The first group was the 'NDC measures' and included those measures contributing to the 2021 updated NDC target for GHG emission reductions. The second group, 'additional measures', included additional measures not included in the GHG reduction target, but which have been included within other plans and strategies in Zimbabwe, to evaluate the extent to which these measures could achieve additional GHG and development benefits beyond those measures included in the NDC. Sector-specific methods are described below.

2.1.1. *Energy sector*

Energy sector emissions were calculated through the development of a model that linked energy supply to the underlying demand for solid (wood, charcoal), liquid (gasoline, diesel, kerosene, heavy fuel oil, liquified petroleum gas (LPG) and gaseous (natural gas) fuels, and electricity (Heaps, 2022). Emissions were calculated separately from final energy consumption in five energy demand sectors (Residential, Commercial and Public Services, Industry and Mining, Agriculture and Transport). Emissions were estimated as the product of fuel consumption in each sector by sector, and fuel and pollutant-specific emission factors. The energy supply module accounted for electricity generation emissions. Only GHG emissions emitted within the territorial boundaries of Zimbabwe were included, e.g. all oil and gas consumed in Zimbabwe is imported and therefore oil extraction, processing and distribution emissions were not included. For CO_2 emissions from biomass combustion, emissions were accounted for under AFOLU, consistent with IPCC (2006) (see Section 2.1.3).

Table 3
Mitigation measures evaluated in GHG mitigation assessment extracted from plans and strategies in Zimbabwe.

Number	Sector	Mitigation Measure	Source: Plan/Strategy/Regulation	Scenario
1	Electricity Generation	Transmission and Distribution losses reduced from 18% in 2020 to 11% in 2025	National Development Strategy	NDC Measures
2	Electricity Generation	Expansion of Solar: Solar: 300 MW in 2025	System Development Plan 2017	NDC Measures
3	Electricity Generation	Expansion of microgrids: Additional of 2.098 MW of capacity added through microgrids by 2028	REF 2021	NDC Measures
4	Electricity Generation	4.1 MW biogas capacity added in 2024	ZERA annual report	NDC Measures
5	Energy Efficiency	Energy Efficiency Improvements: Agriculture: 12% savings (2030 compared to baseline scenario) Commercial: 16% savings Domestic: 22.08% savings Manufacturing: 18.63% savings Mining: 8% savings	ZERA energy efficiency audit	NDC Measures
6	Transport	2% biodiesel in fuel by 2030	Low Emissions Development Strategy	NDC Measures
7	Transport	Fuel economy policy Fuel efficiency improvement 2025–2030: Motorcycles: 2.2% per year LDVs: 2.9%/year Buses: 2.6%/year HGVs: 2.5%/year	Low Emissions Development Strategy	NDC Measures
8	Transport	Public transport (modal shift). 5% shift from private car to public transport in 2030	Low Emissions Development Strategy	NDC Measures
9	Electricity Generation	Planned large hydropower at Batoka (1200 MW, 6000 GWh generation)	Low Emissions Development Strategy/ 2017 System Development Plan	Additional Measures
10	Electricity Generation	Two thousand one hundred Mega Watts (2,100 MW) by the year 2030 or twenty six comma five percent (26.5%) of total generation from RE sources, whichever is higher 2100 MW additional renewable energy capacity installed by 2030 (150 MW small hydro, 1575 MW grid solar, 100 MW wind, 275 MW bagasse)	National Renewable Energy Policy	Additional Measures
11	Transport	Electric- and hydrogen vehicles. Electric vehicle % in vehicle fleet in 2030: Motorcycles: 77% LDVs: 37% Buses: 39% HGVs: 20%	Low Emissions Development Strategy	Additional Measures
12	Residential	Households with improved cookstoves: 60% of rural population using improved cookstoves	SE4All targets	Additional Measures
13	Residential	Households with improved cookstoves: 22% of rural population using LPG	SE4All targets	Additional Measures
14	Residential	Replacement of 250,000 electric geyser water heaters with solar water heaters	National Renewable Energy Policy	Additional Measures
15	Transport	10% increase in journeys taken by walking and cycling compared to private vehicle		Additional Measures
16	IPPU	Increased clinker substitution with fly ash (up to 16% by 2030, 20% by 2050).	Low Emissions Development Strategy	NDC Measures
17	IPPU	Increased clinker substitution with BFS (up to 16% by 2030, 20% by 2050).	Low Emissions Development Strategy	NDC Measures
18	IPPU	Decomposition of N2O emissions through use of a secondary catalyst. Selective De-N2O catalyst results in abatement of approximately 75% of all N2O emissions produced during nitric acid production. Implementation by 2023	Low Emissions Development Strategy	NDC Measures
19	IPPU	HFC Phasedown schedule Kigali Amendment (Freeze, 2024; 2029, 10% reduction)		NDC Measures
20	IPPU	Substitution of coke input to BF/BOF steel making with biocoke Replacement of up to 10% fossil carbon input by sustainable biocoke supply by 2025.	Low Emissions Development Strategy	Additional Measures
21	IPPU	Substitution of coke input to FeCr-production with biomass (bio-coke). Replacement of up to 10% fossil carbon input by sustainable biocoke supply by 2025.	Low Emissions Development Strategy	Additional Measures
22	Forestry and Other Land Use	Increase area of forest land from 9.9 million hectares to 10.4 million hectares by 2025: Add 100,000 ha of natural forest land per year between 2021 and 2025	National Development Strategy	NDC Measures

(*continued on next page*)

Table 3 (*continued*)

Number	Sector	Mitigation Measure	Source: Plan/Strategy/Regulation	Scenario
23	Forestry and Other Land Use	Increase area of forest plantation from 68848 ha to 118848 ha by 2025: Add 10,000 ha of plantation forest land per year between 2021 and 2025	National Development Strategy	NDC Measures
24	Forestry and Other Land Use	Reduce area burned by 500,000 ha between 2020 and 2025	National Development Strategy	NDC Measures
25	Crop Production	Implementation of conservation agriculture. Increasing area under conservation agriculture from 235,905 ha in 2020 to 494,955 ha in 2030	Low Emissions Development Strategy	Additional Measures
26	Solid Waste/ Energy	Waste to Energy: It was assumed that 42% of the methane generated would be collected and used for energy production through waste to energy projects in Bulawayo and other major cities	Low Emissions Development Strategy	NDC Measures
27	Solid Waste	20% of organic matter composted in the long term	Zimbabwe's Integrated Solid Waste Management Plan, Low Emissions Development Strategy	NDC Measures
28	Liquid waste	All urban areas are connected to sewage system by 2030		Additional measures

For the Residential sector, fuel and electricity consumption was estimated separately for urban and rural households. Household annual average fuel consumption (energy intensity) was multiplied by the number of household using each fuel, for cooking and all other energy consumption separately. For cooking, electricity, wood, kerosene, LPG and coal were cooking fuels. Energy intensities were estimated by dividing the total consumption of a particular fuel, obtained from Zimbabwe's national energy balance (MoEPD, 2020), by the total number of urban or rural households consuming that fuel (summarised in Table 4). The projected population growth rate in Zimbabwe's National Development Strategy 1 was used to project the number of households into the future (NDS1, Republic of Zimbabwe, 2020), with the fuel mix for cooking remaining constant (Table 4). Electricity access is projected to increase substantially in the baseline scenario, to 95% of urban households, and 75% of rural households by 2030 to achieve targets in NDS1. The mitigation scenarios reflected increased penetration of clean fuels (electricity and LPG) for cooking, and solar water heaters replacing existing electric geyser water heaters (Table 3).

In the industry and mining, commercial and public services, and agriculture, forestry and fishing energy demand sectors, for historical years, the total fuel consumption was from Zimbabwe's national energy balance (MoEPD, 2020), with no sub-sectoral disaggregation (Table 5). The growth rate in sectoral value-added GDP from NDS1 was used to project fuel consumption in each sector for the baseline scenarios (Table 2). In NDS1, economic projections cover 2021–2025, and explicitly account for the COVID-19 pandemic's impact on Zimbabwe's economy, and expected recovery. For 2026–2030, the 2025 percentage growth rate in the economic variables was used to project fuel consumption for the second half of the decade. The mitigation measures modelled in these sectors represent the improvement in energy efficiency according targets from ZERA (2015) (Table 3).

For transport, rail transport emissions were estimated based on historical fuel consumption taken directly from Zimbabwe's national energy balance (MoEPD, 2020), which was projected for the baseline scenario based on overall GDP growth in Zimbabwe (Republic of Zimbabwe, 2020). Road transport fuel consumption was estimated separately for four vehicle categories (passenger cars, light commercial vehicles, heavy duty vehicles and buses). The total fuel consumption was calculated by multiplying the total number of vehicle-km travelled for each vehicle type separately, by an average fuel consumption per vehicle-km. The number of vehicle-km, and hence fuel consumption, for each vehicle type, was disaggregated by fuel (gasoline, diesel, electric (future scenarios only)), and by vehicle emission standard (Euro I-VI). Due to a lack of recent national data on vehicle fleet composition, the number of vehicles of each of the four types were based on OICA (2021). Passenger cars were assumed to consume gasoline, while heavy duty vehicles and buses were assumed to consume diesel. Light commercial vehicles were assumed to be 50% each running on gasoline and diesel. Due to a limited operational vehicle inspection and maintenance in Zimbabwe, all vehicles were assumed to be equivalent to pre-Euro vehicle

Table 4
Characteristics of urban and rural household energy consumption in 2017.

Geography	Population (People)	Household Size (People per household)	Cooking Fuel (% households)	Cooking fuel energy intensity (Gigajoule/ household/year)	Electricity Access (% households)	Other electricity consumption energy intensity (Gigajoule/ household/year)
Urban	4,878,018	3.9	Electricity: 63.9 Wood: 16.7 Kerosene: 3.9 LPG: 15.4 Coal: 0.13	Electricity: 10.5 Wood: 130.6 Kerosene: 33.04 LPG: 4.67	79%	9.02
Rural	9,748,723	4.3	Electricity: 3.0 Wood: 95.0 Kerosene: 0.56 LPG: 1.4 Coal: 0.06	Electricity: 10.5 Wood: 130.6 Kerosene: 33.04 LPG: 4.67	20%	3.51

Table 5
Final energy consumption in industry, commercial and public services and agriculture sectors in Zimbabwe in 2017, disaggregated by fuel.

Sector	Wood or other biomass (thousand) Gigajoule)	Bituminous Coal (thousand Metric Tonne)	Coke Oven Coke (thousand Metric Tonne)	Coke Oven Gas (thousand Gigajoule	Gasoline (thousand Metric Tonne)	Kerosene (thousand Metric Tonne)	Diesel (thousand Metric Tonne)	Electricity (GWh)
Industry and Mining	6117	252	101	1547	18	1	29	3343
Commercial and Public Services		2						1783
Agriculture, Forestry and Fishing	16,821	19 (2015 vale extrapolated to 2017)			14 (2015 vale extrapolated to 2017)	1 (2015 vale extrapolated to 2017)	114 (2015 vale extrapolated to 2017)	428
Rail transport		258 (Terajoule)						

standards. The average distance travelled was taken from ICCT (2012). Default fuel economy values from EMEP/EEA (2019) were used to estimate fuel consumption (see Table 6).

The future vehicle fleet was estimated for passenger cars by projecting the number of passenger cars per capita to grow at the same rate as GDP per capita. In 2017, there were an estimated 59 passenger cars per 1000 people in Zimbabwe (Table 6). Using GDP per capita growth rates derived from NDS1 resulted in an estimated 69 passenger cars per person in 2030, and 1.3 million passenger cars in total. For light commercial vehicles, heavy duty vehicles and buses, the historical growth rates from OICA (2021) data were used to project the vehicle fleet in these categories and corresponded to a 2.5, 1.3, and 4.3% per year increase, respectively.

For energy supply, the amount of electricity generated was based on domestic demand (modelled as described above), plus transmission and distribution losses and exports, minus imports. Zimbabwe's national energy balance estimates transmission and distribution losses to be 16.44% in historic years and increased to 18% in 2020. The electricity generation system modelled generation for individual power stations whose characteristics are summarised in Table 7. Independent power producers and small hydro installations were modelled as aggregate groups. For historical years, the total fuel consumed was estimated based on the historical electricity generated at each power station, and each power plant's efficiency. In future scenarios, fuel consumption in each power station was estimated using the same approach, but the electricity generated from each powerplant was modelled based on each plant's installed capacity, and availability. The additional electricity generating capacity outlined in Zimbabwe's System Development Plan 2017 is included in the baseline scenario (Zimbabwe Electricity Transmission and Distribution Company, 2017), with the exception of large renewable electricity generation projects, which were included in mitigation scenarios. The additional capacity in the baseline scenario is shown in Table 7. Mitigation scenarios reflect additional renewable electricity generation capacity (large hydro, small hydro, wind and solar), as outlined in Zimbabwe Electricity Transmission and Distribution Company (2017), but adjusted based on expert judgement as to the updated timeline for when specific projects would come online (shown in Tables 3 and 7).

2.1.2. Industrial processes and other product use (IPPU) sector

Following IPCC (2006) Tier 1 methodologies, emissions were estimated for each relevant IPPU subsector in Zimbabwe based on the production or consumption of a particular product and product/consumption-specific emission factors for each pollutant, except for cement manufacturing where the IPCC tier 2 method was used based on clinker production. The industrial sub-sectors included in the IPPU sector in Zimbabwe, their production variables and values in 2017 are shown in Table 8. Industrial production was projected to increase at the same rate as manufacturing value added in NDS1 (Table 2). For sinter and steel production using blast oven furnace (BOF), there has been no production since 2008. For these processes, production was projected in the baseline scenario to restart in 2024, at the historical production levels prior to production stopping. Sinter and steel BOF production was then projected to increase between 2024 and 2030 at the same rate as manufacturing value added (Table 2). The mitigation measures for industrial processes included the replacement of clinker in cement with fly ash and other lower-emitting alternatives, substitution of coke in Steel BOF and ferrochromium production with biocoke, and reducing N_2O emissions from nitric acid production through decomposition using a secondary catalyst (Table 3).

The IPPU sector also includes emissions from the consumption of hydrofluorocarbons (HFCs), estimated using IPCC Tier 1 methods

Table 6
Data and assumptions used to model the road transport sector in 2017 in Zimbabwe.

Vehicle Type	Number of vehicles (thousand vehicles)	Fuel used	Average distance travelled (km per vehicle per year)
Passenger Cars	867.5 Vehicles per capita: 0.059	100% gasoline	5000
Light Commercial Vehicles	48.12	50% gasoline 50% diesel	12,000
Heavy Duty Vehicles	37.43	100% diesel	26,000
Buses	30.14	100% diesel	18,000

Table 7
Characteristics of power plants used to model electricity generation in Zimbabwe in 2017 and 2030 for the baseline and mitigation scenarios.

Power Plant	Fuel	Capacity 2017 (MW)	Generation 2017 (GWh)	Efficiency (%)	Availability (% of year)	Capacity 2030 Baseline (MW)	Capacity 2030 Mitigation (MW)
Hwange 1–6	Bituminous coal	780	3202.3	27	73	780	780
Harare	Bituminous coal	43	72.32	19	40	43	43
Bulawayo	Bituminous coal	80	51.39	19	38	80	80
Munyati	Bituminous coal	57	38.27	16	100	57	57
Independent Power Producers	Bituminous coal	140	180.44	20	100	140	140
Dema	Diesel	100	0	20	100	100	100
Kariba	Hydro	1050	3859.3	95	95	1050	1050
Hwange 7–8	Bituminous coal	0	0	30	92	600 (online in 2020)	600 (online in 2020)
Gwanda Solar	Solar	0	0	100	50	10 (online in 2019)	1585
Mamima Wind	Wind	0	0	100	73	100 (online in 2019)	200
Shilands	Diesel	0	0	27	92	210 (online in 2019)	
Batoka	Hydro	0	0	95	57	0	1200
Devil's Gorge	Hydro	0	0	95	73	0	1000 (online in 2031)
Small Hydro	Hydro	0	0	95	100	0	150
Biogas	Biogas	0	0	40	100	0	4.1

Table 8
Activities variables used to quantify GHG emissions from industrial processes and their values in the last historical year of the assessment (2017).

IPPU subsector	Activity variables	Value in 2017
Cement	Production of Clinker type A (CaO content: 62%)	325,301 tonnes
	Production of clinker type B (CaO content: 65%)	440,026 tonnes
Lime	Production of lime	0 tonnes (last year of historic production was 2008: 29 tonnes)
Glass	Production of glass	0 tonnes (last year of historic production was 2013: 7828 tonnes)
Soda Ash	Production of soda ash	2091 tonnes
Nitric Acid	Production of nitric acid	28604 tonnes
Pig Iron	Production of pig iron	0 (last year of historic production was 2008: 355 tonnes)
Ferrochromium	Production of ferrochromium	328,356 tonnes
Lead smelting	Quantity of lead smelted	3,302 tonnes
Ferrosilicon	Production of ferrosilicon	0 (last year of historic production was 2009: 603 tonnes)
Sinter	Production of sinter	0 (last year of historic production was 2008: 1003 tonnes)
Steel	Production of steel using Blast oven furnace (BOF)	0 (last year of historic production was 2008: 293 tonnes)
	Production of steel using electric arc furnace (EAF)	22,129 tonnes (2016 value extrapolated to 2017)
Beverages	Production of Wine	23,612 hL (2013 value extrapolated to 2017)
	Production of Spirits	54,844 hL (2013 value extrapolated to 2017)
Food	Production of sugar	488,644 tonnes (2013 value extrapolated to 2017)
Lubricant use	Consumption of lubricating oil	723 TJ
	Consumption of grease	31.7 TJ
Paraffin wax use	Consumption of paraffin wax	71.5 TJ
Hydrofluorocarbon (HFC) use	HFC import	820 kg
	HFC-23	119,683 kg
	HFC-32	198,916 kg
	HFC-125	518,892 kg
	HFC-134a	92,911 kg
	HFC-143a	1269 kg
	PFC-116	

(IPCC, 2006). All HFCs consumed in Zimbabwe are imported, and therefore the total annual import of HFCs is assumed to reflect consumption. It was also assumed that all HFCs were consumed in refrigeration and air conditioning equipment, as this is the dominant global use of HFCs. For applications of HFC where the HFC is not intended to be emitted (i.e. contained applications), the emissions of HFCs in a given year are related to the HFCs imported in that year, and to the totality of HFC in equipment that is in use in a country during that year, i.e. the 'bank' of HFCs. Therefore, the annual emissions of HFCs were estimated by accounting for annual losses (emissions) from the bank and the emissions that occur when equipment containing HFCs is retired. HFC import statistics were available for 2015–2018. This was combined with IPCC (2006) Tier 1 assumptions for annual bank losses (15% per year), equipment lifetime (15 years), and assuming emission of all HFC contained within equipment when retired to estimate the bank and annual HFC emissions were calculated for 2015–2018. HFC imports were projected to grow at the GDP growth rate in the base baseline scenario (Table 2).

The limitation of the HFC emission estimates in this analysis is that the HFC in equipment imported before 2015, but which continues to be in use (and emitting) after 2015, are not accounted for. Therefore, the HFC emissions for historical years, and in the baseline, scenario are likely an underestimate of the total HFC emitted. This underestimate is likely to be lower in the final years of the assessment, as equipment sold before 2015 is retired, and HFC sold after 2015 makes up a larger fraction of the HFC bank. The HFC phasedown schedule in the Kigali Amendment to the Montreal Protocol for Annex 5 countries (i.e. freezing HFC consumption in 2024, and a 10% reduction in HFC consumption in 2029 compared to 2021 levels) was included as a mitigation measure (Table 3).

2.1.3. *Agriculture, forestry and other land use*

For agriculture, IPCC (2006) Tier 1 methods were used to estimate emissions from livestock (enteric fermentation (CH_4), and manure management (CH_4, N_2O)), and crop production (application of manure and synthetic fertiliser to managed soils (N_2O), rice cultivation (CH_4), and agricultural residue burning (CH_4, N_2O, SLCPs and air pollutants)). Activity data, such as livestock number and crop production, were obtained from Ministry of Environment, Climate, Tourism and Hospitality Industry of Republic of Zimbabwe (2020) (Table 9). For CH_4 emissions from enteric fermentation and manure management, the animal numbers were multiplied by animal- and regional-specific emission factors from IPCC (2019). For N_2O emissions from manure management, direct and indirect emissions from volatilisation of nitrogen as NO and NH_3 were quantified. The nitrogen excreted in manure by different animals was estimated based on regional default animal weights and nitrogen excretion rates (Table 9). The percentage of nitrogen managed in different manure management systems was based on regional default values from IPCC (2019), as were the management-specific emission factors. Baseline projections of GHG emissions from livestock production were made by projecting the number of animals using the annual percentage growth rates for specific animal groups outlined in Ministry of Lands, Agriculture, Water and Rural Resettlement (2020).

Emissions from agricultural residue burning were estimated as the product of the mass of crop residue openly burnt and crop and pollutant-specific emission factors. The mass of crop residue openly burnt was estimated based on the annual crop production, crop to residue ratio (default values from EMEP/EEA (2019)), and the percentage of residue that is openly burned. Methane produced from rice production, estimated based on the IPCC (2006) Tier 1 methodology, was calculated by multiplying a baseline methane emission factor (kg CH_4 ha^{-1} day^{-1}) by i) a scaling factor accounting for the water management regime (i.e. flooded, and rainfed), ii) the cultivation period (number of days), and ii) area harvested within each water management regime (Table 9). The application of

Table 9
Activity data for quantification of emissions from agricultural sub-sectors.

Sub-sector	Activity variable	Value in 2017
Livestock Enteric fermentation	Number of animals	Head of animals
	Dairy Cattle	640,000
	Other Cattle	4,693,300
	Sheep	350,000
	Goats	4,692,700
	Horses	28,000
	Mules and Asses	539,000
	Pigs	241,500
	Poultry	7,276,000
Livestock manure management	Animal mass, nitrogen excretion rate	275 kg, 0.6 kg/tonne/day
	Dairy Cattle	250 kg, 0.63 kg/tonne/day
	Other Cattle	28 kg, 1.17 kg/tonne/day
	Sheep	30 kg, 1.37 kg/tonne/day
	Goats	238 kg, 0.46 kg/tonne/day
	Horses	130 kg, 0.46 kg/tonne/day
	Mules and Asses	28 kg, 1.57 kg/tonne/day
	Pigs	1.8 kg, 1.11 kg/tonne/day
	Poultry broiler	1.8 kg, 0.82 kg/tonne/day
	Poultry layer	6.8 kg, 0.82 kg/tonne/day
	Poultry turkey	1.52 kg, 0.74 kg/tonne/day
	Poultry indigenous	
Agricultural residue burning	Annual crop production	1699 tonnes
	Rice	38,715 tonnes
	Wheat	1,519,365 tonnes
	Maize	40,515 tonnes
	Cotton	3,452,116 tonnes
	Sugarcane	239,191 tonnes
	Other	
Rice Cultivation	Area harvested	2304 ha
	Continuously irrigated	768 ha
	Rainfed	
Managed soils	Nitrogen inputs from manure and inorganic fertiliser	65000 tonne N

nitrogen to soils (croplands and pasturelands) produces N_2O emissions which were estimated by multiplying the annual nitrogen (applied as manure and synthetic fertilisers) applied to soils (Table 9), by default direct and indirect (volatilisation) N_2O emission factors (IPCC, 2019). In the baseline scenario, population growth was used to project crop production and nitrogen inputs (Table 2).

For FOLU emission sources and sinks for different land uses, the IPCC (2006) Tier 1 methods were used to quantify the net CO_2 emissions, based on data from Ministry of Environment, Climate, Tourism and Hospitality Industry of Republic of Zimbabwe (2020). The area of land in Zimbabwe was divided into 7 categories, Natural Forest Land, Plantation Forest Land, Cropland, Grassland, Wooded Grassland, Settlements, Wetlands, and Other. In Zimbabwe's First Biennial Update Report to the UNFCCC, the area of land in each of these categories, and the area of land converted between land use types was available for two years, 1992 and 2017, as shown in Tables 10 and 11. Due to a lack of data between 1992 and 2017, the total change in land converted to other land use types was equally distributed across the years between 1992 and 2017 to estimate the annual change in land use.

For the two forest land use types (natural forests and plantation forests), CO_2 sources and sinks were calculated for land remaining forest land and land converted to forest land. For land remaining forest land, the IPCC (2006) Tier 1 methods were used to quantify the annual change in biomass stocks in forests, accounting for i) CO_2 sequestered due to biomass growth, ii) net CO_2 emissions due to wood removals and fuel wood use, and iii) net CO_2 emissions due to disturbances (e.g. forest fires). The data used to represent each of these processes were taken from Zimbabwe's First Biennial Update Report (Table 1). For land converted to forest land, it was assumed it takes 20 years for the conversion to be complete, as per IPCC (2006). The average annual biomass growth rates shown in Table 12 for different forest categories were used to estimate the CO_2 sequestered from conversion of land to forest land. The changes in carbon sequestered as dead organic matter and soil carbon from land converted to forest land was also estimated, using the land converted to forest land, and the default parameters for the carbon stocks in dead wood and litter for old and new land use types. For soils, changes in carbon stocks in mineral and organic soils were estimated using IPCC (2006) default methods, and reference soil organic carbon stocks and stock change factors. Tables 11 and 12 show the key parameters applied with the IPCC (2006) Tier 1 methodology to estimate emission and removals from forests.

For other land use types, only changes in CO_2 sources and sinks from conversion to those land use types were accounted for in this assessment (i.e. changes in CO_2 sources and sinks for land remaining as land use types other than forests were not included). The land converted to non-forest land use types, shown in Table 11, were combined with the biomass stocks and other factors shown in Table 12 in the IPCC (2006) Tier 1 methods to quantify net CO_2 emissions from conversion of land to non-forest land use types, accounting for changes in biomass, dead organic matter and soil organic carbon.

The baseline projection assumed that land conversions continued at the same rates between 1992 and 2017. Hence deforestation rates, and the annual area of land converted between different land use types were assumed to remain as outlined in Table 11. The mitigation scenarios represented the achievement of three goals outlined in Zimbabwe's National Development Strategy 1 (2021–2025), including increasing total forest land area by 500,000 ha by 2025, adding 50,000 ha of forest land plantation, and reducing the area of forest affected by fire by 500,000 ha by 2025 (Table 3).

2.1.4. Waste sector

Methane emissions from landfills, CH_4 and N_2O emission from composting, emissions from open waste burning, and CH_4 emissions from domestic liquid waste were covered in the waste sector emission assessment based on IPCC (2006) Tier 1 methods. The total municipal solid waste generated in urban areas was estimated as the product of urban waste generation per person statistics and the urban population in each year. This was disaggregated by type based on the percentage of waste of different types (e.g. food, paper, metal, plastic etc.) (Table 13). The percentage of this waste handled in each waste stream was then calculated, first between collected and uncollected waste. Collected waste assumed to be placed in landfills, both managed anaerobic or unmanaged shallow sites (Table 13). IPCC (2019) Tier 1 default factors for degradable organic content (DOC) of each waste type, and methane generation factors were used to estimate methane emissions. Uncollected waste was assumed to be dumped, and openly burned.

For domestic wastewater, CH_4 emissions were estimated by multiplying the urban population by IPCC (2019) regional default biological oxygen demand (BOD) (13.5 kg/person/year) values and the percentages of domestic wastewater handled in different treatment categories (Table 13). The methane emissions from wastewater handled by each treatment type was calculated by multipling by the IPCC (2019) default methane producing capacity (0.6 kg CH_4/kg BOD), and treatment type-specific correction factors.

Table 10
Area of land in different land use types in 1992 and 2017 in Zimbabwe (Source: Zimbabwe Fourth National Communication).

Land Use Type	Area (ha) 1992	Area (ha) 2017
Natural Forest	20788106.41	17401762.85
Forest plantation	155117.49	179832.26
Wooded grassland	6175828.49	7965520.5
Wetland	295172.43	416615.49
Settlement	139349.43	247877.42
Otherland	78520.1	133643.1
Grassland	689104.79	1474990.41
Cropland	10737372.16	11238329.27
Total	39058571.3	39058571.3

Table 11
Area of land converted between land use types annual between 1992 and 2017, based on equal distribution of total 1992–2017 land conversion (Source: Zimbabwe Fourth National Communication).

		2017								
		Natural forest	Wooded grassland	wetland	settlement	otherland	grassland	forest plantation	Cropland	Total
1992	Natural forest		145418.1408	1782.5472	1381.0428	1447.2216	12374.4312	1403.6976	92418.7968	256226.5
	Wooded grassland	66251.0376		1401.1056	1468.6056	302.2056	21040.0704	262.5192	41575.5504	141522.6
	Wetland	233.2224	138.7656		1.53	1.8756	25.488	1.8036	80.2908	482.976
	Settlement	389.5164	287.7588	9.27		12.7224	49.6404	2.9268	392.2668	1144.105
	Otherland	638.8704	186.2496	0.5148	4.8744		58.77		331.4628	1220.929
	Grassland	3172.9032	3419.4672	333.6048	299.1852	10.6524		240.1488	5542.0812	13018.04
	forest plantation	159.1812	55.5984	10.2348	34.7328	269.442	207.0684		252.7668	989.0244
	Cropland	56431.602	44893.134	828.9792	2099.016	796.4496	9614.4156	105.5592		114769.2
	Total	127276.3332	203620.5756	4366.2564	132224.76	2840.5692	1084247.1	2016.6552	3514830.39	529373.4

Table 12
Parameters used in calculation of net CO_2 emissions from Forestry and Other Land Use.

	Plantation forests	Natural forest	Cropland	Wooded Grassland	Grassland	Wetlands	Settlements	Other Land
Climate region	Tropical Dry	Tropical Dry)	Tropical Dry	Tropical Dry	Tropical Dry	Tropical Dry	Tropical Dry	Tropical Dry
Soil type	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral	High Activity Clay Mineral
Ecosystem/Vegetation/ Type	Tropical Dry Forest	Tropical Dry Forest		Semi Arid	Semi Arid	Flooded land		
Age class	>20yrs	>20yrs						
Growing stock level (m3/ha)	<20	21–40						
Carbon fraction of ABG biomass (CF) (t C/t dm)	0.5	0.5						
Ratio of below ground to above-ground biomass (R)	0.28	0.28						
BCEFr (t/m^3)	6.67	2.11						
ABG biomass (Bw) (t/ dm/ha)	60	36.66	10	4		0 (present on land)	0 (present on land)	0
ABG biomass growth (t/ dm/ha/yr)	10	1.8						
SOC stock (t C/ha)	38	38	38	38	38		38	38
Litter carbon stocks (t C/ha)	5.2	2.1						
FLU	1	1	1	1	1		1	1
FMG	1	1	1	0.67	0.67		1	1
FI	1	1	1	1	1		1	1
Crop type			Annual					
Carbon fraction of dry matter			0.5	0.5	0.5	0.5	0.5	0.5
Herbaceous biomass stocks (t dm/ha)				8.7	8.7			
Woody biomass stocks (t dm/ha)				15	0			
Herbaceous biomass stocks after conversion from other land use (t dm/ha)				8.7	8.7			
Woody biomass stocks after conversion from other land use (t dm/ha)				0	0			
Carbon fraction of dm for herbaceous biomass (t C/t dm)				0.47	0.47			
Carbon fraction of dm for woody biomass (t C/t dm)				0.5	0.5			
Biomass stocks after conversion (t dm/ ha)				0	0	0		
Basic wood density (t/ m^3)	0.45	0.68						
Fraction of biomass lost in disturbance (fd)	0.31	0.49						

In the baseline scenario, the growth rate in urban population was used to project municipal solid waste and liquid waste generation. For urban MSW, per capita waste generation rates were also projected to increase with GDP per capita, with an elasticity of 0.37, per Chen et al. (2020). The mitigation scenarios include two measures from EMA (2014), including landfill gas capture for electricity generation and diversion of organic waste to composting (Table 3).

2.2. Quantification of sustainable development benefits from GHG mitigation measures

To quantify the broader impacts from implementation of Zimbabwe's climate change mitigation measures, the ~200 Sustainable

Table 13
Key variables used to estimate emissions from municipal solid waste (urban population only) and domestic wastewater.

Variable	Value in 2017
Waste generation rate	374.3 kg/capita/year
Municipal Solid Waste Composition	Food: 44%
	Garden: 0%
	Disposable Diapers: 0%
	Paper: 16%
	Wood: 1%
	Textiles: 4%
	Plastic: 35%
	Other: 0%
MSW Collection Rate	68% total urban MSW collected
Percentage of waste collected treated at landfill sites	Managed Anaerobic landfill: 41%
	Unmanaged shallow: 59%
Percentage of urban domestic wastewater treated with different treatment types	Latrine: 31%
	Septic tank: 32%
	Aerobic treatment plant: 37%

Development Goal (SDG) targets were evaluated to identify those i) directly impacted by the implementation of the mitigation measures and ii) where a quantitative methodology could be applied to estimate the magnitude of the impact on the particular SDG. The SDG target level was selected, as opposed to the SDG indicators, because some of the indicators are too broad to be directly relevant to the implementation of specific GHG mitigation measures. For example, SDG Target 3.4 on the reduction in mortality from non-communicable diseases, for which the SDG indicator is the mortality rate from non-communicable diseases. The reduction in air pollutant emissions that occur alongside GHGs will reduce the number of deaths from *specific* non-communicable diseases. Therefore, specific indicators that are relevant for the SDG targets *and* the specific mitigation measures for each relevant SDG target were defined. These are summarised in Table 14.

Some indicators are user-defined, exogenous input into the GHG mitigation assessment modelling. For others, it is an output of the modelling conducted using the LEAP tool. For those indicators, the methodologies described in Section 2.1 provide the necessary modelling to quantify its magnitude in the historic and baseline scenarios. For other SDG targets, additional impact assessments were undertaken, as described in the following sub-sections.

2.2.1. Ambient and household air pollution health impact assessment (SDG 3 and 11)

Ambient and household fine particulate matter ($PM_{2.5}$) air pollution exposure are the risk factors for which premature mortality attributable to air pollution is quantified, as they contribute the largest fraction of air pollution's overall health burden (Murray et al., 2020). Changes in air pollutant emissions that occur alongside GHG emission reductions as the mitigation measures evaluated in this study are implemented are linked to changes in population-weighted annual average $PM_{2.5}$ concentrations across Zimbabwe, and the number of premature deaths attributable to exposure to these levels of $PM_{2.5}$ concentrations (or avoided as a result of reduction in air pollutant emissions), using methods described in Kuylenstierna et al. (2020). The number of premature deaths attributable to $PM_{2.5}$ exposure (ΔMort) was calculated by age (*a*), sex (*s*), and disease (*d*) using Eq. (1).

$$\Delta Mort = \sum_{a,s,d} \left(y_{o_{a,s,d}} * \frac{RR - 1}{RR} * pop_{a,s} \right) \tag{1}$$

Where y_o is the baseline mortality rate for the diseases associated with air pollution exposure (Abbafati et al., 2020), *pop* is the population exposed to $PM_{2.5}$ concentrations (i.e. the population of Zimbabwe disaggregated by sex and into 5-year age groups) (UN DESA, 2019), and RR is the relative risk of premature death associated with $PM_{2.5}$ exposure of a particular magnitude above the minimum risk exposure level.

Ambient and household $PM_{2.5}$-attributable health burdens were estimated for adults above 30 years old (due to chronic obstructive pulmonary disease, ischemic heart disease, ischemic stroke, lung cancer, and type 2 diabetes), and children under 5 years (lower respiratory infections), following Murray et al. (2020).

For household air pollution, Equation (1) was applied separately for populations in urban and rural areas, using different primary fuels for cooking, and for adults disaggregated into primary cooks and other adults living in the household. The primary cooks in urban and rural households were assigned $PM_{2.5}$ exposure estimates based on the average value of female $PM_{2.5}$ exposure in households cooking using different fuels for eastern Africa compiled in a review of empirical studies (electricity: 107 μg m^{-3}, wood: 388 μg m^{-3}, efficient wood stove: 197 μg m^{-3}, kerosene: 102 μg m^{-3}, LPG: 102 μg m^{-3}, coal: 75 μg m^{-3}). The exposure of other adults in each household, and children was calculated based on the ratio of male and child exposure to the primary cook exposure (Shupler et al., 2018).

For ambient air pollution, Equation (1) was applied based on estimated ambient annual $PM_{2.5}$ exposure averaged across the population. Air pollutant emissions, estimated as national totals as described in Section 2.1, were converted to ambient $PM_{2.5}$ concentrations using the methodology outlined in Kuylenstierna et al. (2020). First, emissions of the air pollutants contributing to primary and secondary $PM_{2.5}$ (black carbon, organic carbon, other primary PM, nitrogen oxides, sulphur dioxide and ammonia) were gridded

Table 14
Sustainable Development Goal Targets for which quantifiable indicators can be quantified to evaluate the GHG mitigation measures against.

Sustainable Development Goal Target	Indicator Quantified in GHG mitigation Assessment	Methodology used to quantify indicator	Reference for methodology
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	Area of land under conservation agriculture practise	User-defined input to GHG mitigation assessment	N.A.
3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births	Number of infant premature deaths from exposure to household and ambient air pollution	Household: Exposure to household air pollution from solid biomass cooking fuels linked to health impacts using integrated exposure response functions for acute lower respiratory infections. Ambient: GEOS-Chem Adjoint coefficients link air pollutant emissions to $PM_{2.5}$ exposure. Integrated exposure response functions link exposure to premature mortality from acute lower respiratory infections.	Kuylenstierna et al. (2020)
3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being **3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination** **11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management**	Number of premature deaths from exposure to household and ambient air pollution Number of premature deaths from low physical activity	Household: Exposure to household air pollution from solid biomass cooking fuels linked to health impacts using integrated exposure response functions for 5 diseases. Ambient: GEOS-Chem Adjoint coefficients link air pollutant emissions to $PM_{2.5}$ exposure. Integrated exposure response functions link exposure to premature mortality for 5 diseases. Estimate distribution of physical activity among population disaggregated by age and sex (characterised by Metabolic Equivalent Task hours (MET-h) per week) and quantify premature mortality due to the fraction of population with low physical activity.	Kuylenstierna et al. (2020) Murray et al. (2020) Garcia et al. (2021)
3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents	Number of deaths due to road traffic collisions	National data on the historic number of road traffic fatalities per year is disaggregated between collision types, and divided by vehicle-km travelled by different vehicle types to develop to estimate risk of fatal road traffic accidents per vehicle-km travelled by vehicle type which are then applied to projections of vehicle-km	Woodcock et al., 2013 Garcia et al., (2021)
5.4 Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate	Number of hours saved in wood collection and cooking from switching to more efficiency biomass stoves and cooking using gas instead of solid biomass	Number of hours required for wood collection and cooking calculated for households cooking using wood, charcoal, efficient biomass stoves, and gas, LPG and electricity. Total hours for all households calculated for each scenario based on proportion of households using different fuels/ technologies.	
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Premature mortality due to diarrheal diseases due to unsafe sanitation	Need to assess whether any wastewater measures could be added to assessment.	Murray et al. (2020)
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services **11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums**	% population with access to electricity % population using modern fuels for cooking	User-defined input to GHG mitigation assessment User-defined input to GHG mitigation assessment	N.A. N.A.
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	% electricity generated from renewable sources	Output from LEAP electricity generation model	Section 2.1.1

(*continued on next page*)

Table 14 (*continued*)

Sustainable Development Goal Target	Indicator Quantified in GHG mitigation Assessment	Methodology used to quantify indicator	Reference for methodology
7.3 By 2030, double the global rate of improvement in energy efficiency	Primary Energy Consumption per unit GDP	Output from LEAP model	Section 2.1.1
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	Total waste generated % of waste recycled, composted	Output from LEAP waste model User-defined input to GHG mitigation assessment	
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Number of hectares of land converted from forest to other types of land	User-defined input to GHG mitigation assessment	
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	Tonnes carbon removed from forest land remaining forest land	Output from Forestry and Other Land Use model	
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Biodiversity indicators	Potential avoided species loss characterisation factors for animal and plant types, eco-regions, land use types, and land use intensity multiplied by area of land converted to forest land	Chaudhary and Brooks (2018)

in 0.5° grids across Zimbabwe using international gridded proxy datasets for each of the major source sectors. Residential sector emissions were gridded according to population distribution (CIESIN, 2016). Industry, Services and Transport sector emissions were gridded according to the spatial distribution of GDP (Kummu et al., 2018). Agriculture emissions were gridded according to the distribution of cropland (Yu et al., 2020), and electricity generation gridded according to the location of power plants, disaggregated by fuel and weighted by power plant capacity (S&P Global Market Intelligence, 2017). The gridded emissions were then multiplied by coefficients from the GEOS-Chem Adjoint model that quantify the sensitivity of changes in emissions of $PM_{2.5}$ and $PM_{2.5}$-precursor pollutants in 2 × 2.5° grids globally to national population-weighted $PM_{2.5}$ concentration in Zimbabwe (Henze et al., 2007). The product of emissions for each year and scenario, and GEOS-Chem Adjoint coefficients parameterised for annual population-weighted $PM_{2.5}$ concentrations for Zimbabwe provides estimated of $PM_{2.5}$ exposure in historic years, and future years for each scenarios, that are used to determine the RRs used in Equation (1). (see Kuylenstierna et al. (2020) for more details).

2.2.2. Road traffic accidents (SDG 3)

Measures designed to reduce emissions that impact the composition of the vehicle fleet can affect road traffic accidents and associated health impacts by changing the vehicle fleet composition and likelihood of collisions between vehicle types. Therefore, the number of road traffic accident fatalities estimated in the different scenarios were estimated by applying the methodology outlined in Garcia et al. (2021). First, for historic years, total road traffic fatalities reported in ZimStat between 2013 and 2018 were disaggregated into collision categories, e.g. car colliding with pedestrian, car colliding with car etc., as shown in Table 15 based on the fraction of deaths from different collisions in Ghana, due to a lack of Zimbabwe-specific data (Garcia et al., 2021). Previous studies have shown similar levels of road traffic fatalities occurring in Ghana and Zimbabwe (Ishrat, 2018). Each fatality is assigned to a collision between two vehicle categories, and therefore does not take into account collisions involving more than two/vehicle categories. The number of fatalities for each category are then divided by the total number of vehicle-km travelled per year for each transport mode/vehicle category to estimate the risk of a fatal collision per vehicle-km travelled. For future scenarios, the risk of a fatal collision per vehicle-km travelled was assumed to stay constant, but the number of vehicle-km travelled by different vehicle types were projected as outlined in Section 2.1.1 for the baseline and mitigation scenario, resulting in the estimated changes in the number of fatal collisions as a result of baseline changes in transport activity, and from implementation of measures that impact the number of vehicle-km travelled on different transport modes.

Table 15
Total road traffic fatalities reported in Zimbabwe in 2018 and disaggregation between impacting mode (Ped = Walking, BC = Bicycle, LDV = Light Duty Vehicle, HDV = Heavy Duty Vehicle (Truck)).

Total Ped – 1532		Total BC -92		Total Car – 166		Total LDV - 25		Total Bus – 78		Total HDV - 23	
Ped x Ped	0.00	BC x Ped	0.00	Car x Ped	0.33	LDV x Ped	0.00	Bus x Ped	0.11	HDV x Ped	0.00
Ped x Bicycle	0.22	BC xBC	0.00	Car x BC	0.00	LDV x BC	0.00	Bus x BC	0.11	HDV x BC	0.00
Ped x Car	47.48	BC x Car	2.63	Car x Car	3.17	LDV x Car	0.33	Bus x Car	0.88	HDV x Car	0.33
Ped x Bus	23.85	BC x Bus	1.20	Car x Bus	2.74	LDV x Bus	0.44	Bus x Bus	1.53	HDV x Bus	0.44
Ped x HDV	8.32	BC x HDV	1.09	Car x HDV	2.41	LDV x HDV	0.55	Bus x HDV	1.42	HDV x HDV	0.44

2.2.3. Physical health benefits of active travel (SDG 3)

In addition to road traffic collisions, mitigation measures that promote active travel could reduce GHG emissions and yield further health benefits. The health impacts estimated are the number of premature deaths associated with low physical activity, as outlined in Garcia et al. (2021). Zimbabwe's population was disaggregated by age and sex, and the indicator of weekly physical activity for each population group was characterised using the Metabolic Equivalent of Task-hours (MET-h) metric. The distribution of physical activity in each population group was characterised by assigning a fraction of each population group to different MET-hs bins ranging from the least physically active (0–300 MET-h/week), to the most physically active (>4500 MET-h/week). For historic years, and for the baseline scenario, due to a lack of Zimbabwe-specific data, the MET-hr distribution for each population group was taken from Garcia et al. (2021). For the mitigation measure to encourage walking and cycling, a larger fraction of the population in each population group were assigned to the more active MET-h/week bins.

The health burden associated with a certain level of physical activity was calculated using Eq. (1) following the methods outlined in Murray et al. (2020). Low physical activity is associated with increased mortality due to ischemic heart disease, ischemic stroke, Type-II diabetes, breast cancer, and colorectal cancer. The premature deaths for each population group and disease were calculated using Eq. (1). The relative risks (RR) and baseline mortality rates (y_0) for different levels of physical activity (MET-h/week), disease, sex and age were taken from Murray et al. (2020).

2.2.4. Time saved from domestic cooking (SDG 5)

Cooking with cleaner fuels/technologies has time-saving benefits which disproportionately benefit women and girls and could be used for economic or educational purposes. Equation (2) was applied to estimate the time spent by primary cooks cooking using different fuels and technologies (Jeuland and Pattanayak, 2012).

$$CT_i = Pop. * cook_{t0} * TE_i * (1 - SF_i) * 365 \tag{2}$$

Where CT_i is the time spent cooking using a particular fuel/stove (hours per year), *Pop.* is the number of primary cooks in households cooking using a particular fuel/stove in each scenario (Section 2.2.1), $cook_{t0}$ is the number of hours spent cooking per day using a traditional wood stove, SF_i is the fraction of the population switching to a new stove/fuel that is sustained (i.e. without backsliding to the previous cooking fuel), and was assumed to be 1 in this application. TE_i is the fraction of time required for cooking using a particular fuel/technology relative to a traditional woodstove. The values used in this work are shown in Table 16, and due to the absence of Zimbabwe-specific data, were taken from studies undertaken in similar contexts across Africa (Ghana Statistical Service, 2014; Jeuland and Pattanayak, 2012).

2.2.5. Unsafe water and sanitation health impacts (SDG 6)

Lack of access to modern domestic wastewater treatment systems (i.e. sewer connection or septic tanks) is associated with increased risk of premature mortality from diarrheal diseases. The methodology outlined in Murray et al. (2020) for quantifying the number of premature deaths attributable to unsafe sanitation was applied to the populations using different wastewater treatment systems in Zimbabwe. As outlined in Section 2.1.4, the emissions from domestic wastewater were estimated only for the urban population, and therefore health impacts were only quantified for the urban population. Equation (1) was applied to quantify the number of premature deaths due to diarrheal diseases attributable to unsafe sanitation, and was applied separately for population groups disaggregated by age (5-year age groups), sex, and wastewater treatment system. Baseline mortality rates for diarrheal diseases for each population group were taken from Abbafati et al. (2020). As shown in Table 13, the wastewater treatment types in urban areas were disaggregated into three categories, latrines (31% of urban population), septic tanks (32%) and centralised wastewater treatment plants (37%). Septic tanks and sewage connections to centralised wastewater treatment were assigned a relative risk of 1, i.e. no increased risk of premature mortality for diarrheal disease. For latrines, the relative risk for unimproved sanitation (3.203 (95% C.I.: 2.987–3.513) from Murray et al. (2020) were used.

2.2.6. Biodiversity impacts (SDG 15)

Zimbabwe's NDS1 includes measures to increase the area of forest land, and to increase forest plantations, as well as reducing the incidence and extent of forest fires, which were included as part of the updated NDC. Chaudhary and Brooks (2018) have developed the Countryside species-area relationship (SAR) to quantify potential species losses per m^2 land area due to land occupation and

Table 16
Key variables used to quantify the number of hours required for cooking.

Variable	Value
Time spent cooking by Primary cook using traditional wood stove (hours per day)	0.743
Fraction of time for cooking compared to traditional stove	
Traditional wood stove	1
Improved wood burning	0.95
Traditional charcoal burning	0.75
Improved charcoal burning	0.75
Kerosene	0.7
Propane (LPG?)	0.67
Electric	0.63

transformation for five taxa, six land use types, three intensities and 804 eco-regions. Whilst not encapsulating all forms of potential biodiversity change, the characterisation factors developed provide an estimate of the contribution of land use changes to potential species extinction, hence results are an indicator of the impact of changes in land use, and land use intensity on the continued existence of mammal, bird, amphibian, reptile and plant species within the ecoregion where the land use change takes place. In this study, the average global land transformation characterisation factors provided by Chaudhary and Brooks (2018) were applied to assess the potential 'avoided species losses' from the NDS1 measures to increase forest area (500,000 ha between 2021 and 2025) and increase the area of forest plantations (50,000 ha, Table 3). NDS1 does not specify the ecoregions where the reforestation will occur, what type of land will be afforested, or the nature of forests that will be replanted, e.g. if it is land currently used for pasture, crop production, or degraded land. Therefore, in this study, different scenarios were constructed to estimate a range of potential avoided species losses for different implementations of the NDS1 mitigation measures in the forestry sector.

The terrestrial eco-regions used in Chaudhary and Brooks (2018) disaggregates Zimbabwe into 7 eco-regions (Olson et al., 2001). These ecoregions include i) Drakensberg montane grasslands, woodlands and forests (1.14 thousand ha area in Zimbabwe in 2005), Eastern Zimbabwe montane forest-grassland mosaic (664 thousand ha), Kalahari Acacia-Baikiaea woodlands (309 thousand ha), Southern Africa bushveld (6,222 thousand ha), Southern Miombi woodlands (17,500 thousand ha), Zambezian and Mopane woodlands (10,700 thousand ha), Zambezian Baikiaea woodlands (3,403 thousand ha). The characterisation factors in Chaudhary and Brooks (2018) include, for each ecoregion, the potential species loss per m^2 land converted from natural habitat/vegetation to pasture, crop land, urban land, or plantation/logging, accounting for the persistence potential of species in new habitats. Characterisation factors for each of these conversions are also disaggregated by 3 levels of intensity of activity on the deforested land for each new land use type (minimal, medium and intensive). Each scenario assessed the impact of converting land back to the natural habitat or plantation for.

i) each taxonomic group;
ii) conversion from pasture, cropland or urban land;
iii) conversion from minimal, medium or intensive use of each type of land; and
iv) conversion of land in each of the eco-regions in Zimbabwe, with the exception of Drakensberg montane grasslands, woodlands and forest, which covers too small an area of Zimbabwe to support conversion of 500,000 ha of land to forest type in this eco-region.

The characterisation factors developed in Chaudhary and Brooks (2018) were developed to assess the potential species loss per m^2 area converted from the natural habitat in each ecoregion to each alternative land use type. In the scenarios included in this work, two approaches are taken to their application to land converted to forest, and estimating the potential avoided species loss from this conversion. In Approach 1, each characterisation factor from a species/land use/intensity was multiplied by the area of land converted to forest/plantation, and the mean value estimated for each scenario. This provides an estimate of the potential avoided species loss from conversion of the land back to the natural vegetation characteristics of each eco-region. In Approach 2, the difference between the characterisation factors for each species/land use/intensity and for minimal intensity plantation forest for each species was calculated as this is likely to be the land use most accurately representing reforestation objectives. This difference was then multiplied by the number of years and then by the area of land converted. The aim of Approach 2 is to assess the potential avoided species loss if the reforestation does not achieve a return to the original vegetation type in each eco-region. The set of scenarios included in Approaches 1

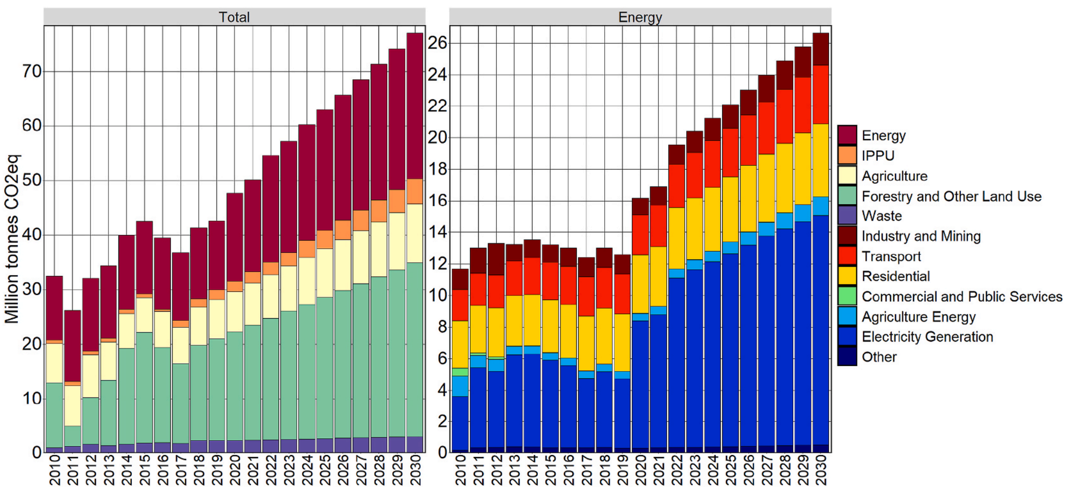

Fig. 1. a) National total GHG emissions (including all sources and sinks from FOLU) in Zimbabwe between 2010 and 2017 (historical years) and 2018–2030 for a baseline scenario, and b) Total GHG emissions from the energy sector in Zimbabwe for historical (2010–2017) and future (2018–2030) years.

and 2 were then averaged across intensity of land use type, and crop, pasture and urban land use types, to assess the potential avoided species loss from making the conversion in each eco-region, and for a return to the natural vegetation and a lightly used plantation forest.

3. Results

3.1. Historical (2010–2017) and baseline (2030) emission estimates

Total GHG emissions varied from 26.2 million tonnes CO_2-equivalent emissions in 2011 to 42.5 million tonnes in 2015 (Fig. 1). Forestry and Other Land Use was the largest GHG source, with an average net emissions between 2010 and 2017 of 13 million tonnes CO_2-equivalent (38% of the 2010–2017 average total GHG emissions). However, there was substantial variability in the magnitude of FOLU emissions. The energy sector also emitted, on average, approximately 13 million tonnes CO_2-equivalent GHG emissions (36%), with less interannual variation. Electricity generation contributed approximately half of total energy sector GHG emissions, with residential, transport, and industry sub-sectors also substantial sources (Fig. 2). Agriculture contributed 20% of total GHG emissions, and IPPU and waste contributed 2% and 4%, respectively (Fig. 1).

Different GHGs have different source contributions (Table 15, Fig. 3). For CO_2, 40% of emissions came from FOLU in 2017, with 15% from electricity generation, 15% from industry, with smaller contributions from transport, industry and agricultural energy consumption. Methane and nitrous oxide emissions were predominantly emitted from agriculture, with the residential energy (biomass) combustion, and waste sectors also contributing to CH_4 emissions. The residential sector (biomass cooking) makes the largest contribution to black carbon and other particulate matter air pollutant emissions, contributing >95% of particulate matter air pollutants (black carbon, organic carbon, and overall $PM_{2.5}$).

Total estimated GHG emissions in 2030 in the baseline scenario were 77.0 million tonnes CO_2-equivalent, 109% higher than in 2017 (Fig. 1). FOLU, and Energy were also the largest GHG emission sources in 2030 in the baseline. The increased energy sector emissions is largely due to electricity generation (Fig. 2), through installed coal-fired generating capacity between 2019 and 2022 (including Hwange 7–8 coal power plant expansion) (Zimbabwe Electricity Transmission and Distribution Company, 2017). There were also increases in other energy sub-sectors, as a result of projected population and GDP increases that were used as drivers of activity in these energy demand sectors (Section 2.1). These drivers also result in a substantial increase in emissions of black carbon and particulate matter co-emissions from the energy sector, with national total emissions increasing 60% and 57%, respectively (Table 19). The baseline scenario highlights that while Zimbabwe makes a very small contribution to global GHG emissions, emissions are projected to increase without the implementation of GHG mitigation policies and measures. The overlapping sources of GHGs and co-emitted SLCPs and air pollutants indicates that the projected baseline increases in GHG emissions could also increase local air pollution emissions, exposure and impacts in Zimbabwe, particularly for those population groups that rely on wood and other biomass fuels for cooking.

3.2. Emission reduction potential of mitigation measures

The 17 mitigation measures included in the 'NDC measures' scenario were estimated to reduce GHG emissions by 40% in 2030 compared to baseline emissions in 2030 (Fig. 3, Table 17). Implementation of the NDC and 8 additional measures resulted in a 63% reduction in GHG emissions in 2030 compared to the baseline scenario, and a 22% reduction compared to 2017 levels. The largest

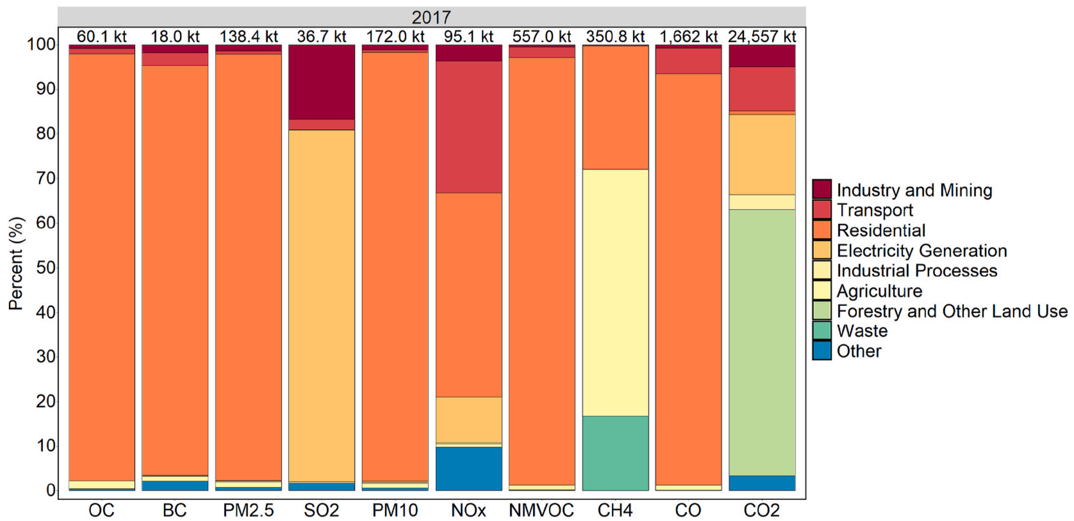

Fig. 2. Contribution of different major emitting source sectors to total emissions of GHGs, SLCPs and air pollutants in Zimbabwe in 2017.

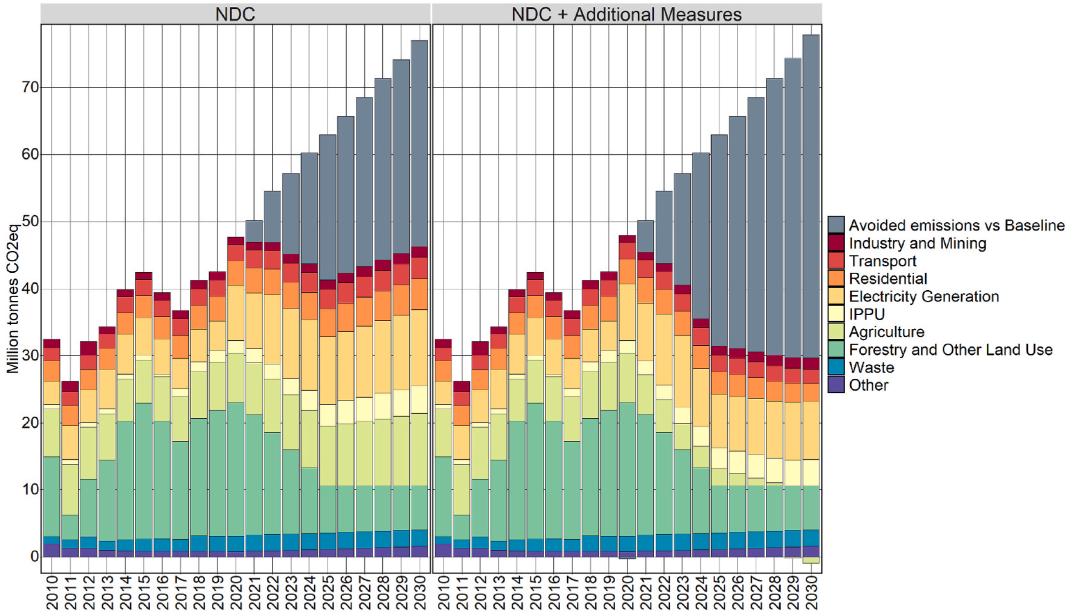

Fig. 3. Reduction in GHG emissions from implementation of a) NDC Measures and b) NDC Measures + Additional measures.

absolute and proportional GHG emission reductions occur in AFOLU (Table 17), followed by energy.

When GHG emission reductions are assessed for individual measures, the three measures targeting the FOLU sector result in the largest net GHG emission reductions. Increasing forest area by 500,000 ha, and reducing the areas affected by fires by 500,000 ha by 2025 could reduce national total GHG emissions by 12.5% and 27.2% in 2030 compared to a baseline scenario, respectively. In the energy sector, reducing demand for electricity through energy efficiency improvements was estimated to achieve the largest reduction in energy sector GHG emissions of the NDC measures, followed by reducing transmission and distribution losses, and 300 MW solar expansion (Table 18). However, the most effective energy sector mitigation measures were included in the additional measures scenarios, i.e. measures not included within the NDC but included in other plans and strategies in Zimbabwe, including greater expansion of renewable electricity generation, and switching to cleaner fuels for cooking (Table 18). Despite large reductions, FOLU, and electricity generation are still the largest GHG emission sources in 2030 after implementation of all mitigation measures. Within the energy sector transport becomes a relatively larger proportion of total GHG emissions after implementation of all 28 mitigation measures.

Carbon dioxide are reduced by the largest proportion of individual GHG emissions, 78% in 2030 compared to the baseline scenario from implementation of the NDC and additional measures scenarios (Table 20) compared to only 23% for CH_4. This reflects a lack of measures targeting the major methane sources in agriculture (enteric fermentation and manure management). Co-emitted air pollutants like $PM_{2.5}$ emissions are approximately halved in 2030 compared to the baseline from the implementation of all mitigation measures. The largest portion of this reduction is achieved from households switching to more efficient biomass stoves, and cleaner fuels for cooking, which were included as 'additional measures' and not included in the updated NDC. NO_x emissions, and those of other gaseous air pollutants, are reduced less, due to substantial emissions from sources other than residential which are reduced by less (e.g. transport). For the NDC measures, there is a modest reduction in the emissions of air pollutants, which would yield some public health benefits from reduced air pollution exposure. More substantial reduction in air pollutant emissions alongside the GHGs occur from implementation of the 'additional measures' (Table 20). This highlights that there are substantial local public health benefits in Zimbabwe due to improved air quality that would result from implementation of the additional climate change mitigation

Table 17
Sectoral reductions in GHGs in 2030 compared to a baseline scenario.

Sector	2017 GHG emissions (million tonnes CO_2-equivalent)	2030 baseline GHG Emissions (million tonnes CO_2-equivalent)	2030 NDC measures GHG emissions (million tonnes CO_2-equivalent)	2030 NDC + Additional measures GHG emissions (million tonnes CO_2-equivalent)
Energy	12.41	26.62	22.42 (−15.8%)	19.8 (−27.07%)
IPPU	1.22	4.56	4.06 (−11.1%)	3.93 (−13.9%)
Agriculture, Forestry and Other Land Use	21.38	42.78	17.43 (−59.3%)	5.62 (−86.9%)
Waste	1.76	3.00	2.4 (−19.9%)	2.4 (−19.9%)
Total	36.77	76.97	46.32 (−39.8%)	28.75 (−62.7%)

Table 18
Summary of GHG emission reduction potential in 2030 compared to a baseline scenario (emissions: 76.97 million tonnes CO2-equivalent emissions) for mitigation measures extracted from plans and strategies in Zimbabwe.

Number	Sector	Mitigation Measure	Scenario	Percent GHG reductions vs 2030 baseline (%)	Absolute GHG emission reduction 2030 vs baseline (thousand tonnes CO_2-equivalent)
1	Electricity Generation	Transmission and Distribution losses reduced from 18% in 2020 to 11% in 2025	NDC Measures	0.99	760.36
2	Electricity Generation	Expansion of Solar: Solar: 300 MW in 2025	NDC Measures	0.60	459.74
3	Electricity Generation	Expansion of microgrids: Additional 2.098 MW of capacity added through microgrids by 2028	NDC Measures	0.00	3.27
4	Electricity Generation	4.1 MW biogas capacity added in 2024	NDC Measures	0.01	9.30
5	Energy Efficiency	Energy Efficiency Improvements: Agriculture: 12% savings (2030 compared to baseline scenario) Commercial: 16% savings Domestic: 22.08% savings Manufacturing: 18.63% savings Mining: 8% savings	NDC Measures	2.66	2,048.82
6	Transport	10% biodiesel in fuel by 2030	NDC Measures	0.05	37.76
7	Transport	Fuel economy policy Fuel efficiency improvement 2025–2030: Motorcycles: 2.2% per year LDVs: 2.9%/year Buses: 2.6%/year HGVs: 2.5%/year	NDC Measures	0.72	554.22
8	Transport	Public transport (modal shift). 10% shift from private car to public transport in 2030	NDC Measures	−0.11	−88.05
9	Electricity Generation	Planned large hydropower at Batoka (1200 MW, 6000 GWh generation) comes online in 2030	Additional Measures	3.21	2,470.34
102	Electricity Generation	2100 MW additional renewable energy capacity installed by 2030 (150 MW small hydro, 1575 MW grid solar, 100 MW wind, 275 MW bagasse)	Additional Measures	4.42	3,401.00
11	Transport	Electric- and hydrogen vehicles. Electric vehicle % in vehicle fleet in 2030: Motorcycles: 77% LDVs: 37% Buses: 39% HGVs: 20%	Additional Measures	1.64	1,265.37
12	Residential	Households with improved cookstoves: 60% of rural population using improved cookstoves	Additional Measures	1.62	1,246.36
13	Residential	Households with cleaner fuels for cooking: 22% of rural population using LPG	Additional Measures	0.87	667.46
14	Residential	Replacement of 250,000 electric geyser water heaters with solar water heaters	Additional Measures	0.52	402.27
15	Transport	10% increase in journeys taken by walking and cycling compared to private vehicle	Additional Measures	–	
16	Industrial Processes and Product Use	Increased clinker substitution with fly ash (up to 16% by 2030, 20% by 2050).	NDC Measures	0.04	28.74
17	Industrial Processes and Product Use	Increased clinker substitution with BFS (up to 16% by 2030, 20% by 2050).	NDC Measures	0.04	28.74
18	Industrial Processes and Product Use	Decomposition of N2O emissions through use of a secondary catalyst. Selective De-N2O catalyst results in abatement of approximately 75% of all N2O emissions produced during nitric acid production. Implementation by 2023	NDC Measures	0.11	84.46
19	Industrial Processes and Product Use	HFC Phasedown schedule Kigali Amendment (Freeze, 2024; 2029, 10% reduction)	NDC Measures	0.51	391.74
20	Industrial Processes and Product Use	Substitution of coke input to BF/BOF steel making with biocoke Replacement of up to 10% fossil carbon input by sustainable biocoke supply by 2025.	Additional Measures	0.07	57.68

(*continued on next page*)

Table 18 (*continued*)

Number	Sector	Mitigation Measure	Scenario	Percent GHG reductions vs 2030 baseline (%)	Absolute GHG emission reduction 2030 vs baseline (thousand tonnes CO_2-equivalent)
21	Industrial Processes and Product Use	Substitution of coke input to FeCr-production with biomass (bio-coke). Replacement of up to 10% fossil carbon input by sustainable biocoke supply by 2025.	Additional Measures	0.09	70.51
22	Forestry and Other Land Use	Increase area of forest land from 9.9 million hectares to 10.4 million hectares by 2025: Add 100,000 ha of natural forest land per year between 2021 and 2025	NDC Measures	12.47	9,598.73
23	Forestry and Other Land Use	Increase area of forest plantation from 68848 ha to 118848 ha by 2025: Add 10,000 ha of plantation forest land per year between 2021 and 2025	NDC Measures	13.00	10,006.89
24	Forestry and Other Land Use	Reduce area burned by 500,000 ha between 2020 and 2025	NDC Measures	27.19	20,925.13
25	Crop Production	Implementation of conservation agriculture. Increasing area under conservation agriculture from 235,905 ha in 2020 to 494,955 ha in 2030	NDC Measures	13.68	10,526.51
26	Solid Waste/ Energy	Waste to Energy: It was assumed that 42% of the methane generated would be collected and used for energy production through waste to energy projects in Bulawayo and other major cities	NDC Measures	1.23	947.08
27	Solid Waste	20% of organic matter composted in the long term	NDC Measures	0.52	402.52
28	Liquid waste	All urban areas are connected to sewage system by 2030	Additional measures	–	

Table 19
National total emissions of GHGs, SLCPs and air pollutants for 2010 and 2017 (historical years) and for 2020, 2025 and 2030 for a baseline scenario (unit: kilotonnes).

Pollutant	2010	2017	2020	2025	2030
Carbon Dioxide	21,194	24,556	33,283	45,468	55,969
Methane	328.2	350.8	397.0	467.7	553.8
Nitrous Oxide	5.50	5.08	5.49	6.27	7.17
HFCs (total, 100 year GWP)					
Carbon Monoxide	1,462	1,662	1,776	2,053	2,311
Non Methane Volatile Organic Compounds	481.6	557.0	592.3	668.4	750.8
Nitrogen Oxides	80.90	95.10	104.92	132.52	158.32
Sulphur Dioxide	40.88	36.67	50.78	80.92	97.58
Particulates PM10	151.9	172.0	184.4	212.1	238.1
Particulates PM2pt5	122.7	138.4	148.3	171.3	192.4
Black Carbon	15.64	17.96	19.18	22.13	25.05
Organic Carbon	52.84	60.10	64.67	75.05	84.02

Table 20
GHG, SLCP and air pollutant emissions in 2030 for Baseline, NDC Measures and Additional Measures scenarios.

Scenario	OC	BC	$PM_{2.5}$	PM_{10}	NOx	NMVOC	CH_4	CO	CO_2
Baseline	84.0	25.0	192.4	238.1	158.3	750.8	553.8	2,310.7	55,969.2
NDC Measures	83.9 (−0.2%)	24.9 (−0.4%)	191.7 (−0.4%)	237.2 (−0.4%)	150.9 (−4.7%)	749.3 (−0.2%)	533 (−3.8%)	2300.5 (−0.4%)	26417.6 (−52.8%)
Additional Measures	46.2 (−45%)	13.9 (−44.4%)	105.1 (−45.4%)	129.0 (−45.8%)	102.9 (−35%)	396.2 (−47.2%)	427 (−22.9%)	1252.6 (−45.8%)	12266.9 (−78.1%)

measures beyond those included in Zimbabwe's revised NDC, but which are included within other plans and strategies in Zimbabwe.

3.3. Sustainable development benefits of GHG mitigation

Implementation of the 28 mitigation measures evaluated could also achieve substantial benefits locally in Zimbabwe that align with achieving multiple sustainable development goals in addition to GHG emission reductions (summarised in Table 21). Firstly, the implementation of mitigation measures to reduce GHG emissions in Zimbabwe could also achieve substantial human health benefits. The largest health benefits are associated with reduction in exposure to air pollution. Exposure to ambient and household $PM_{2.5}$ air

Table 21
Summary of quantified SDG targets for which implementation of GHG mitigation measures lead to benefits in Zimbabwe.

Sustainable Development Goal Target	Indicator Quantified in GHG mitigation Assessment	Reference value for 2017	Baseline value 2030	Mitigation value 2030 NDC measures	Mitigation value 2030 NDC + Additional measures	Key mitigation measures contributing to achieving benefit
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	Area of land under conservation agriculture practise (hectares)	235,905 (2020 value)	235,905	494,955	494,955	Measure 25
3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births	Number of infant premature deaths from exposure to household and ambient air pollution	Household air pollution: infant deaths 5423 Ambient air pollution: 539 infant deaths	Household air pollution: 6662 infant deaths Ambient air pollution: 657 infant deaths	Household air pollution: 6640 infant deaths Ambient air pollution: 656 infant deaths	Household air pollution: 5772 infant deaths Ambient air pollution: 514 infant deaths	Measure 4 Measure 5
3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Number of premature deaths from exposure to household and ambient air pollution Number of premature deaths from low physical activity	Household air pollution: 5834 premature deaths (adults >30 years) Ambient air pollution: 2540 premature deaths (adults >30 years)	Household air pollution: 7784 premature deaths (adults >30 years) Ambient air pollution: 3324 premature deaths (adults >30 years) 4848	Household air pollution: 7780 Ambient air pollution: 3314 premature deaths (adults >30 years) 4848	Household air pollution: 7403 Ambient air pollution: 2756 premature deaths (adults >30 years) 4826	Measure 4 Measure 5
3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents	Number of road traffic fatalities (deaths)	1595 deaths	2966 deaths	2876 Deaths avoided vs 2030 baseline: 90 deaths		
5.4 Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate	Number of hours spent by primary households cooks spent cooking (million hours)	842	1116	1116	1035 Hours saved vs 2030 Baseline:80 million	

(continued on next page)

Table 21 (*continued*)

Sustainable Development Goal Target	Indicator Quantified in GHG mitigation Assessment	Reference value for 2017	Baseline value 2030	Mitigation value 2030 NDC measures	Mitigation value 2030 NDC + Additional measures	Key mitigation measures contributing to achieving benefit
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	Premature deaths attributable to unsafe sanitation (urban population only)	All ages: 337 Under 5: 94	All ages: 236 Under 5: 37	All ages: 236 Under 5: 37	All ages: 0 Under 5: 0	
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services 11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	% households with access to electricity % households using modern fuels for cooking (Electricity, LPG)	Urban: 79% Rural: 20% Urban: 79.3% Rural: 4.4%	Urban: 95% Rural: 75% Urban: 79.3% Rural: 4.4%	Urban: 95% Rural: 75% Urban: 79.3% Rural: 4.4%	Urban: 95% Rural: 75% Urban: 79.3% Rural: 25%	
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	% electricity generated from renewable sources	52.0%	36.4%	42.4%	55.7%	
7.3 By 2030, double the global rate of improvement in energy efficiency	Primary Energy Consumption per unit GDP(GJ/billion USD)	39.7	49.9	45.0	36.7	
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	Total waste generated (urban population only, million tonnes) % of waste recycled, composted (urban population only, %)	2219 0%	4961 0%	4961 20%	4961 20%	
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Deforestation: hectares of land converted from forest to other land types (hectares per year) Reforestation: Hectares of land converted from other land to forest land (hectares per year)	253,859 ha/y 56,537 ha/y	253,859 ha/y 56,537 ha/y	161,440 ha/y 110,000 ha/y	161,440 ha/y 110,000 ha/y	
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Biodiversity indicators		N.A.	Conversion to natural forest of eco-region type (potential avoided species losses averaged across eco-region, intensity and type of land use converted from) Mammals: 0.0176 potential avoided species lost Birds: 0.0133 Amphibians: 0.0260 Reptiles: 0.0039 Plants: 0.604 Conversion to minimal use plantation forest (potential avoided species loss averaged	N.A.	N.A.

(*continued on next page*)

Table 21 (*continued*)

Sustainable Development Goal Target	Indicator Quantified in GHG mitigation Assessment	Reference value for 2017	Baseline value 2030	Mitigation value 2030 NDC measures	Mitigation value 2030 NDC + Additional measures	Key mitigation measures contributing to achieving benefit
				across eco-region, intensity and type of land use converted from) Mammals: -1.081 × 10^{-5} potential avoided species lost Birds: -1.1 × 10^{-4} Amphibians: -1.4 × 10^{-4} Reptiles: -3.3 × 10^{-4} Plants: -0.0630		

pollution was estimated to be associated with approximately 3,100 and 11,000 premature deaths, respectively, in 2017, consistent with other estimates of air pollution disease burdens in Zimbabwe (Murray et al., 2020). Almost half of the disease burden from household air pollution is estimated to fall on children, with almost 6,000 infant deaths estimated in 2017. In the baseline scenario, the health burden from air pollution is estimated to increase, with a 23% increase in infant mortality, and a 33% increase in adult mortality attributable to ambient and household air pollution. These increases result not only from increases in air pollutant emissions, but also increases in population, and demographic shifts in 2030 compared to 2017. The implementation of the measures included in the NDC result in a very small reduction in air pollution disease burden in 2030 compared to the baseline, due to the small reduction in air pollutant emissions estimated to result from the implementation of the NDC measures (Table 20). However, implementation of the additional measures, in particular the implementation of more efficient biomass cookstoves, and cleaner fuels for cooking (Measures 12 and 13, Table 18), lead to a larger health benefit due to reduced ambient and household air pollution exposure (Table 21). The implementation of additional measures was estimated to avoid approximately 1,000 infant deaths per year in 2030 compared to the baseline scenario, and just under 1,000 adult premature death per year (Table 21).

Other health benefits were estimated to result from implementation of mitigation measures in the transport sector due to reduced road traffic fatalities and switches to active travel, and from expansion of connection to centralised wastewater treatment systems. However, in general the reductions in premature deaths were lower than the reductions due to air pollution exposure. In the case of unsafe sanitation, approximately 300 premature deaths per year by 2030 were estimated to be avoided through expanding connection to sewage systems. However, this did not consider the health burden, or potential benefits for the rural population in Zimbabwe, and therefore excludes a substantial portion of the health burden from this risk factor, due to a lack of data on wastewater treatment in rural areas. For the transport measures, the health burden from low physical activity is comparable with the health burden from air pollution, but the proposed measure to increase walking and cycling has a limited impact on reducing this burden because of the level of ambition of the measures (10% modal shift in journeys to walking and cycling), and feasibility of large changes. For road traffic accidents, the overall number of fatalities from road traffic accidents is smaller than estimated for air pollution exposure, and the measures which changes the number of vehicle-km travelled by different transport modes do not substantially change the frequency of collisions between different vehicle types, and therefore do not substantially reduce the risk of fatal collisions.

Mitigation measure 21 (Table 3), conversion of 500,000 ha of land to natural forest land was the key measure for which the impact on biodiversity (potential avoided species loss) was evaluated. The biodiversity impact assessment showed how and where this measure is implemented could result in large differences in its biodiversity impact, alongside the benefits of enhancing GHG sinks (Table 21). If the land converted to forest land is restored to its natural state and vegetation types, then there was estimated to be a positive impact on biodiversity across all taxonomic groups. On average across the six eco-regions for which potential avoided species loss was assessed, the global potential avoided species loss for plants (0.1 avoided species lost on average) had the largest absolute potential biodiversity benefit, because the larger number of species of plants within each of the eco-regions evaluated compared to other taxa (between 1300 and 2500 plant species per eco-region, Chaudhary and Brooks (2018)). Fewer amphibian and reptile species are present in each of ecoregions (between 22 and 153), and therefore the absolute avoided species loss for these animal types was lower. Between 108 and 200 mammals species, and 400 and 552 bird species are supported in each of the ecoregions, and the potential avoided species loss for these was larger than for reptiles.

However, if the land is converted to a plantation forest, even if the intensity of land use is minimal, then the impact on biodiversity was estimated to be, on average, negative for all taxonomic groups assessed and land types. The specific description of this measures in the NDC or NDS1 does not detail the specific type of forest that will be reforested. This assessment shows that to maximise the biodiversity benefits from the implementation of this measure, it is important to consider where this will occur and the type of forest that will be afforested on the land converted to forest land, and that conversion to the vegetation in the natural ecoregion to the greatest extent possible is most effective in ensuring that the biodiversity benefits are maximised. It is important to note that the overall avoided species loss metric used in this work does not disentangle potential species losses when conversion to forests, other natural habitats and/or plantation forests takes place, i.e. it provides an overview of the net potential avoided species loss for a particular taxonomy. This highlights the utility in undertaking more detailed species and habitat specific assessments, and/or utilising additional biodiversity metrics, in addition to the aggregate assessment undertaken in this study. In addition, the way in which Measure 21 is implemented will also determine the quantity of CO_2 that can be sequestered from conversion of land to forest land. As the NDC moves to implementation, the GHG mitigation reductions from Measure 21 should be revised and updated with climate change monitoring systems to reflect the specific way in which it will be implemented.

Finally, Table 21 shows that the implementation of the mitigation measures included in this assessment would also lead to positive benefits for other development areas, including energy (energy efficient and access to modern energy services), forestry, and sustainable agriculture. For those benefits related to biodiversity, sustainable forestry and agriculture, the implementation of Zimbabwe's NDC achieves the entirety or majority of these benefits. However, for human health, the majority of the health benefits quantified in this assessment are not achieved through implementation of the measures that underpin Zimbabwe's NDC target, but are achieved from the implementation of the additional mitigation measures. This underlines that there are actions that could be the basis for increasing Zimbabwe's climate change mitigation targets that could yield local benefits for public health in Zimbabwe.

4. Discussion

4.1. Implications for climate change and sustainable development planning in Zimbabwe

The ability to integrate sustainable development benefits into climate change mitigation assessments that inform climate change mitigation targets increases understanding of how countries will directly benefit from the action they take. This provides an opportunity for climate change mitigation targets to be more ambitious, through the inclusion of additional mitigation actions motivated by the quantifiable local development benefits they can achieve. The application of an integrated climate change mitigation and development assessment methodology has several implications for climate change planning, in terms of the level of ambition of the target, and the national development priorities that can be achieved.

In 2015, Zimbabwe submitted its Intended Nationally Determined Contribution (INDC) which committed to reduce per capita *energy sector* GHG emissions by 33% in 2030 compared to a baseline scenario (Republic of Zimbabwe, 2017). To achieve this target, 5 mitigation measures were identified, including i) ethanol blending in gasoline for transport, ii) increased penetration of solar water heaters, iii) energy efficiency improvements, iv) increasing hydro in the energy mix, and v) refurbishment and electrification of the rail system. The GHG mitigation assessment described here was used as the basis for Zimbabwe's 2021 NDC update, and is substantially more detailed compared to the INDC mitigation commitment, due to the larger number and broader scope of mitigation measures evaluated in the energy sector, and the inclusion of mitigation measures in non-energy sectors (AFOLU, IPPU and waste) (Government of Zimbabwe, 2021).

In Zimbabwe's INDC, per capita energy sector GHG emissions in the baseline scenario in 2030 were estimated to be 3,313 kg/per person, which, using the population projection used here (19.34 million people in 2030), equates to 64.1 million tonnes CO_2-eq baseline GHG emissions in 2030. In this study, baseline energy sector GHG emissions in 2030 were projected to be substantially lower, 26.2 million tonnes CO_2-eq emissions. The reasons for the difference in baseline GHG emissions from the energy sectors between the 2015 INDC and this study are difficult to disentangle, but likely include.

1. Different historic estimates of GHG emissions as the starting point for projections: Historic energy sector GHG emissions were estimated to be 12.4 million tonnes in 2017 in this study, compared to approximately 14.6 million tonnes in the INDC. This reflects the fact that in the 2015 INDC, 2017 energy sector emissions were projected, rather than represented using actual data as in this work.
2. Differences in assumptions about socioeconomic development in Zimbabwe: The methodology for projecting GHG emissions from the energy sector in the INDC are not detailed in the document, but are likely to differ substantially from the assumptions described here. For example, the GDP and value added growth rates from the NDS1 are economic projections that account for the COVID-19 pandemic's impact, and the expected economic recovery, and hence anticipate slower short-term economic growth than previous economic projections (Republic of Zimbabwe, 2020).
3. Growth rate time period: the period over which economic growth projections are made is smaller than for the INDC. In the 2015 INDC, historic GHG emissions were projected from the year 2016–2030, i.e. 14 years. In contrast, here, projections are made from 2018 to 2030, i.e. 12 years. Projecting for a larger number of years increases the chances that projected economic growth (and hence emissions) diverge from actual economic growth.

Due to the different baseline energy sector GHG emission projections in the 2015 INDC and updated GHG mitigation assessment for the revised NDC, the percentage reduction in per capita energy sector emissions in both the INDC and 2021 NDC reflect different levels of GHG emission reductions. In the 2015 INDC, the 33% reduction in per capita energy sector emissions implies that in 2030, instead of emitting 64 million tonnes CO_2-eq emissions from the energy sector, Zimbabwe's energy sector emissions will be 42.7 million tonnes. In contrast, the updated NDC estimates that total energy sector GHG emissions will be reduced by 16% from implementation of the mitigation measures included in the revised NDC. While this percentage reduction is lower than the INDC, the absolute emissions emitted in Zimbabwe in 2030 are substantially lower than the INDC, at 22.4 million tonnes CO_2-eq emissions (Table 16).

Therefore, in comparison to Zimbabwe's 2015 INDC, the 2021 NDC update establishes a target that results in substantially lower GHG emissions in 2030 from the energy sector compared to the previous national climate change mitigation target. In addition, the updated NDC also expands the scope of Zimbabwe's GHG reduction target to include all GHG emitting sectors. As outlined in Section

3.1, more than 60% of Zimbabwe's current GHG emissions come from non-energy source sectors, and therefore the updated NDC covers a substantially larger fraction of total GHG emissions than previously. In addition to establishing a more ambitious, and comprehensive target to reduce GHG emissions in Zimbabwe, the GHG mitigation assessment presented in this work also provides a clear pathway by which these targets can be achieved. This results from the updated GHG mitigation target in the 2021 NDC being based on the aggregated reduction in GHG emissions from implementation of specific, concrete and target-based mitigation measures in each sector.

To achieve the Paris Agreement, the need for more ambitious climate change mitigation commitments in NDCs has been emphasised (Meinshausen et al., 2022). Studies that have attempted to apportion the required emission reductions to achieve the long-term temperature goals in the Paris Agreement identify Africa as the region with lowest responsibility, and necessity for emission reductions (Climate Action Tracker, 2021; Krapp et al., 2016). The NDC target specified by Zimbabwe was stated as being entirely conditional on receiving sufficient international support (Government of Zimbabwe, 2021). In general, implementation of NDCs is not guaranteed because the international climate finance is insufficient to support implementation of all conditional commitments (Pauw et al., 2019). The expansion of the GHG mitigation assessment to include quantification of the broader sustainable development benefits achieved within Zimbabwe provides additional motivation and justification for the implementation of the mitigation measures included in Zimbabwe's NDC. These development benefits are achieved within Zimbabwe, and are additional to the GHG emission reductions. Previous studies have outlined the necessity for climate change mitigation actions, particularly in low- and middle-incomes countries, with small to negligible contributions to global GHG emissions to be more closely aligned with development targets (Linnér et al., 2012; Malley et al., 2021b). This can build a broader coalition of support for the implementation of specific mitigation measures, due to the larger range of areas that are shown to be affected (and benefit) from a particular climate change mitigation action (Linnér et al., 2012; Malley et al., 2021b).

Previous studies have quantified 'co-benefits', 'multiple benefits', or 'non-climate benefits' from climate change mitigation actions. However, many of these assessments are made at global and regional scale (Hamilton et al., 2021; UNEP/WMO, 2011; UNEP, 2019b). Where non-climate change benefits of climate change mitigation are assessed at national level, quantitative assessments are typically undertaken outside of the process of setting climate change mitigation targets (Nakarmi et al., 2020). Assessment of the non-climate benefits of NDCs specifically have been made, but have been undertaken retrospectively, and qualitatively (Antwi-Agyei et al., 2018; Dal Maso et al., 2020). Public health, biodiversity, energy security, and the other development benefits quantified in this study for Zimbabwe show the direct relevance of Zimbabwe's climate change mitigation actions to groups that may not see the relevance of climate change action to their mandate (e.g. Government Department's responsible for health, energy, civil society etc.). It is therefore important that the development benefits of climate change actions are understood *during* the process for setting climate change targets or agreeing climate change plans. This can help to increase climate change mitigation ambition due to the inclusion of more mitigation actions within climate change plans, because of the development benefits shown to be achievable. In contrast to previous studies, which provide retrospective, qualitative assessment of development benefits of NDCs (Wagner et al., 2022), this study provides a practical example as to how progress to achieving development targets can be quantified can be integrated into GHG mitigation assessments, which can be used to provide a prospective understanding of non-climate benefits of climate change action to inform climate change plans and targets before they have been finalised.

In Zimbabwe, the SDG benefits quantified from the implementation of the 2021 updated NDC indicate the broader areas that the achievement of Zimbabwe's NDC could affect, in addition to climate change mitigation. Multiple mitigation measures directly contribute to improved public health through reductions in air pollution exposure, both indoors and outdoors, as well as health benefits from improved wastewater treatment, greater physical activity, and reduced road traffic accidents. The natural forest restoration and afforestation mitigation measures are shown to have the potential to improve biodiversity, and to achieve key SDG targets on energy access, efficiency and sustainability. Many of these SDG benefits quantified in this study are the responsibility of different Government departments, or are the issue of importance for civil society and non-governmental organisations. Hence their quantification highlights how Zimbabwe's NDC is relevant and useful for different stakeholders, potentially expanding the coalition supporting and contributing to its implementation.

Finally, the evaluation of mitigation measures that are not included in Zimbabwe's NDC, but included within other plans, policies or strategies in Zimbabwe (Table 3), provides the basis for achieving additional GHG emission reductions, beyond those committed to in Zimbabwe's updated NDC. The full range of 28 mitigation measures included in this study could reduce GHG emissions by over 60% in 2030 compared to baseline GHG emission projections. This provides a clear basis for exceeding Zimbabwe's climate change mitigation commitment, and/or increasing climate change mitigation ambition in future NDC updates. The additional mitigation measures included in this assessment are also those that have some of the largest SDG benefits quantified in this study, particularly related to improving public health. Hence Zimbabwe could also increase the local benefits achieved from its climate change mitigation actions through the inclusion of the additional mitigation measures in its climate change plans.

4.2. Key uncertainties and limitations

This GHG mitigation assessment has benefitted from the progressive improvement in the data available in Zimbabwe to estimate emissions across all major source sectors. This improvement has resulted from the regular development of national GHG emission inventories as part of reporting to the UNFCCC. These data have allowed for a comprehensive, economy-wide GHG mitigation assessment to be undertaken in this work utilised in this work (Ministry of Environment, Climate, Tourism and Hospitality Industry of Zimbabwe, 2020). However, uncertainties and key areas for improvement remain. The updating of the GHG mitigation assessment presented here to integrated updated data and assumptions on a regular basis could facilitate the progressive improvement of GHG mitigation in Zimbabwe, including for the next update to the NDC due in 2025.

Data needed to quantify GHG emissions with a long time series in Zimbabwe is available for energy from the national energy balance (MoEPD, 2020). However, this data is limited in the disaggregation of energy consumption into subsectors, that allows the identification of more detailed source contributions, and the evaluation of more specific mitigation measures. In this GHG mitigation assessment, this limitation was most evident for the industry and commercial and public services sector, which had no sub-sector disaggregation and meant that the mitigation measures modelled included sector-wide energy efficiency targets from the national energy audit. Developing bottom-up assessments of energy consuming activities (and technologies) in the industry and commercial and public services sector, as well as other energy consuming sectors (e.g. residential outside of cooking would allow technology and sub-sector specific energy efficiency, or technological changes to be modelled.

The transport sector analysis required a more detailed characterisation than is provided from aggregate fuel consumption data in the national energy balance. Firstly, the mitigation measures evaluated included specific changes in technology and behaviour (e.g. electric vehicles and increased public transport use), and secondly to quantify the co-emissions of SLCPs and air pollutants (EMEP/EEA, 2019). However, the lack of recent vehicle fleet data collected in Zimbabwe required that this more detailed assessment of the transport sector used international data to characterise the vehicle fleet (OICA, 2021). Therefore, the compilation of national data on vehicle fleet composition could allow for the future improvement in transport sector emissions, and mitigation potential.

In the IPPU sector, for HFC consumption, a key limitation is that the activity data (HFC imports) is only available from 2015. This limits assessment of HFC emissions to years after 2015, but also means that HFC emissions from HFC imported before 2015, and in use in more recent, and future years, is not accounted for in emission estimates and projections. As HFC imported before 2015 becomes a smaller fraction of the bank, and equipment is eventually retired, this limitation will result in a smaller underestimate of HFC emissions in the future.

In agriculture, the IPCC Tier 1 methods used limit the development of a detailed assessment of mitigation options in livestock and crop production. For livestock production, the number of animals as the activity variable, and regional default emission factor do not allow levers representing mitigation measures such as improved breeding, and feed optimisation, as well as behaviour changes such as reducing food loss and dietary shift, to be represented and modelled. There are more detailed (Tier 2) methodologies that can be used to provide the ability to represent these variables, and to quantify the emission reduction potential of these measures, e.g. through characterisation of herd structure, energy requirements, feed composition for the livestock herd (Malley et al., 2021a). The application of these methods in Zimbabwe, which would require additional data collection, would provide the basis for a more detailed assessment of agricultural GHG emission reductions (IPCC, 2019).

For FOLU emissions, only two data points (1992 and 2017) were available to characterise land use change over the historic time period. The change in land use of the 25 years were converted into the average annual change in land use, which was then applied over the entire historic time period, and used as the basis for the development of future land use change in the baseline scenario. Updating data on land use in Zimbabwe to include a greater number of historical years, particularly during more recent historical years, would improve the allocation of net GHG emissions over the historic time series. If more data is collected during recent historic years, it would also allow a more realistic baseline scenarios to be constructed for land use, rather than using a 25-year average value.

Finally, in the waste sector, extending the analysis to include the rural population would provide a more comprehensive assessment of the historic, and future emissions and mitigation potential of mitigation measures in the sector. This requires that data collection systems and processes are extended to include rural areas, particularly to understand the volume of waste generated, its composition and the method of disposal, including, importantly, the fraction that is openly burned.

5. Conclusions

In 2021, Zimbabwe committed to reduce Greenhouse Gas (GHG) emissions by 40% in 2030 compared to a baseline scenario. This represents a large increase in ambition compared to its previous climate change mitigation commitment, due to the larger reduction target, and its inclusion of all GHG-emitting sectors in Zimbabwe (compared to only the energy sector previously). This work documents the underlying assessment that provides the basis for this more ambitious climate change mitigation target. In doing so, it highlights three important conclusions that are relevant for Zimbabwe as the climate change mitigation targets moves forward to implementation.

Firstly, the GHG mitigation assessment presented in this work identifies specifically how the 40% reduction in Zimbabwe's GHG emissions can be achieved, by evaluating specific mitigation measures and quantifying their GHG emission reduction potential. This provides the starting point for development of implementation plans to achieve this target, as the mitigation measures to be taken forward to reduce GHG emissions have already been identified. Secondly, the method by which this GHG mitigation assessment was undertaken, by a team of national experts using a transparent modelling platform, provides the basis for regular updating of the analysis as new data becomes available. This framework for GHG assessments in Zimbabwe can be updated to evaluate progress against the GHG mitigation targets over the period of implementation, as well as providing the basis for updating, and increasing the ambition of climate change mitigation targets in the future. The GHG mitigation assessment evaluated additional mitigation measures, which show that Zimbabwe has the potential to reduce GHG emissions by over 60% in 2030 compared to baseline emissions, and hence increase its climate change mitigation ambition. Finally, the assessment shows that implementation of Zimbabwe's climate change mitigation commitment would not only benefit international climate change mitigation, but could also result in tangible, quantifiable benefits in Zimbabwe for public health, biodiversity, energy efficiency and sustainable energy use. These benefits could build a broader coalition of support for the climate change mitigation measures that need to be implemented for Zimbabwe to achieve its climate change mitigation targets. As Zimbabwe's NDC is also conditional on international support for its implementation, this study also strengthens the case for investment in implementing Zimbabwe's NDC by showing multiple positive outcomes can be achieved simultaneously from implementation of the mitigation actions identified.

Credit author statement

Dingane Sithole: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Caroline Tagwireyi: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Tendayi Marowa: Conceptualization, Writing – drafting, reviewing & editing, Fadzai Muwidzi: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Farai Mapanda: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Walter Svinurai: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Tatenda Gotore: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Sekai Ngarize: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Anderson Muchawona: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Samantha Chigoverah: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Gamuchirai Takavingofa: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Kudzai Ndidzano: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Lawrence Mashungu: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Washington Zhakata: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Tafadzwa Dhlakama: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Christopher S. Malley: Conceptualization, Methodology, Software, Formal Analysis, Writing – drafting, reviewing & editing, Jessica Slater: Conceptualization, Methodology, Software, Formal Analysis, Writing – drafting, reviewing & editing, Eve Palmer: Conceptualization, Methodology, Software, Formal Analysis, Writing – drafting, reviewing & editing, Amy Molotoks: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Chris West: Conceptualization, Methodology, Formal Analysis, Writing – drafting, reviewing & editing, Jason Veysey: Conceptualization, Methodology, Software, Formal Analysis, Writing – drafting, reviewing & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors acknowledge the Nationally Determined Contribution Partnership (NDC Partnership) Climate Action Enhancement Package (CAEP) for funding this work. A.M. and C.W. acknowledge the United Kingdom Research Institute (UKRI) Global Challenges Research Fund Transport, Development and the Environment Hub project (ES/S008160/1) for funding their contribution to this work.

References

Abbafati, C., Machado, D.B., Cislaghi, B., Salman, O.M., Karanikolos, M., McKee, M., et al., 2020. Global Burden of 369 Diseases and Injuries in 204 Countries and Territories, 1990–2019: a Systematic Analysis for the Global Burden of Disease Study 2019. Lancet. https://doi.org/10.1016/S0140-6736(20)30925-9.

Antwi-Agyei, P., Dougill, A.J., Agyekum, T.P., Stringer, L.C., 2018. Alignment between nationally determined contributions and the sustainable development goals for West Africa. Clim. Pol. https://doi.org/10.1080/14693062.2018.1431199.

Chaudhary, A., Brooks, T.M., 2018. Land use intensity-specific global characterization factors to assess product biodiversity footprints. Environ. Sci. Technol. 52, 5094–5104. https://doi.org/10.1021/acs.est.7b05570.

Chen, D.M.C., Bodirsky, B.L., Krueger, T., Mishra, A., Popp, A., 2020. The world's growing municipal solid waste: trends and impacts. Environ. Res. Lett. 15 https://doi.org/10.1088/1748-9326/ab8659.

CIESIN, 2016. Center for international earth science information network - CIESIN - columbia university. In: Gridded Population of the World, Version 4 (GPWv4): Administrative Unit Center Points with Population Estimates. NASA Socioeconomic Data and Ap, Palisades, NY, 2016.

Climate Action Tracker, 2021. Global Update - Glasgow's 2030 Credibility Gap - Nov 2021, Report.

Dal Maso, M., Olsen, K.H., Dong, Y., Pedersen, M.B., Hauschild, M.Z., 2020. Sustainable development impacts of nationally determined contributions: assessing the case of mini-grids in Kenya. Clim. Pol. 20 https://doi.org/10.1080/14693062.2019.1644987.

EMA, 2014. Zimbabwe's integrated solid waste management plan. In: Ministry of Environment, Water and Climate Report. Environmental Management Agency. https://www.ema.co.zw/agency/ziswmp.

Air pollutant emission inventory guidebook guidebook: Technical guidance to prepare national emission inventories. European Monitoring and Evaluation Programme/European Environment Agency Report No. 13/2019. In: ISBN: 1977-8449, 2019.

Garcia, L., Johnson, R., Johnson, A., Abbas, A., Goel, R., Tatah, L., Damsere-Derry, J., Kyere-Gyeabour, E., Tainio, M., de Sá, T.H., Woodcock, J., 2021. Health impacts of changes in travel patterns in greater Accra metropolitan area, Ghana. Environ. Int. 155, 106680 https://doi.org/10.1016/j.envint.2021.106680.

Ghana Statistical Service, 2014. Ghana Living Standards Survey Round 6 (GLSS 6): Main Report. Ghana Statistical Service Report. August 2014. http://www.statsghana.gov.gh/glss6.html.

Government of Zimbabwe, 2021. Zimbabwe revised nationally determined contribution. Government of Zimbabwe submission to the United Nations framework convention on climate change. https://www4.unfccc.int/sites/ndcstaging/Pages/Party.aspx?party=ZWE&prototype=1.

Haines, A., Amann, M., Borgford-Parnell, N., Leonard, S., Kuylenstierna, J., Shindell, D., 2017. Short-lived climate pollutant mitigation and the sustainable development goals. Nat. Clim. Change. https://doi.org/10.1038/s41558-017-0012-x.

Hamilton, I., Kennard, H., McGushin, A., Höglund-Isaksson, L., Kiesewetter, G., Lott, M., Milner, J., Purohit, P., Rafaj, P., Sharma, R., Springmann, M., Woodcock, J., Watts, N., 2021. The public health implications of the Paris Agreement: a modelling study. Lancet Planet. Health 5, e74–e83. https://doi.org/10.1016/S2542-5196(20)30249-7.

Heaps, C.G., 2022. LEAP: the Low Emissions Analysis Platform. Stockholm Environment Institute, Somerville, MA, USA [Software version: 2020.1.56. https://leap.sei.org.

Henze, D.K., Hakami, A., Seinfeld, J.H., 2007. Development of the adjoint of GEOS-Chem. Atmos. Chem. Phys. 7, 2413–2433.

ICCT, 2012. Global Transportation Roadmap Model. International Council on Clean Transportation Model. Available at: https://theicct.github.io/roadmap-doc/. Available at:

IPCC, 2019. Task force on national greenhouse gas inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html.

IPCC, 2006. Guidelines for national greenhouse gas inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf.

Ishrat, R., 2018. Global Status Report on Road Safety 2018: Summary. World Heal, Organ.

Jeuland, M.A., Pattanayak, S.K., 2012. Benefits and costs of improved cookstoves: assessing the implications of variability in health, forest and climate impacts. PLoS One 7. https://doi.org/10.1371/journal.pone.0030338.

Krapp, M., Gütschow, J., Rocha, M., Schaeffer, M., 2016. Historical Responsibility for Climate Change-From Countries Emissions to Contribution to Temperature Increase. Geophysical Research Abstracts.

Kummu, M., Taka, M., Guillaume, J.H.A., 2018. Gridded global datasets for gross domestic product and human development Index over 1990-2015. Sci. Data 5, 1–15. https://doi.org/10.1038/sdata.2018.4.

Kuylenstierna, J.C.I., Heaps, C.G., Ahmed, T., Vallack, H.W., Hicks, W.K., Ashmore, M.R., Malley, C.S., Wang, G., Lefèvre, E.N., Anenberg, S.C., Lacey, F., Shindell, D. T., Bhattacharjee, U., Henze, D.K., 2020. Development of the low emissions analysis platform – integrated benefits calculator (LEAP-IBC) tool to assess air quality and climate co-benefits: application for Bangladesh. Environ. Int. 145 https://doi.org/10.1016/j.envint.2020.106155.

Linnér, B.O., Mickwitz, P., Román, M., 2012. Reducing greenhouse gas emissions through development policies: a framework for analysing policy interventions. Clim. Dev. https://doi.org/10.1080/17565529.2012.698587.

Malley, C.S., Hicks, W.K., Kulyenstierna, J.C.I., Michalopoulou, E., Molotoks, A., Slater, J., Heaps, C.G., Ulloa, S., Veysey, J., Shindell, D.T., Henze, D.K., Nawaz, O., Anenberg, S.C., Mantlana, B., Robinson, T.P., 2021a. Integrated assessment of global climate, air pollution, and dietary, malnutrition and obesity health impacts of food production and consumption between 2014 and 2018. Environ. Res. Commun. 3 https://doi.org/10.1088/2515-7620/ac0af9.

Malley, C.S., Omotosho, D., Bappa, B., Jibril, A., Tarfa, P., Roman, M., Hicks, W.K., Kuylenstierna, J.C.I., de la Sota Sandez, C., Lefèvre, E.N., 2021b. Integration of climate change mitigation and sustainable development planning: lessons from a national planning process in Nigeria. Environ. Sci. Pol. 125, 66–75. https://doi.org/10.1016/j.envsci.2021.08.022.

Meinshausen, M., Lewis, J., McGlade, C., Gütschow, J., Nicholls, Z., Burdon, R., Cozzi, L., Hackmann, B., 2022. Realization of Paris Agreement pledges may limit warming just below 2 °C. Nature 604, 304–309. https://doi.org/10.1038/S41586-022-04553-Z.

Ministry of Environment Climate Tourism and Hospitality Industry of Zimbabwe, 2020. Zimbabwe's first biennial update report to the United Nations framework convention on climate change. In: Ministry of Environment, Climate, Tourism and Hospitality Industry Report. https://unfccc.int/sites/default/files/resource/Zimbabwe%20Bienn.

Ministry of Environment Water and Climate Change of Zimbabwe, 2017. Zimbabwe third national communication to the united Nations framework convention on climate change. Ministry of environment, water and climate document. https://unfccc.int/documents/89310.

Ministry of Lands Agriculture Water and Rural Resettlement, 2020. Livestock growth implementation Strategy. In: Ministry of Lands, Agriculture, Water and Rural Resettlement Report. August 2020.

MoEPD, 2020. Zimbabwe national energy balance 2020. In: Ministry of Energy and Power Development Report.

Murray, C.J.L., Aravkin, A.Y., Zheng, P., Abbafati, C., Abbas, K.M., Abbasi-Kangevari, M., et al., 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. https://doi.org/10.1016/S0140-6736(20)30752-2.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H., 2013. IPCC 2013 AR5 - Chapter 8: anthropogenic and natural radiative forcing. Clim. Chang. 2013 Phys. Sci. Basis. Contrib. Work. Gr. I to Fifth Assess. Rep. Intergov. Panel Clim. Chang. https://doi.org/10.1017/CBO9781107415324.018.

Nakarmi, A.M., Sharma, B., Rajbhandari, U.S., Prajapati, A., Malley, C.S., Kuylensiterna, J.C.I., Vallack, H.W., Henze, D.K., Panday, A., 2020. Mitigating the impacts of air pollutants in Nepal and climate co-benefits: a scenario-based approach. Air Qual. Atmos. Heal. https://doi.org/10.1007/s11869-020-00799-6.

OICA, 2021. International organization of motor vehicle manufacturers vehicle in use DataBase. Available at: https://www.oica.net/category/vehicles-in-use/. (Accessed 31 December 2021).

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R., 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51, 933–938. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO.

Pauw, W.P., Castro, P., Pickering, J., Bhasin, S., 2019. Conditional nationally determined contributions in the Paris Agreement: foothold for equity or Achilles heel? Clim. Pol. https://doi.org/10.1080/14693062.2019.1635874.

Republic of Zimbabwe, 2020. National development Strategy 1: 2021-2025. Republic of Zimbabwe document. Available at: http://www.zimtreasury.gov.zw/index.php?option=com_phocadownload&view=category&download=336:national-development-strategy-presentation-nds1&id=64:national-development.

Republic of Zimbabwe, 2017. Zimbabwe's intended nationally determined contribution (INDC) submitted to the United Nations framework convention on climate change (UNFCCC). Republic of Zimbabwe. Available at: https://unfccc.int/sites/default/files/NDC/2022-06/Zimbabwe%20First%20NDC.pd.

S&P Global Market Intelligence, 2017. World Electric Power Plants Database (WEPP). https://doi.org/10.7910/DVN/OKEZ8A. March 2017.

Shupler, M., Godwin, W., Frostad, J., Gustafson, P., Arku, R.E., Brauer, M., 2018. Global estimation of exposure to fine particulate matter (PM2.5) from household air pollution. Environ. Int. 120, 354–363. https://doi.org/10.1016/j.envint.2018.08.026.

UN DESA, 2019. World Population Prospects 2019. Department of Economic and Social Affairs. World Population Prospects 2019.

UNEP/WMO, 2011. Integrated assessment of black carbon and tropospheric ozone. In: United Nations Environment Programme. World Meteorological Organisation Report. https://wedocs.unep.org/rest/bitstreams/12809/retrieve.

UNEP, 2019a. Air pollution in Asia and the Pacific: science-based solutions. In: Climate and Clean Air Coalition/United Nations Environment Programme Report. http://www.ccacoalition.org/en/resources/air-pollution-asia-and-pacific-science-based-solutions.

UNEP, 2019b. Air Pollution in Asia and the Pacific: Science-Based Solutions. United Nations Environment Programme (UNEP). https://doi.org/10.13140/2.1.4203.8569.

United Nations, 2015. Paris agreement. In: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

United Nations Development Programme, 2020. Human Development Report 2020. UNDP, New York, NY, USA.

Wagner, C., Veysey, J., Nolan, S.T., Malley, C., 2022. Overcoming Barriers to Integrated Planning – Tools and Training for Countries to Combine Climate and Development Aims. SEI Discussion Brief. https://doi.org/10.51414/sei2022.023.

World Bank, 2021. World Bank Open Data. https://data.worldbank.org/indicator/NY.GDP.PCAP.KD. (Accessed 17 February 2022).

Yu, Q., You, L., Wood-Sichra, U., Ru, Y., Joglekar, A., Fritz, S., Xiong, W., Lu, M., Wu, W., Yang, P., 2020. A cultivated planet in 2010: 2. the global gridded agricultural production maps. Earth Syst. Sci. Data Discuss. https://doi.org/10.5194/essd-2020-11.

ZERA, 2015. National Energy Efficiency Audit for Zimbabwe. Zimbabwe Energy Regulatory Authority (ZERA) Report. Tender No. ZERA INF 03/2013. August 2015. Available at: https://rise.esmap.org/data/files/library/zimbabwe/Renewable%20Energy/RE%2013_3.pdf.

Zimbabwe Electricity Transmission and Distribution Company, 2017. System development plan. June 2017. In: Zimbabwe Electricity Transmission and Distribution Company Report. https://rise.esmap.org/data/files/library/zimbabwe/Cross%20Cutting/CC%202.pdf.