Ecosystem-Based Adaptation and Mitigation in Botswana’s Communal Rangelands

Annex 22:

A: GHG Reduction Estimates

B: FP References

Annex 22 – Section A: GHG Reduction Estimates

Please note – the below GHG Reduction Estimates are adapted from Feasibility Study Section 3, Subsection 4. More information on Carbon and Water baselines are available in section 3 of the Feasibility Study.

Avoiding degradation, and restoring rangelands, have direct greenhouse gas mitigation benefits. The declining soil carbon stocks following degradation are lost as emissions into the atmosphere, in addition to the reduced rate of sequestration of atmospheric carbon in the soil carbon pool. In the context of Botswana, the reduced forage digestibility on degraded rangelands has implications for the emissions of the substantial livestock sector. Poor forage digestibility from degraded rangelands results in increased methane emissions intensity through enteric fermentation by ruminants such as cattle, goats, and sheep. Avoiding the degradation of, and restoring, rangelands increases the abundance of palatable, digestible grass species, as well as grass cover. Emission reduction benefits are therefore achieved by sequestering carbon into the soil, mitigating the further loss of soil carbon and avoiding livestock methane emissions, which have a heating effect 26 times greater than carbon dioxide over a 100-year period.

1. *Mitigation targets*

The mitigation targets for the project interventions are derived from reduced emissions from livestock enteric fermentation and from soil carbon sequestration and reduced emissions resulting from improved land and livestock management that contribute to restoring and conserving ecosystem function. Details on the project activities, outputs, components and the theory of change are provided in the Project Funding Proposal.

The Project mitigation potential has been modelled under maximum, moderate and conservative assumptions. The most conservative assumption scenarios about the rate and efficacy of implementation have been applied in estimating the mitigation targets. Specific assumptions relevant to each mitigation source are detailed below. One implication of the conservative assumption, for example, is that the projected coverage of project interventions within the eight-year implementation period is approximately 20% less than the planned coverage. It is therefore likely that the projected mitigation target underestimates the probable mitigation potential. Given the irreducible complexity of ecological systems, and particularly rangeland ecosystems within highly erratic climate contexts, the conservatism of the mitigation potential is appropriate.

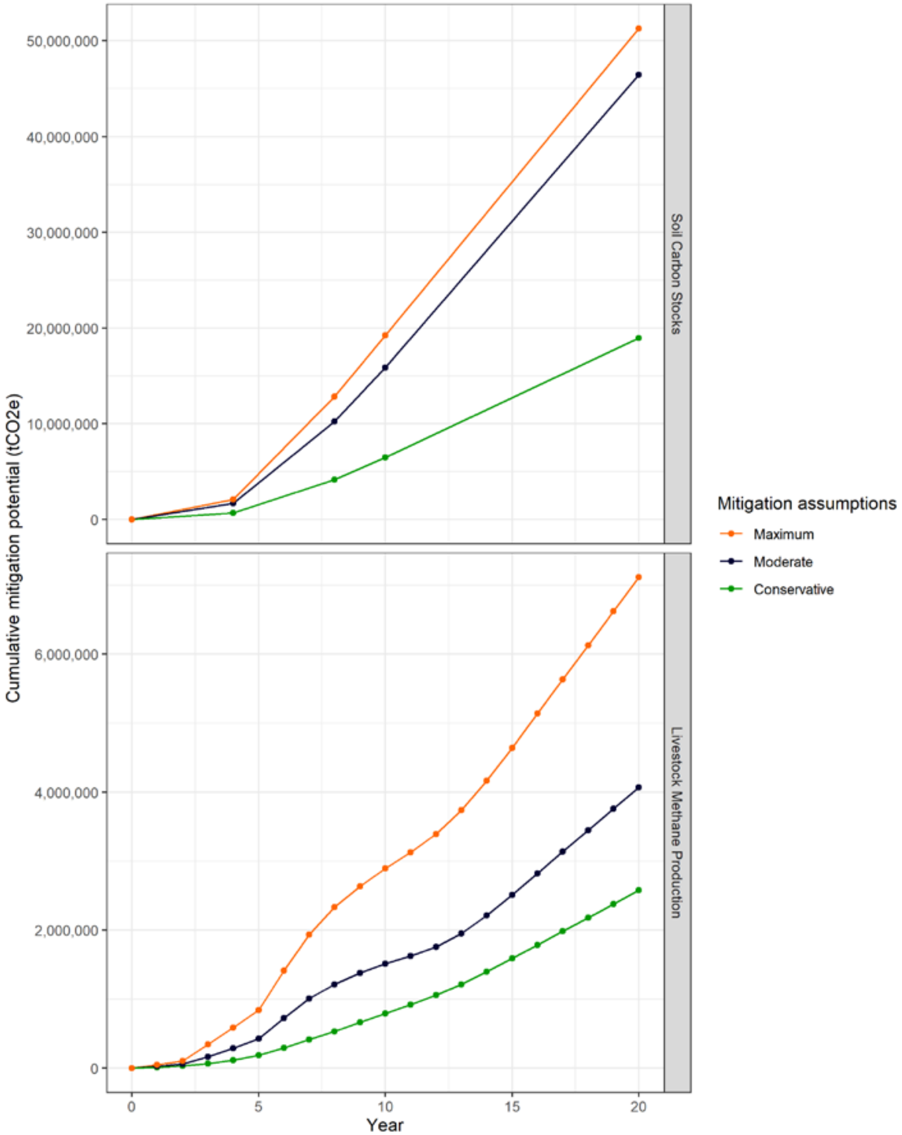

Figure 1. Cumulative mitigation potential (tCO_2e) from the primary sources under three mitigation impact assumption scenarios. Soil carbon stocks (top) includes mitigation from ecosystem restoration and reduced degradation; livestock methane production (bottom) includes emissions reduction from livestock enteric fermentation.

2. Livestock enteric fermentation

The emissions reduction target from livestock enteric fermentation was determined based on the mitigation potential resulting from an improved feed digestibility, methane conversion factor and feeding situation. The background rationale and definitions of these parameters are provided in Section 4.3. To ensure that the carbon mitigation targets are comparable to the other specialist studies conducted for this project, the input model assumptions have been standardised where feasible. The number of livestock across the 20-year projection period are assumed to be consistent with that of the Financial and Economic Analysis (FEA)[1]. The without-project scenario from the FEA assumed a greater loss in the number of livestock relative to the with-project scenarios in response to a modelled single, isolated drought event. This assumption can be considered conservative for the assessment of the mitigation potential, as fewer livestock results in reduced total greenhouse gas emissions.

A study on the direct methane emissions of South African dairy and beef cattle (Du Toit et al. 2013) found that the IPCC Tier 1 methane emissions factors significantly under-estimate the emissions within a Southern African context. The average emissions intensity estimated using the conservative assumptions of this assessment where at the lower bound of the estimates reported by Du Toit et al. (2013), which ranged from 83–113 kgCH4/head/year for mature beef cattle. Given that the natural pastures and rangelands within South Africa experience are, on average, more mesic and generally support more palatable species than occurs within traditional livestock production systems in Botswana, these estimates can be considered conservative.

In the arid, poorly-managed, traditional livestock systems that this project is targeting, the forage quality (and therefore feed digestibility) is extremely poor and well below the regional average for comparable systems. With the greater intensity, frequency and duration of droughts that are expected in Botswana due to climate change, the feed digestibility in the absence of improved land and livestock management practices are expected to decline further. This is expected to be further exacerbated by a greater incidence of incidence of alien plant invasions, bush encroachment, and veld degradation that has already been observed and is expected to worsen due to climate change.

Although it is reasonable to expect the average feed digestibility to be reduced below 45% (as validated by the Botswana Department of Animal Production), this assessment, conservatively compared the with-project scenario to that of the baseline scenario, not the without-project scenario, to estimate the emission reductions. The feed digestibility values applied are therefore consistent with the IPCC defaults, which can be considered conservative. Further background information supporting the feed digestibility estimates are provided in Chapter 4.3 of Annex 2 Section 3: Carbon and Water Baseline.

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[1] See Financial and Economic Analysis

The methane conversion factor (Ym) is impacted by several interacting parameters, including feed quality, cattle breed, genetic pools and herd composition. The Ym factors from the 2006 guidelines (6.5 ± 1.0) were applied to this assessment. The 2019 Refinement of the 2006 IPCC Guidelines notes on page 10.44 that “It is possible for a country’s national herd, or for parts of the national herd, to have production levels that are inconsistent with the feed quality bounds that are defined by the categories in Table 10.12. In these cases, it is good practice to develop their own country-specific Ym factors, and they should also use their information on animal diets to validate their choice of Ym against methane yield equations recommended in Niu et al. (2018).”

The nature of traditional livestock production in Botswana, particularly for the segment that this project is targeting, is that minimal, if any, land and livestock inputs are invested in improving beef production or livestock health. Because of limited market access and other historical, socioeconomic and cultural factors, the proportion of bulls and older cattle is greater than would be typical under a commercial system and there is often very poor genetic diversity, as reflected by the prevalence of genetically-linked diseases in communal herds. The methane yield equations developed by Niu et al. (2018) were based on data from commercial systems in Europe, USA and Australia where Ym ranged from 2.7 to 9.8. The Ym factors applied under this assessment (7.5 and 6.5), therefore, likely underestimates the potential improvements in the methane conversion factor following the introduction of improved land and livestock management practices.

Nationally, the livestock population has shown no consistent directional change from 2004–2015[2]. There has, however, been a short-term decline in the traditional sector livestock population, which has been attributed to recent drought conditions. Analogous projects implemented in South Africa with communal livestock farmers have, anecdotally, resulted in a voluntary reduction in the livestock population, which is consistent with maximizing livestock production efficiency[3]. Improved livestock and land management practices are expected to result in additional emissions reduction because of improved access to vaccinations and reduced rate of disease and parasite load. To ensure the mitigation targets are conservative, these expectations and their associated emissions reduction are not considered in the model assumptions.

Three comparative scenario assumptions about the rate at which the project can scale across the three project areas and the efficacy of implementation have been made. These relate to the maximum, moderate and conservative mitigation potential models with the latter defining the mitigation target. The conservative model assumes, for example, that the efficacy of the project implementation in its first year at a given site starts at 10% and increases incrementally to a maximum efficacy of 80% by the fourth implementation year. The sites that are included after the project period (after year eight of project implementation) are assumed to not exceed 50% efficacy. By contrast, the maximum mitigation potential model assumes an efficacy of 70% to 90% over the same period. With the increasing climate change impact on Botswana’s rangeland ecosystems (see Section 2, it is expected that the emissions intensity per livestock head will increase. Following the recent droughts, for example, the average available feed digestibility has been

[2] Statistics Botswana, “Botswana Agricultural Census Report 2015.”

[3] Peace Parks Foundation, “Herding 4 Health,” 2020, https://www.peaceparks.org/h4h/.

observed to be as low as 30%, considerably worse than the minimum IPCC default of 45%. The maximum mitigation potential model assumes the baseline emissions intensity of 2.05 will increase to 3.11 tCO2e/head/year. The conservative mitigation potential model, however, assumes that the emissions intensity remains constant.

Under all model scenarios, only the emissions reduction achieved within the project areas are conservatively considered in the model, despite maximising the annual emissions reduction within the first decade and the likelihood of expanding the implementation beyond the project areas once the enabling environment has been provided and the benefits demonstrated.

Over the eight-year project implementation period, the cumulative conservative emissions reduction is projected to total 534,658 tCO_2e (66,832 tCO_2e/yr). This is expected to increase substantially to more than 2.5 million tCO_2e (128,876 tCO_2e/yr) over the full 20-year capitalisation period (Table 10). These mitigation benefits are expected to be further enhanced by the additional emissions reduction co-benefits described above and by the scaling of climate-resilient land and livestock management practices beyond the project areas.

The emissions reduction targets for the eight-year project implementation period were compared with that of the FAO Ex-Ante Carbon-balance Tool (Ex-ACT)[4] result for the same number of livestock, over the same period. The emissions reduction from enteric fermentation under the project implementation scenario has been conservatively assumed to be 70% that of the projected reduction calculated using the IPCC Tier 2 inventory. In total, the mitigation potential estimated using the Ex-ACT tool is 678,556 tCO_2e (84,819 tCO_2e/yr), approximately 27% more optimistic than the conservative emissions reduction target.

Table 1. Conservative number of sites, livestock and mitigation targets over 4-, 8-, 10-, and 20-year impact periods from reduced emissions intensity through livestock enteric fermentation.

Impact period	Sites	Livestock (without project)	Livestock (with project)	Cumulative mitigation (tCO_2e)	Annual mitigation (tCO_2e/yr)
4-year	44	136,382	137,064	**116,090**	**29,023**
8-year	83	192,025	226,717	**534,658**	**66,832**
10-year	103	186,972	268,991	**794,351**	**79,435**
20-year	104	286,254	329,526	**2,577,525**	**128,876**

[4] FAO, "Ex-Ante Carbon Balance Tool (Ex-ACT). Version 8.5.4.," accessed November 13, 2019, http://www.fao.org/tc/exact/ex-act-home/en/.

The Botswana GHG Inventories for Biennial Update Report[1], First Biennial Update Report[2] and Third National Communication[3] to the UNFCCC have all based their accounting of the emissions from the livestock sector on the IPCC Tier 1 approach. The objective of updating the national inventory to the Tier 2 approach has been recommitted in each report. This study therefore represents a positive development that can serve as a foundation for the updated national livestock emissions inventory. Notably, the default cattle methane emissions factor from enteric fermentation applied under Botswana's Tier 1 inventory (32–38 kgCH_4/head/year) represents the commercialized sector for all of Africa and the Middle East and the IPCC guidelines recommend the Tier 2 method for countries with large livestock populations, such as Botswana. It is expected that the poor fodder quality available to livestock on communal land and significant energy requirements to acquire feed over large grazing areas compared with the commercial sector considerably increases the livestock emissions intensity. This is reflected in the greater baseline annual methane emission rate per head of cattle under the Tier 2 inventory (80–83 kgCH_4/head/year).

3. *Restored Ecosystem Function*

Ecosystem restoration and avoided degradation from improved rangeland and livestock management, results in improved ecosystem function, a reduction of bare ground cover and improvements in forage productivity. These improvements are expected to result in mitigation within the soil carbon pool. To quantify the sequestration potential, the FAO Ex-Ante Carbon-balance Tool (Ex-ACT)[5] was applied, with conservative assumptions about the proportion of successful restoration and conservation outcomes across the project areas (Table 11).

As for the mitigation target from reduced livestock enteric fermentation, multiple assumptions about the mitigation potential from ecosystem restoration have been modelled. These assumptions relate to the maximum, moderate and conservative mitigation potentials with the latter defining the mitigation target. The assumptions that define the conservatism of the mitigation potential relate to the implementation rate and efficacy achieved over the project implementation period. Where the assumptions approximate the expected rate or efficacy of the project, they are assumed to be moderate. These moderate assumptions include the IPCC Tier 1 default differences in soil carbon stocks for the geographic, climate, soil and moisture regime of Botswana; and the implementation of project activities at all target sites within the implementation period.

[5] Ibid.

Relative differences in the soil carbon stocks determine the mitigation potential from project interventions. The default IPCC Tier 1 soil carbon stocks for moderately- and non-degraded grassland systems are 36% and 43% greater than for severely degraded systems on sandy-dominant soils in dry, warm temperate African climates. To account for the lag in soil carbon accumulation following improved management practices and improved ecosystem function, the relative differences were conservatively reduced by more than half to only 15% and 20% for moderately- and non-degraded systems, respectively, compared with the default for severely degraded systems. The degradation state of the rangelands under the project and in the control sites will be determined based on detailed veld condition assessments (detailed protocol provided in Annex 11, Appendix 11.1).

Fractional bare ground, herbaceous biomass and seasonal change in biomass (based on disc pasture meter measurements), grass species composition and repeat photography will all be factored into the categorization of the degradation state. This information will be captured in the Rangeland Stewardship Information Portal and complemented by remote sensing products and ad hoc assessments and observations by the Graduate Monitors. The soil carbon stocks under different states of degradation will be validated using a combination of biogeochemical models and soil carbon sampling.

Conservatively, the ex-ante calculations were based on modified IPCC Tier 1 default soil carbon stocks for each category. The severely degraded category under the conservative scenario was the same as the Tier 1 default based on the broad climate and soil categories as provided by the FAO Ex-ACT template (Annex 2 Section 3 Appendix 3.5). An 85% reduction in the default values, however, were applied moderately degraded and non-degraded categories. This conservatively reduces the ex-ante estimates of emission reductions from conservation and restoration activities.

Table 2. Baseline and final degradation states under different ecosystem restoration and conservation scenarios with and without project activities.

Scenario	Baseline degradation	Final degradation	
		Without project	With project
Maximum restoration	Severe	No change	Non-degraded
Moderate restoration	Severe	No change	Moderate
Moderate restoration	Moderate	No change	Non-degraded
Successful conservation	Moderate	Severe	Non-degraded

Moderate conservation	Moderate	Severe	Moderate
No effect	All	No change	No change

The baseline vegetation biomass and above-ground carbon stocks have been estimated and are presented in Annex 2, Section 3 (pg. 17–25). For the purposes of ex-ante emission reduction (ER) accounting, however, changes to the above-ground biomass carbon pools are excluded as they are expected to be de minimis. Two considerations, in particular, for this exclusion are highlighted below in relation to: i) the nature of the proposed activities; and ii) the changes to above-ground biomass carbon stocks following bush thinning.

As outlined in Table 11 of the FP (pg. 39), bush thinning is defined by this project as a restoration tool involving the pruning of lower branches (<1.5 m) where woody densification prevents livestock access to the grazing land. This differs from other approaches to addressing bush encroachment, such as the felling and clearing of all trees within a woodland or savanna in order to create an artificial grassland or grazing lawn. Such a practice would be maladaptive in the context of an extensive grazing system in Botswana that is expected to experience exacerbated heat waves and heat stress due to climate change.

The woody cover, even where intense bush encroachment has occurred, is not fully removed in order to maintain the canopy for shade, for soil protection, and for habitat niche diversity that improves the grazing quality and resilience of the ecosystem. The woody material that is pruned (small branches and leaves) is not removed from the landscape or used to make wood fuels such as charcoal under this project, as is often the practice elsewhere. It is used for brush packing in erosion gullies, on bare ground (see images in Annex 2, Section 4 pg 30-31), and to create physical barriers that reduce over-utilization of cattle paths that can cause erosion. Depending on the species, the thinned material may also be chipped and included as bulk material in dry season fodder supplementation, which further supports the restoration outcomes by reducing dry season overgrazing and soil erosion, stimulating new grass establishment, and reducing overall grazing pressure. These approaches also avoid the exportation of nutrients and carbon out of the landscape, which would occur if the woody material were removed. Bush thinning is expected to vary across the project area depending on the site-specific baseline conditions and project requirements. The average amount of bush encroached woody material that thinned is expected to be <1 tDM/ha.

Management of the spread of Invasive Alien Plants (IAPs) includes hand pulling of small saplings (<50 mm) and the use of manual hand tools to remove IAPs from riparian areas will also be conducted. The complete eradication of IAPs is not planned under the proposed project as they provide important ecosystem services such as shade and dry season fodder material, despite the negative impact that they often have on rangeland productivity, water balance, and drought resilience.

The assumption that there will be no rangeland land cover type conversions, for example from woodlands or savannas to grasslands, is therefore met under the interventions proposed by this project (Output 2.2., Activity 2.2.2.). An example of the desired end-state vegetation structure post-bush thinning is provided below, for reference.

Figure 2. Example of the desired end-state vegetation structure post-bush thinning.

As described in Annex 2 Section 3 (pg. 9–17), the changes to above-ground biomass carbon stocks following bush thinning are not limited to the pruning of branches. Herbaceous (grass) above-ground biomass production is stimulated by bush thinning, observed to have led to the accumulation of 0.5–2 tDM/ha (Smit 2005), with associated benefits to soil carbon stocks, drought resilience and livestock production. The total woody vegetation in Botswana has also been shown to be greater where bush encroachment intensity is lowest (Moleele et al. 2002). This counter-intuitive observation has been attributed to the complex interactions of herbivore intensity and selectivity, fire frequency and severity, soil nutrients and interspecific competition of encroaching and non-encroaching trees (particularly for water resources).

As a result of the uncertain directionality in the above-ground biomass stocks following bush thinning, IAP management and other restoration activities, the AGB carbon pool was conservatively assumed to be de minimis and excluded from the emission reduction (ER) estimates.

As part of Project M&E, the above-ground vegetation dynamics will be monitored for the purposes of evaluating the rangeland condition to inform management decisions, implementation success and to evaluate project impacts. Herbaceous biomass production will be measured using a disc pasture meter and changes to woody cover and vegetation structure will be measured using fixed-point wheel spoke repeat photographs, line-point intercept transects and remote sensing products. All the measurements will be captured in the Rangeland Stewardship Information Portal with trend analyses conducted by the Graduate Monitors. These data are not intended to be used to claim any ER benefits from changes in the above-ground carbon stocks as a result of the conservative de minimis assumption.

Adjustments to the target implementation rate are required to account for the conservative assumptions used for estimating the mitigation potential. The project target coverage of improved management practices over the eight-year implementation period is 4,600,000 ha. For the conservative Ex-ACT model, as for the livestock enteric fermentation model, it is assumed that full coverage is only achieved in year 11. The model, therefore, assumes that the entire project duration until year 11 is the implementation phase and the remaining duration is the capitalisation phase, where applicable. The project implementation area is also scaled to reflect this difference in the projected implementation rate (Table 12).

Table 3 . Conservative number of sites, area under improved management and mitigation targets over 4-, 8-, 10-, and 20-year impact periods from improved rangeland condition or avoided degradation.

Impact period	Sites	Area (ha)	Cumulative mitigation (tCO_2e)	Annual mitigation (tCO_2e/yr)
4-year	44	1,200,000	**681,340**	**170,335**
8-year	83	3,671,154	**4,168,840**	**521,105**
10-year	103	4,555,769	**6,466,724**	**646,672**
20-year	104	4,600,000	**18,935,574**	**946,779**

4. *Total Project GHG Emissions Reductions:*

Combining the GHG emission reductions resulting from reduced enteric livestock emissions and increased carbon sequestration resulting from improved rangeland condition yields the GHG mitigation estimates for the overall project during implementation (year 8) and over the Project lifetime (year 20), shown below in table 4 (conservative estimate, see figure 1 above for moderate and maximum scenarios):

Table 4: Total Project GHG Emissions Reductions

Period	Cumulative (tCO_2e)			Annual (tCO_2e/yr)		
	Soil	Livestock	**Total**	Soil	Livestock	**Total**
Year 4	681 340	116 090	**797 430**	170 335	29 023	**199 358**
Year 8	4 168 840	534 658	**4 703 498**	521 105	66 832	**587 937**
Year 10	6 466 724	794 351	**7 261 075**	646 672	79 435	**726 107**
Year 20	18 935 574	2 577 525	**21 513 100**	946 779	128 876	**1 075 655**

5. ***Monitoring and Reporting of Mitigation impacts:***

The Full M&E plan for this Project will be developed during the first six months of implementation. The full M&E plan will include detailed information on the roles and responsibilities for data collection and management, project components' impact chains, information flows and reporting systems, finalized indicators and means of verifications, monitoring protocols and tools, implementation plans and schedules, alignments and collaborations with existing national M&E systems (e.g. stats Botswana). The M&E plan will also include participatory methods for data collection and learning Progress towards mitigation targets will be monitored annually and reported to the GCF through the Project's Annual Performance Reports (APRs).

As described in the Project Feasibility Study, Section 3 (Carbon and Water Baseline); measurement of Emissions Reductions achieved by the Project will be undertaken by proxy measurements of rangeland condition and fodder availability / quality for livestock (outlined below). The Project will annually measure changes in rangeland condition (soil sequestration capacity) and fodder quality / availability (enteric fermentation emissions) and apply the Ex-ACT Methodology (soil) and IPCC Tier 2 methodology along with information gathering on total livestock numbers (enteric emissions) to determine and report on the Emissions Reductions achieved by the Project activities. Data collection will be through the Rangeland Stewardship Information Portal, with ground truthing by CI staff and project partners.

To measure the impacts of grazing and restoration management on emissions reduction, the following indicators will be gathered:

- "**Grazing intensity", informed by**:
    - **Biomass** (kg/ha) from disc pasture meter, remote sensing models and satellite-based products such as FAO WaPOR (presented in Annex 2 Section 3 pg. 19–25)
    - **Basal cover** from long-term rangeland condition monitoring (Appendix 11.1), remote sensing models and satellite-based products such as fractional bare ground.

- **Lignin and cellulose content, informed by**
    - **Grass species composition** from long-term rangeland condition monitoring (Appendix 11.1) for Project sites. Reference sites will also be measured for mid-term and final impact evaluation reports. Remote sensing models will also be utilized (e.g., Ramoelo et al. 2015)

- **Livestock numbers and weight**
  - For Project sites, livestock numbers will be gathered and updated monthly by Ecorangers and captured in the Rangeland Stewardship Information Portal with trend analysis by the Graduate Monitors and referenced against the Stats Botswana Annual Agricultural Survey Report. Average weight trends per village herd will be integrated into reports on wet and dry season vaccinations. This will be compared to reference site estimates from MoA veterinary records as without the RSA it will be impossible to get similar detail on livestock where farmers are not participating in active communal management (e.g. BAU/status quo).

- **Feed digestibility**
  - **Grass species composition** (as described above)
  - **Biomass** (as described above)
  - **Manure evaluation augmented by fecal nitrogen analysis.** Ecorangers to undertake sampling of dung viscosity as an indicator for feed digestibility that can then be translated into an estimate for emissions reductions. The exact methodology may vary per Area and season due to climate/habitat factors. This information will be reviewed and augmented with chemical analyses carried out by the MoA Nutrition specialist.

- **Activity coefficient**
  - Qualitative categorization of the average energy expended (distance walked per day) to acquire enough grazing material. This can be monitored based on the number of livestock within controlled herds as captured in the Rangeland Stewardship Information Portal with input from the Graduate Monitors.

- **Methane conversion factor**
  - This is based on feed digestibility (described above), herd structure (number and age of males/females), and livestock health indicators (vaccinations, fertility rate, death rate) that can be monitored based on the Rangeland Stewardship Information Portal with input from the Graduate Monitors.

CI will use these indicators as model parameters for the SNAP biogeochemical model (Ritchie 2014) to estimate the emissions reductions (ER) from the project's livestock and rangeland management activities. This modelled approach quantifies the ER in a manner consistent with VCS VM0032 (https://verra.org/methodology/vm0032-methodology-for-the-adoption-of-sustainable-grasslands-through-adjustment-of-fire-and-grazing-v1-0/).

6. Additionality of interventions:

There are several alternative land-use scenarios to the proposed project interventions, most notably the continuation of the existing land use that has contributed to the observed, reinforcing degradation cycles that are being exacerbated by the impacts of climate change[4] (leading to a further loss of soil carbon and increased livestock GHG emissions). The Verified Carbon Standard (VCS) provides three approaches to demonstrating the additionality condition of mitigation interventions in the Agriculture, Forestry and Other Land Use (AFOLU) sector[5]. The applicability of any one of these three conditions is sufficient to determine that a project is additional. For this project, additionality can be demonstrated across all three conditions. The approaches include the demonstration that the project interventions do not yield an attractive financial return (investment analysis), that they face barriers that prevent their implementation (barrier analysis), or that similar project activities in a comparable environment and at a similar scale are not common practice in the geographical area of the project (common practice analysis).

- An investment analysis has been conducted and reported in Section 2: Options Analysis & Financial and Economic Analysis of the Feasibility Study (see Annex 2). The total net benefits of the project, relative to the without-project scenario, has been shown to total US$235 per-beneficiary over the 20-year period considered (US$11.75/beneficiary/year). By any metric, this does not constitute an attractive financial return and would not be a viable investment option through conventional financing mechanisms. A barrier analysis has been conducted and reported in Section B.2. of the Funding Proposal, including:weak community awareness and governance mechanisms for designing and implementing climate responsive rangeland restoration and livestock production strategies;
- insufficient government resource allocation and coordination for governing communal rangelands and community adoption of climate-resilient livestock management strategies;
- herding not being an attractive career and traditional knowledge of managing livestock, particularly in times of climate stress, being lost;
- lack of spatially explicit information, analytical tools, and monitoring effort on climate, rangeland health, livestock management, and emissions reduction strategies;
- lack of policy-enabling platforms on climate-resilient rangeland and livestock management;
- reactive, rather than proactive, investments aimed at reducing vulnerability of communal farmers;

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[4] See Annex 2: Feasibility Study, Section 3: Carbon and Water Baseline Assessment, Chapter 3: Drivers of rangeland degradation.

[5] Verified Carbon Standard, “VT0001: Version 3.0 Tool for the demonstration and assessment of additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) project activities,” 2012. https://verra.org/wp-content/uploads/2017/11/VT0001v3.0.pdf

- lack of scientific understanding of linkages between rangeland restoration, climate smart livestock production, GHG emission reductions, ecological impacts, and social co-benefits;
- trade barriers for communal farmers with detrimental impacts on their livelihoods; and
- lack of awareness and support for climate resilient livestock value chains.

As a result of these complex, structural barriers, the proposed project would result in a significant paradigm shift for the country and the region (see Section B.2. of the Funding Proposal). The activities of the project are, therefore, not common practice in Botswana nor in the region, particularly not at the scale proposed. It is anticipated that the implementation of this project has a considerable potential for multiplicative benefits in the region by catalyzing similar paradigm shifts in other districts and across Africa (see Section D.2. of the Funding Proposal).

Annex 22 - Section B: FP References

A. Warren and C. Agnew, (1988) "An Assessment of Desertification and Land Degradation in Arid and Semi-Arid Areas," *International Institute for Environment and Development, Drylands Programme, Paper 2* (London, UK).

Abel, N. O. J., & Blaikie, P. M. (1989). Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe. *Land Degradation and Development*, *1*(2), 23a doi: 10.1002/ldr.3400010204

African Union (2010) Policy Framework for Pastoralism in Africa: Securing, Protecting and Improving the Lives, Livelihoods and Rights of Pastoralist Communities. *Department of Rural Economy and Agriculture.* Online: https://au.int/sites/default/files/documents/30240-doc-policy_framework_for_pastoralism.pdf

Agricultural Statistics Section - Ministry of Agricultural Development and Food Security - Department of Agricultural Research, Statistics and Policy Development (2019). Annual Agricultural Survey Report 2017. [online] *Gaborone: Statistics Botswana*. Available at: http://www.statsbots.org.bw/sites/default/files/publications/ANNUAL%20AGRIC%20SURVEY%202017.pdf

Archer van Garderen, E.R.M. (2011). Reconsidering cattle farming in Southern Africa under a changing climate. *Weather, Climate & Society* 3(4): 249-253

University of Cape Town - Assar.uct.ac.za. (2019). *ASSAR's Work In Botswana* | *Adaptation At Scale In Semi-Arid Regions*. [online] Available at: http://www.assar.uct.ac.za/Botswana

Atkinson, SJ, M. Penrith, and N Ramsen (eds) 2019. Gap Analysis on the Implementation of Commodity-based Trade of Beef in Ngamiland. Available at http//www.wcsahead.org.za/kaza

Basupi et al (2017). Land use, rangeland degradation and ecological changes in the southern Kalahari, Botswana. *African Journal of Ecology* 54, 59–67

Berkes, F. (2007) Community-based conservation in a globalized world *PNAS* September 25 104 (39) 15188-15193; https://doi.org/10.1073/pnas.0702098104

Berrian, A. VanRooyen, J. et al (2016) One Health profile of a community at the wildlife-domestic animal interface, Mpumalanga, South Africa *Preventive Veterinary Medicine* Volume 130, 1 August, Pages 119-128

Botswana Press Agency, (2018). *Government Commits Millions For Drought Relief Measures*. [online] Available at: http://www.dailynews.gov.bw/news-details.php?nid=44600.

Brandt, M., Wigneron, J. P., Chave, J., Tagesson, T., Penuelas, J., Ciais, P., Fensholt, R. (2018). Satellite passive microwaves reveal recent climate-induced carbon losses in African drylands. *Nature Ecology and Evolution*, 2(5), 827-835. https://doi.org/10.1038/s41559-018-0530-6

C. J. Barrow. (1991) Land Degradation: Development and Breakdown of Terrestrial Environments. *Cambridge, UK: Cambridge University Press*.

C. Vanderpost, S. Ringrose, D. Kgathi & W. Matheson (2007) The nature and possible causes of land cover change (1984 –1996) along a rainfall gradient in southeastern Botswana, *Geocarto International*, 22:3

Carnie, T., (2020). Tourist Anger Over Cattle Grazing In Mapungubwe National Park. [online] *Daily Maverick.* Available at: https://www.dailymaverick.co.za/article/2018-01-15-tourist-anger-over-cattle-grazing-in-mapungubwe-national-park/

Charles, T. (2019) Why Okavango Delta Is Drying - Experts Speak. [online] *Mmegi Online.* Available at: http://www.mmegi.bw/index.php?aid=82034&dir=2019/august/02

Cherchi, L. and Kirkwood, D. (2019). Crossovers in Botswana: Women Entrepreneurs Who Operate in Male-Dominated Sectors. *Component of World Bank Women and Entrepreneurship Study.* [online] Washington, D.C. http://documents.worldbank.org/curated/en/290451565250128807/Crossovers-in-Botswana-Women-Entrepreneurs-Who-Operate-in-Male-Dominated-Sectors-Output-for-Women-Entrepreneurship-Study.

Climpact HWD-EHF Analysis (2020) https://climpact-sci.org/indices/

Climpact SPEI Analysis (2020) https://climpact-sci.org/indices/

Columbia University - Iridl.ldeo.columbia.edu. 2020. *Standardized Precipitation Index*. [online] Available at: https://iridl.ldeo.columbia.edu/maproom/Global/Precipitation/SPI.html

Conservation International (2011) Climate Diaries: Businesses Building Resilience to Climate Change. *Conservation South Africa (CSA) Available at:*https://www.conservation.org/south-africa/video?ytVideoId=r14ivmgPp7M)

Cristilla, C. and R. Tebaldi, 2016. Social Protection in Africa: an Inventory of Non-contributory Programmes. www.ipc-undp.org.

Darkoh, BK. and Joseph E Mbaiwa (2010), Land-use and Resource Conflicts in the Okavango Delta, Botswana. *Harry Oppenheimer Okavango Research Centre*, Maun.

David Ward, (2010) A Resource Ratio Model of the Effects of Changes in CO2 on Woody Plant Invasion, *Plant Ecology* 209, no. 1: 147–52, https://doi.org/10.1007/s11258-010-9731-z.

Dept. of Environmental Affairs, Ministry of Environment, Wildlife & Tourism, [2006] Botswana National Action Programme to Combat Desertification (OCoLC)760176303

Dept of Environmental Affaris, Republic of South Africa. Briefing on the EPWP and Job Creation. Dr Guy Preston (2019) < https://static.pmg.org.za/180606EPWP.pdf>

Doughill, Andrew J, Lawrence Akanyang, Jeremy S. Perkins, Frank D. Eckardt, Lindsay C. Stringer, Nicola Favretto, Julius Atlhopheng and Kutlwano Mulale (2016). Winners and losers: privatizing the commons in Botswana, *IIED,* Hertfordshire

Dreber N., Kong, T.M., Kellner, K., Harmse, C.J., Van Eeden, A., and Ocampo-Melgar, A. (2014). Towards Improved Decision-Making in Degraded Drylands of Southern Africa: an Indicator Based Assessment for Integrated Evaluation of Restoration and Management Actions in the Kalahari Rangelands. *GRF Davos Planet@Risk,* 2(1) Special Issue, pp.104-106.

Dube, M. (2009) Botswana Drought Makes Wasteland Of Harvests, Livestock. [online] *Voice of America News.* Available at: https://www.voanews.com/africa/botswana-drought-makes-wasteland-harvests-livestock

Dube, O.P. 2013. Challenges of wildland fire management in Botswana: Towards a community inclusive fire management approach. *Weather and Climate Extremes*, 1:26–41

Durán y Lalaguna, P.; Fernández Liesa, C.R.; Morán Blanco, S. y Díaz Barrado, C. M. (dirs.), Verdiales López, D. M. (coord.) (2019). Public-private partnerships and sustainable development goals: proposal for the implementation of the 2030 Agenda. *Instituto Universitario de Estudios Internacionales y Europeos "Francisco de Vitoria",. Colección electrónica*, nº 10. ISBN 978-84-09-07176-0

Du Toit, C.J.L.; Meissner, H.H.; van Niekerk, W.A. (2013) Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *South African Journal of Animal Science*. 43 (3). 320-339

E. Nkonya, A. Mirzabae, J. von Braun (2016) Economics of Land Degradation and Improvement - A Global Assessment for Sustainable Development. *Springer Open*, Heidelberg New York Dordrecht London

Emdat.be. 2020. *EM-DAT* **|** *The International Disasters Database*. [online] Available at: http://www.emdat.be/

Favretto, N, Stringer, L C, et al (2014) Assessing the Socio-Economic and Environmental Dimensions of Land Degradation: A Case Study of Botswana's Kalahari 1–28, http://www.see.leeds.ac.uk/research/sri/eld/

Food and Agriculture Organization (2009) Review of evidence on drylands pastoral systems and climate change: Implications and Opportunities for Mitigation and Adaptation.
http://www.fao.org/fileadmin/user_upload/rome2007/docs/Drylands_pastoral_systems_and_climate%20change.pdf

Food and Agriculture Organization (2011) The state of the world's land and water resources. *FAO* http://www.fao.org/3/i1688e/i1688e03.pdf

Food and Agriculture Organization (2016). Southern Africa. Situation report. September 2016 http://www.fao.org/3/a-br082e.pdf

Food and Agriculture Organization (2018) Horn of Africa: Impact of Early Warning Early Action. http://www.fao.org/3/ca0227en/CA0227EN.pdf

Foreign Agricultural Service, United States Embassy in South Africa (2015) *Botswana Agricultural Economic Fact Sheet*. [online] Pretoria. Available at:
https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Agricultural%20Economic%20Fact%20Sheet_Pretoria_Botswana_6-9-2015.pdf

Frits Van Oudtshoorn, (2015) Veld Management: Principles and Practices Pretoria: *Briza Publications*.
Galvin et al, (2001) Impacts of climate variability on East African pastoralists: linking social science and remote sensing. *Climate Research.* Vol 19, pp 161-172

Gain-new.crc.nd.edu. 2020. *Botswana* **|** *ND-GAIN Index*. [online] Available at: <https://gain-new.crc.nd.edu/country/botswana>

Genevieve V. Weaver et al., (2013) "Foot and Mouth Disease: A Look from the Wild Side," *Journal of Wildlife Diseases* 49, no. 4: 759–85, https://doi.org/10.7589/2012-11-276.

Giampiero Grossi et al., (2019) "Livestock and Climate Change: Impact of Livestock on Climate and Mitigation Strategies," *Animal Frontiers* 9, no. 1: 69–76, https://doi.org/10.1093/af/vfy034.

Government of Botswana (2011). Botswana land policy: *Ministry of Lands and Housing*.

Government of Botswana (2012). Agriculture and Food Security Policy Brief: Reflecting on the challenges of attaining a Green Economy for Botswana. https://sustainabledevelopment.un.org/content/documents/1008National%20Report%20(Agriculture)%20-%20Botswana.pdf

Government of Botswana (2019). Botswana National Atlas page 11. *www.atlas.gov.bw*

Government of Botswana 2020. *Okavango Delta Monitoring And Forecasting*. [online] Available at: <http://okavangodata.ub.bw/ori/

Government of Botswana, (2019). FINAL STRATEGY. A National Climate Change Strategy for Botswana *(not currently available online)*

GRA and SAI (2015) "Reducing Greenhouse Gas Emissions from Livestock: Best Practice and Emerging Options" https://ccacoalition.org/es/resources/reducing-greenhouse-gas-emissions-livestock-best-practice-and-emerging-options.

Green, KM et al (2019) A Meta-Analysis of Social Marketing Campaigns to Improve Global Conservation Outcomes. *Social Marketing Quarterly*, Volume 25, Issue 1. Pp1-19

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas*. International Journal of Climatology* 25: 1965-1978 http://onlinelibrary.wiley.com/doi/10.1002/joc.1276/pdf

Hulme, Mike & RM, Doherty & Ngara, T.N.M. & New, Mark & Lister, David. (2001). African Climate Change: 1900-2100. *CLIMATE RESEARCH.* 17. 145-168. 10.3354/cr017145.

Jones, R., Thurber, K.A., Wright, A., Chapman, J., Donohoe, P., Davis, V., and Lovett, R. (2018). Associations between Participation in a Ranger Program and Health and Wellbeing Outcomes among Aboriginal and Torres Strait Islander People in Central Australia: A Proof of Concept Study. *International Journal of Environmental Research and Public Health* 15(7), 1478.

Jongman, K (2018) "Sustainable livelihood and poverty eradication in Botswana", *International Journal of Development and Sustainability*, Vol 7 No4 pp1317-1324

Juana, J., *et al*. (2014). "Socioeconomic Impact of Drought in Botswana." *International Journal of Environment and Sustainable Development*, 11(1).

Keesing et al, 2018 Consequences of integrating livestock and wildlife in an African savannah. Nature Sustainability. Available at: https://doi.org/10.1038/s41893-018-0149-2)

Liniger, HP. and Mekdaschi Studer, R. (2019) Sustainable rangeland management in Sub-Saharan Africa – Guidelines to good practice. *TerrAfrica; World Bank*, Washington D.C

Liniger, HP. and Mekdaschi Studer, R. 2019. Sustainable rangeland management in Sub-Saharan Africa – Guidelines to good practice. TerrAfrica;

Lotta Andersson et al. (2006) “Impact of Climate Change and Development Scenarios on Flow Patterns in the Okavango River,” *Journal of Hydrology* 331, no. 1–2: 43–57, https://doi.org/10.1016/j.jhydrol.2006.04.039.

Maddox, G., Chatty, D., and Colchester, M. (2003). Conservation and Mobile Indigenous Peoples: Displacement, Forced Settlement, and Sustainable Development. *The International Journal of African Historical Studies*. 36(3), pp. 1-20.

Masih, I., S. Maskey, F. E. F. Mussá, and P. Trambauer (2014) "A Review of Droughts on The African Continent: A Geospatial and Long-Term Perspective". *Hydrology and Earth System Sciences* 18 (9).
Mguni, M. (2020). Hunger Games 2019: Drought Leaves 38,000 In Need. [online] *Mmegi Online.* Available at: https://www.mmegi.bw/index.php?aid=81912&dir=2019/july/26

Michael Murray-Hudson, Piotr Wolski, Susan Ringrose (2006) “Scenarios of the Impact of Local and Upstream Changes in Climate and Water Use on Hydro-Ecology in the Okavango Delta, Botswana,” *Journal of Hydrology* 331, no. 1–2: 73–84, https://doi.org/10.1016/j.jhydrol.2006.04.041.

Ministry of Agriculture Development and Food Security Department of Agricultural Research, *Statistics & Policy Development* (2020). Botswana Agricultural Census Report 2015. [online] *Gaborone: Statistics Botswana*. Available at: http://www.statsbots.org.bw/sites/default/files/publications/Botswana%20Agriculture%20Census%20Report%20Final%202015..pdf

Ministry of Environment, Natural Resources Conservation and Tourism, (2019) Botswana's Third National Communication To The United Nations Framework Convention On Climate Change. [online] Available at: https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/3567491_Botswana-NC3-1-BOTSWANA%20THIRD%20NATIONAL%20COMUNICATION%20FINAL%20.pdf

Mogotsi, K., *et al.* (2011). The perfect drought. Constraints limiting Kalahari agropastoral communities from coping and adapting. *African Journal of Environmental and Science Technology* 5.

Moleele, N.M.; Ringrose, S.; Matheson, W.; Vanderpost, C., (2002). More woody plants? The status of bush encroachment in Botswana's grazing areas. *J. Environ. Manage*., 64 (1): 3-11

Monde Rapiya, Heidi-Jayne Hawkins, Voster Muchenje, John F Mupangwa, Munyaradzi C Marufu, Kennedy Dzama & Cletos Mapiye (2019) Rotational grazing approaches reduces external and internal parasite loads in cattle, *African Journal of Range & Forage Science,* 36:3, 151 - 159, DOI: 10.2989/10220119.2019.1628104

Muller et al. (2020) Building resilience in rangelands through a natural resource management model: a case study of Ecosystem-based Approaches to Adaptation. *IIED*. https://pubs.iied.org/G04444/

Murray-Hudson, Mike & Wolski, Piotr & Ringrose, S. (2006). Scenarios of the impact of local and upstream changes in climate and water use on hydro-ecology in the Okavango Delta, Botswana. *Journal of Hydrology.* 331. 73-84. 10.1016/j.jhydrol.2006.04.041.

N. Wrage et al. (2011) “Phytodiversity of Temperate Permanent Grasslands: Ecosystem Services for Agriculture and Livestock Management for Diversity Conservation,” *Biodiversity and Conservation* 20, no. 14: 3317–39, https://doi.org/10.1007/s10531-011-0145-6.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, 2014: Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Omari, K. (2010) Climate Change Vulnerability and Adaptation Preparedness in Southern Africa—A Case Study of Botswana. *Heinrich Böll Stiftung* Cape Town.

P.J. Gerber et al. (2013) Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities, *Most*, vol. 14 (Rome, Italy: Food and Agriculture Organization of the United Nations (FAO) https://doi.org/10.1016/j.anifeedsci.2011.04.074.

Peace Parks Foundation (2020) Herding 4 Health - Peace Parks Foundation. [online] Available at: https://www.peaceparks.org/h4h/

Ramoelo, A et al. (2015) Monitoring grass nutrients and biomass as indicators of rangeland quality and quantity using random forest modelling and WorldView-2 data. International Journal of Applied Earth Observation and Geoinformation. 43. 43–54. http://dx.doi.org/10.1016/j.jag.2014.12.010

Ritchie, M (2014) Plant compensation to grazing and soil dynamics in a tropical grassland. PeerJ 2:e233; DOI 10.7717/peerj.233

Rust, JM, and T.Rust (2013) Climate change and Livestock Production: A review with a focus on Africa. *South African Journal of Animal Science*, 43 (No. 3)

SANBI. 2018. Biodiversity Stewardship Guideline. A guideline produced for the Department of Environment, Forestry and Fisheries. Developed by Wilson, N., Kershaw, P., Marnewick, D. and Purnell, A

Santiago Beguería, F (2020). *Data Base: SPEI, The Standardised Precipitation-Evapotranspiration Index*. [online] Spei.csic.es. Available at: <https://spei.csic.es/database.html>

Sejian, Veerasamy & Bhatta, Raghavendra & Soren, N M & Malik, Pradeep & Ravindra, J.P. & Prasad, C.s & Lal, Rattan. (2015). Introduction to Concepts of Climate Change Impact on Livestock and Its Adaptation and Mitigation. Climate Change Impact on Livestock*: Adaptation and Mitigation.* 1-23. 10.1007/978-81-322-2265-1_1.

Setshwaelo LL. (2001) A study of Grassland/livestock vulnerability and adaptation to climate change *Government of Botswana*

Sitters et al. 2020.Effects of cattle and megaherbivores on soil carbon and nutrient pools. Nature Sustainability. Available at: https://doi.org/10.1038/s41893-020-0490-0

Smit GN (2005) Tree thinning as an option to increase herbaceous yield of an encroached semi-arid savanna in South Africa. *BMC Ecology* 5: 4. DOI 10.1186/1472-6785-5-4

Statistics Botswana / World Bank (2010) Mapping Poverty in Botswana. *Government of Botswana* http://www.statsbots.org.bw/sites/default/files/publications/POVERTY%20Mapping%202010_May%2028%202015.pdf

Statistics Botswana (2015). *Botswana Poverty Map*. [online] Available at: http://www.statsbots.org.bw/sites/default/files/publications/POVERTY%20Mapping%202010_May%2028%202015.pdf

Stephanie Bailey and Michelle Cohan, C., (2020). *Solar Powered Kiosks Are Charging Phones In Rwanda*. [online] CNN. Available at: https://edition.cnn.com/2019/09/23/tech/solar-kiosks-rwanda-intl/index.html

Susan Ringrose (2003) "Characterization of Riparian Woodlands and Their Potential Water Loss in the Distal Okavango Delta, Botswana," *Applied Geography* 23, no. 4: 281–302, https://doi.org/10.1016/j.apgeog.2003.08.006.

The World Bank (2019). *The World Bank in Botswana - Overview*. [online] Available at: https://www.worldbank.org/en/country/botswana/overview

Thornton, P., Herrero, M., Freeman, A., Mwai, O., Rege, E., Jones, P. & McDermott, J. (2007) Vulnerability, climate change and livestock – Research opportunities and challenges for poverty alleviation. *SAT eJournal* 4 (1), 1-23.

Tripp, R., (2016) The Future Of Veterinary Medicine: Drones In Veterinary Practice. [online] *dvm360.* Available at: https://www.dvm360.com/view/future-veterinary-medicine-drones-veterinary-practice

Venter, Z.S., Cramer, M.D. & Hawkins, H. (2017) Drivers of woody plant encroachment over Africa. *Nat Commun* **9,** 2272 https://doi.org/10.1038/s41467-018-04616-8

Whitmee, S et al (2015) Safeguarding human health in the Anthropocene epoch: *report of The Rockefeller Foundation–Lancet Commission on planetary health*

Wilkes A. 2017. Measurement, reporting and verification of greenhouse gas emissions from livestock: current practices and opportunities for improvement. CCAFS Info Note. Copenhagen, Denmark: CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS).

World Bank Project Database. Ethiopia Rural Productive Safety Net Project. https://projects.worldbank.org/en/projects-operations/project-detail/P163438?lang=en

World Bank, Washington D.C.; World Overview of Conservation Approaches and Technologies (WOCAT); World Bank Group (WBG), Washington DC, USA and Centre for Development and Environment (CDE),University of Bern, Switzerland. Available at https://www.wocat.net/library/media/174/.

UNICEF & Ministry of Local Government (2012) Final report for the review of the Ipelegeng Programme. *Gaborone* Available: https://www.unicef.org/evaluation/files/Botswana_2012-004_Final_Ipelegeng.pdf

UNFCCC (2015). *Botswana Intended Nationally Determined Contribution (INDC)*. [online] https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Botswana%20First/BOTSWANA.pdf/

Zhou P.P., Simbini, T., Ramokgotlwane, T.,Thomas, T.S., Hachigonta, S., and Sibanda, L.M. (2013). Botswana. In: Hachigonta, S, Nelson, G.C., Thomas, T.S., and Sibanda, L.M, eds., *Southern African Agriculture and Climate Change: A Comprehensive Analysis,* 1st ed., Washington, D.C.: International Food Policy Research Institute (IFPRI), [online]. Available at: http://dx.doi.org/10.2499/9780896292086