Protecting Lands and Wilderness

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Background paper for World Social Report (WSR) 2021

Rural Development for Achieving Sustainable Development Goals (SDGs)

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Introduction

Protection of land will play a key role in achieving 10 of the 17 Sustainable Development Goals (SDGs) (UNEP 2019). The interrelationships between SDGs have generally shown to be synergistic and effective in achieving all goals (Stafford-Smith et al 2017). In this background paper, we will discuss state of the land resources and wilderness, the policies and strategies for ensuring land and wilderness protection in rural areas and their impacts on protection of land and restoration of degraded lands. The discussion is not comprehensive. Instead, it focuses on two to three key policies and strategies for achieving rural development for land protection.

As stipulated in the Terms of Reference (TOR), the discussion hinges around three research questions:

1) What is the current status of protection of land in the light of pressures emanating from the three different dimensions of rural development, namely (a) agriculture, (b) non-agricultural activities, and (c) infrastructure and settlements?

2) What are 2-3 strategic options in each of the three dimensions, including technologies, which could be used to protect lands and restore degraded lands, in the most cost-effective and sustainable manner?

3) What are the impacts of implementing the 2-3 strategies on achieving the sustainable development goals (SDGs)?

To underscore the centrality of SDG15 in achieving the 2030 Agenda for Sustainable Development, the following section discusses the relationship between SDG15 and 10 other SDGs. This is followed by discussion of the status of protection of land in agriculture, non-farm activities and infrastructure. Then discussion of strategic options for Land Protection and Wilderness in cost effective and sustainable manner is given. This is followed by discussion of the impacts of the strategies on achieving the SDGs. The last section of the paper reflects on the policy implications of the results.

SDG15 relationship with other SDGs

SDG15 aims to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification as well as halt and reverse land degradation and the loss of biodiversity.

Figure 1 summarizes the interlinkages of SDG 15 with 10 other SDGs. SDG15 is directly interlinked with SDG1 of *no poverty* since 75% of poor people rely on agriculture (World Bank 2015). This means land protection and restoration of degraded lands will contribute directly to achieving SDG1. Likewise achievement of SDG15 will directly enhance achievement of SDG2 (*zero hunger*) since agriculture accounts for 50% of habitable land (UNEP 2019). SDG3 (*good health*) is directly affected by achievement of SDG15 since food produced on land accounts for 97% of energy and 87% of protein consumed (FAOSTAT 2019).

Achievement of SDG15 will enhance achievement of SDG5 on gender equality since studies have shown that ownership and control of land by women enhances gender equality in developing countries, where gender inequality is more severe (Meinzen-Dick et al 2019). Achievement of SDG15.1, which specifically aims to "conserve and restore terrestrial and freshwater ecosystems" will directly improve water quality. For example, producing one kilogram of beef leads to excess nutrient runoff of 365.29g of phosphate equivalents (PO_4eq) (Poore & Nemecek 2018).The excess nutrient runoff ends in waterways and eventually degrades the quality of water (Mateo-Sagasta et al 2017).

SDG7 on *affordable clean energy* is directly related to SDG15 since solid and liquid biofuels are produced on land. Liquid bioenergy accounted for 12.4% of total global energy consumption of 370 Exajoule (EJ) in 2017 (World Bioenergy Association 2018). About 2.8 billion people or 31% of the global population use woodfuel for cooking and heating (UNDESA 2019a). Woodfuel, charcoal and other solid bioenergy is the largest of energy in developing countries (Reid et al 2020).

SDG9 on *industry, innovation and infrastructure* is strongly anchored on land. SDG9.1 aims to "*Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all."* Sustainability of roads and telecommunication infrastructure heavily depend on land management. For example, the World Bank reported that US$18 billion loss is incurred per year due to destruction of transport, power, water and sanitation, and telecommunications infrastructure due to flooding in low and medium income countries (Hallegatte et al 2019). Infrastructure destruction translates into an annual loss of $391 to $647 billion for households and firms – which use such infrastructure (Ibid). Such destruction could be reduced significantly if there is protection of land cover. On the other hand, construction of roads and other infrastructure could contribute to soil erosion (Seutloali and Beckedahl 2015; Yousefi et al 2016).

SDG9.2 aims to "Promote inclusive and sustainable industrialization", in which value addition is one of its indicators. Agricultural value addition in least developed countries is still low and its improvement will enhance land protection and restoration. Agro-processing reduces post-harvest losses and increases shelf life – all of which contributes to land protection (Wilkinson and Rocha 2009). This is an aspect, which is consistent with SDG9.4 and aims to "upgrade all industries and infrastructures for sustainability."

SDG11 on *sustainable cities and communities* is strongly linked with land since building material are derived from land. Cities occupy only 0.5% of land area (OECD and European Commission 2020), but their indirect land use in rural areas is estimated to be 20 times higher than their direct land use (Zeng and Ramaswami 2020). SDG11.1 aims to achieve "safe and affordable housing" – a target which could be achieved by utilizing timber, non-metal material like quarry, sand and other land resources for building affordable houses in slums and other neighborhoods in cities. SDG11.3 aims to achieve "inclusive and sustainable urbanization." The rapid urban growth and sprawl have direct impact on land degradation since they are turning fertile lands into settlement – leading to soil sealing and other forms of landuse/cover changes, which result into land degradation (Salvati et al 2018).

SDG13 on climate action has a direct and strong linkage with SDG15 since food production accounts for 26% of greenhouse gas (GHG) emission (Poore and Nemecek 2018). At the same time, terrestrial plants and soils absorb about 9.5 $PgCO_{2e}$ per year or 20% of anthropogenic GHG emissions (Le Quéré et al. (2015). This means land management practices have a direct and strong impact on climate change mitigation. For example, climate-smart agriculture are designed to simultaneously increase agricultural productivity, enhance adaptation to and mitigation of climate change (van Wijk et al 2020). Forests also play a key role in mitigation of climate change. For example Pan et al (2011) estimated that established and re-growing forests sequestered 73 Petagrams (Pg) of carbon per year – equivalent to 60% of global fossil fuel emissions 126 Pg C in 1990-2007.

SDG14 on *life below water*. Agriculture accounts for 78% of the global ocean and freshwater eutrophication 78% (Poore and Nemecek 2018). Nutrient use efficiency and other practices will reduce eutrophication and contribute to achieving SDG14.

Figure 1: SDG15 interlinkages with other SDGs

Direct and strong linkage with SDG15

Weak and/or indirect linkage with SDG15

Sources for each SDG: 1= World Bank 2015; 2= UNEP 2019; 3= FAO et al. 2020; 5=Meinzen-Dick et al 2019; 6=Mateo-Sagasta et al (2017); 7=Reid et al 2020; 9=OECD & FAO. 2019; 11=Cecchini et al 2019; 13= Smith et al 2019; 14=Anderson et al 2002

Current status of protection of land in agriculture, non-agricultural activities and infrastructure and settlements

Agriculture

Land degradation affects the most agriculture – which includes cropland, grazing land and forests. Recent estimates by Song et al. (2018) show that between 1982 and 2016, South America and Africa experienced loss of forest extent while all other regions experienced gain (Table 1). Short vegetation – which includes grasslands, cropland and all other types of vegetation shorter than 5 m – experienced the most severe degradation – especially in Europe, North America and Asia (Table 1). Bare land – which is the most degraded land decreased – underscoring progress in restoration of degraded lands.

Table 1: Share of degraded lands by type of biome across world regions, 1982-2016

Region	Forest net change		short vegetation net change		Bare land net change	
	000 km^2	% of 1982 area	000 km^2	% of 1982 area	000 km^2	% of 1982 area
South America	-431	-4.92	431	6.02	10	0.58
Africa	-5	-0.11	303	2.60	-266	-1.98
Oceania	16	2.35	-82	-1.78	78	2.81
North America	378	6.50	-308	-2.38	-46	-0.95
Asia	992	11.73	-501	-2.30	-440	-3.16
Europe	741	27.25	-623	-9.86	-83	-12.43
Global	1691	5.40	-780	-1.22	-747	-2.01

Source: Computed from Song et al. 2018.

Forest extent has increased in Europe, North America and most Asians sub-regions – underscoring success stories of land restoration and protection of non-degraded lands. In addition to the biome level of agricultural degradation, there are specific types of degradation – including soil erosion, soil carbon and nutrient depletion, overgrazing, forest degradation, and soil and water pollution due to improper and/or over-application of fertilizer and other agrochemicals. The discussion below briefly explores each of these types of land degradation.

Soil erosion affects agriculture and nonagricultural sectors. Sartori et al (2019) observed soil erosion increases food price by 0.4%–3.5% in the world. Panagos et al (2018) estimated that 12 million hectares of agricultural land in the European Union is affected by soil erosion – an aspect that has reduced crop yield by 0.43% - equivalent to annual loss of 1.25 billion euro. A study by Borrelli et al (2017) showed a 5.3% decrease in soil erosion in high-income countries and an 11.7% increase in least developed economies.

Soil carbon stock has been falling in all country groups, but for different reasons. At a global level, agricultural land area per capita has fallen by more than 50% from its level in 1961 (Ritchie and Roser 2020). The decline is especially high in SSA – whose per capita agricultural land area is smaller than a third of its level in 1961 (Richtie and Roser 2020). With limited adoption of improved production technologies, declining per capita agricultural land area has translated into continuous farming, which is more serious in developing countries with high population density. In high and middle-income countries, use of heavy machinery and deep-plowing cause compaction and loss of soil organic matter (SOM). For example, Krauss et al (2020) conducted a 15-year experiment and observed that topsoil SOM and microbial biomass in Europe increased by 25% and 32% respectively in reduced tillage plots compared to those under conversional tillage. Similarly, a long-term experiment at Kabete Agricultural research Institute in Kenya observed declining yield – largely due to declining SOM for continuously cultivated plots (Nandwa and Bekunda 1998).

Soil nutrient depletion is a serious problem in developing countries whose practices include low-external inputs (Titonell et al 2006; Grote et al 2005). The per hectare loss of soil nutrient is highest in SSA and it is estimated that the cost of restoration of mined nutrients is approximately 7% of the region's GDP (Craswell and Vlek 2013).

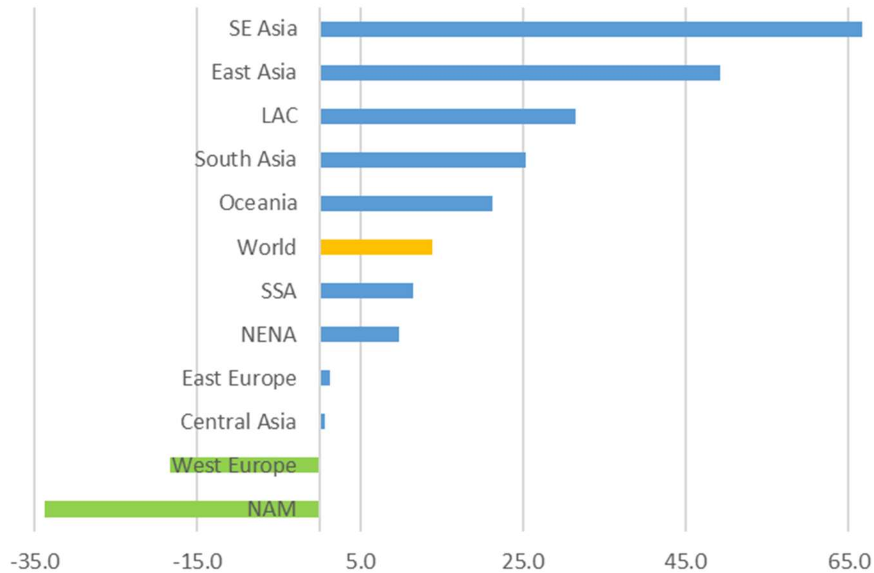
Soil, air and water pollution from agriculture and non-agricultural sources is increasingly becoming a challenge. Fertilizer over-application or improper application pollute soils, water and the atmosphere. This paper will focus on soil pollution and will not discuss water pollution from agriculture since Rosegrant in this volume addresses it. Soil pollution reduces SOM, soils' biodiversity and regulation capacity (Rodríguez-Eugenio et al 2018). Soil pollution is largely caused by agrochemicals and solid waste from agricultural and nonagricultural sectors. For example, in China, 16% of agricultural soils are polluted (FAO 2018).

Overgrazing is a major problem in SSA, the Benelux, North and South of the Alps and Northwestern of France (Hocquette et al 2018), North America, and Australia (Asner et al 2010). Overgrazing is more serious in arid and semiarid areas (Steinfeld et al 2006). The increasing demand for livestock is driving the livestock population, which is responding to the growing middle-income population and urbanization in middle and low-income countries. This has increased the incentive for increasing livestock production and eventually grazing land area in many regions (Figure 2). Unfortunately, livestock products are land-intensive. For example, 163.6 m^2 is required to produce 100gm of protein from grass-fed cattle compared to only 3.4m^2 from peas (Poole and Nemecek 2018). Similarly, producing 1000 kilocalories are produced from 119.49 m^2 of land compared to only 0.76 m^2 from rice (Ibid). The grazing land expansion has been encroaching on critical habitat – thus endangering biodiversity. For example, grazing land expansion is the leading cause of deforestation in the Amazon region (De Sy et al. 2015; Henders, Persson, and Kastner 2015).

Improvement of feed conversion efficiency and importation – mainly from the South America - have contributed to the reduction of the pasture and cropfeeds area reduction in West Europe and North America (Figure 1).

Forest degradation occurs when forest loses ecosystem service provision capacity due to anthropogenic activities and/or environmental changes. In this case, forest biome does not change, but its density, functions and structure are altered (Gao et al 2020). Fires affected about 98 million hectares in 2015 (FAO, 2020). Causes other than fires degraded 142 million hectares of forests between 2003 and 2012 (van Lierop et al., 2015).

Figure 2**:** Change of grazing area across regions, 1967-2017



Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.

Source: Extracted from Ritchie and Roser (2019).

Non-Agricultural Activities

There is two-way cause-effect relationship between agriculture and non-agricultural sectors – which is built on the key role that land plays in life on land. Industrial and mining activities have been associated with soil contamination that arises from improper disposal of heavy metal (e.g. Cadmium, mercury, arsenic), persistent organic chemicals (FAO 2018). Additionally, some large and small-scale mining sites are located in rainforest and other biodiversity rich sites and their activities lead to loss of biodiversity (IRP 2019). Soil pollution threatens achievement of the following SDG goals: 1, 2, 3, 6, 9, 11, 12, 13, 14, 15 and 17 (Ibid) – illustrating the intricate relationship of soils with non-agricultural sector. Landrigan et al (2018) observed that in 2016, 16.7 million people were exposed to mercury and the majority (65%) were African artisanal miners. The report further shows that annual losses due to environmental pollution are more than US$ 4.6 trillion, or 6.2% of the global GDP (Ibid).

Solid waste that end up in landfills has been increasing rapidly with income (UNEP 2015) while quantity of solid waste is strongly correlated with per income (Kaza et al 2018). East accounts for the largest share of solid waste disposal while NENA and SSA account for the smallest share (Table 2). About 44% of solid waste is organic (Table 2) and 38% are recyclable products – plastics, metal, glass, paper and cardboard (Kaza et al 2018).

Land degradation increases the cost of land-based products and this affects non-agricultural sectors. For example, deforestation contributes directly to the high price of timber and non-timber products. Studies have shown that the Amazon deforestation has caused water scarcity in Sao Paolo, where nonagricultural industries are directly affected (Nobre 2014). An assessment of the cost of land degradation have shown that the global cost of land degradation is 2007 US$296 billion per year (Nkonya et al 2016). The share of the cost is much larger on non-agricultural sectors, given that agriculture accounts for only 4% of the global DGP (World Bank 2018). For example soil erosion alone causes food prices to increase by 0.4%–3.5% (Sartori et al 2019) – an aspect which affects almost all sectors.

Table 2: Solid waste by region, 2016

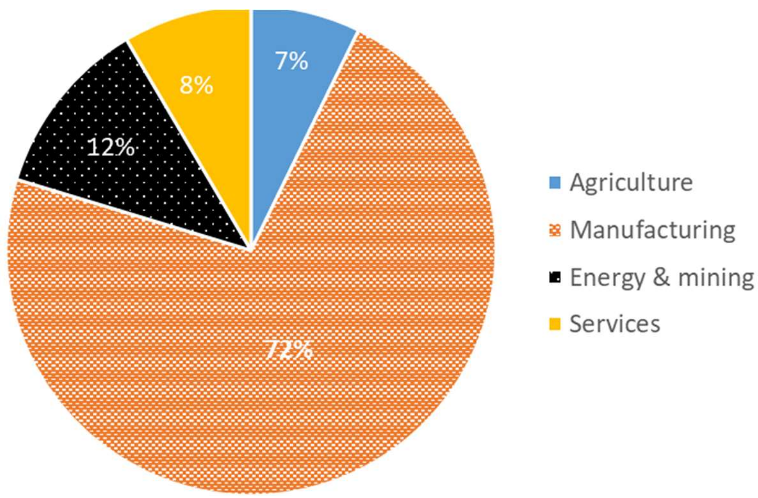
	Solid waste disposal			
Region	Percent organic	Total (Billion tons)	Tons per capita)	Percent of total
SSA	45	0.20	0.25	9.5
LAC	46.81	0.22	0.42	10.2
NAM	28.3	0.28	0.97	13.3
East Asia	33.62	0.52	0.45	24.3
Oceania	32.89	0.02	0.39	0.9
South Asia	51.54	0.28	0.19	13.3
SE Asia	41.4	0.08	0.32	3.7
East Europe	39.29	0.13	0.48	5.9
West Europe	28.4	0.22	0.6	10.2
Central Asia	32.84	0.01	0.2	0.7
NENA	54.98	0.17	0.39	8.1
World	42.04	2.13	0.37	

Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.

Source: Computed from Kaza et al (2018).

Land degradation could cause flooding – which has been shown to have an annual cost of $36.7 billion across both agricultural and nonagricultural sectors (International Disaster Database 2017). For example, a two-year study in China, found that manufacturing accounted for 72% of total cost of flooding (Figure 3). Clearing land cover is a major contributor to flooding (Marshall et al 2009).

Figure 3: Impact of flooding across agricultural and non-agricultural sectors in China



Source: Extracted from Hu et al (2019).

Infrastructure and settlement

Infrastructure development could lead to sustainable land management or to degradation. A classic example is the impact of construction of roads in the Amazon in the 1960s, which led to more severe deforestation (Nelson G, Hellerstein 1997; Pfaff et al 2007). A more recent study in the Democratic Republic of Congo (DRC) showed that road development caused reduction of more than 2% of forest cover, a total carbon stock loss of 316 TgC and a 16% agricultural expansion (Li et al., 2015). However, impact of infrastructure is affected by strength of institutions and policies of the host country. For example, for the past 30 years (1990-2020), forest extent in Europe and Asia has increased (FAO & UNEP 2020) even though road density in Europe is among the highest in the world and road density in Asia has increased significantly during the same period (Carter et al 2020).

In addition to population growth, urban sprawl has been driven by rural-urban migration – especially in developing countries. Additionally urban population densities have been falling in high income countries due to inner city populations moving to suburban areas. For example, population densities of 120 large cities around the world decreased by 2% per year between 1990 to 2000 due to urban sprawl (Angel et al., 2010). Eventually, high income have greater per capita built-up area and urban sprawl than low-income countries (EC JRC 2018; Paresi et al 2016). The urban areas in low-income countries are getting denser with large slums as poor people are pushed out and live exposed to open spaces (Paresi et al 2016). If no changes in urban population densities occur, it is estimated that global built-up area would account for 0.73% of land area by 2030 and if urban population densities decrease, built up area will increase by 140% from their levels in 2010 (Angel et al 2011).

In addition to degradation, the urban sprawl replaces agricultural land, which has direct impact on food security. For example, urban sprawl has claimed about 500,000 hectares of agricultural land in Spain from 1975-2008 (Barbero-Sierra, Marques, & Ruíz-Pérez 2013). A study of 76 South European countries showed that urban sprawl occurred on high quality agricultural land and contributed to land degradation (Salvati et al 2018).Additionally, expansion of urban extent is encroaching on natural habitat, protected areas – and thus loss of biodiversity (The Nature Conservancy 2018; McDonald et al. 2020). Urban sprawl is also encroaching on critical ecosystems like wetlands; forest habitat (Hasse and Lathrop 2003;). Likewise, urban expansion has led to a 25% decrease of the area of olive farms in Turkey in 2006 from its extent in 1985 (Doygun 2009). About 60% of the olive extent loss was due to building constructions, and 40% was due to residential gardens, roads and other urban infrastructure (Ibid).

Beyond deforestation, construction of roads contribute to soil erosion and land degradation in general (Eisenbies et al. 2007; Xiao et al. 2017). The impact of road construction is worse when roads are planned without considering their impact on drainage and other land management objectives ((Xiao et al. 2017). Poorly planned and/or constructed roads lead to disturbance of natural drainage system.. The annual cost of destruction of transport, power, and water and sanitation infrastructure in low and medium-income countries is estimated to be US$18 billion (Hallegatte et al 2019). Infrastructure destruction translates into an annual loss of $391 billion to $647 billion for households and firms – which use such infrastructure (Ibid). On the other, construction of roads and other infrastructure could contribute to soil erosion (Seutloali and Beckedahl 2015; Yousefi et al 2016). Soil sealing in urban area is one of the leading drivers of flooding. This means, land protection and restoration will affect infrastructure and settlement favorably.

Wildfires, dust storms and other land degradation processes have affected cities so much so that their intensity and frequency are increasing. Air quality is now the most important environmental health hazard in cities (UNEP 2019). The recent Sahara dust storm and the California wildfires, which traveled across continents shows the impacts of land degradation and its effect on air quality knows no boundaries and its effect could be felts thousands of miles away from its sources (Çapraz and Deniz 2020; Cabanatuan 2020). Poor indoor and outdoor air quality is estimated to cause 6.5 million deaths annually (World Health Organization [WHO] 2020).

Strategic options for Land Protection and Wilderness in cost effective and sustainable manner

Technologies for achieving zero net land degradation (SDG15.3).

The discussion in this section examines the strategies, which could be used to achieve SDG15.3 goal of net zero land degradation. For brevity, the discussion focuses on cropland, grazing land and forest. Key technologies for protection of land and restoration of degraded lands for each of the three components of agriculture are discussed. Given that the type, extent and severity of land degradation differs across countries, strategies for restoration and protection of agricultural land differ. Such differences are reflected in the discussion.

Restoration of degraded croplands:

Technologies for addressing soil nutrient depletion: The approach to address this challenge is to design strategies for adoption of low-cost practices, which the smallholder farmers could afford. One of such technologies is integrated soil fertility management (ISFM) practice, which is a combination of improved germplasm, organic inputs and judicious amount of chemical fertilizer (Vanlauwe et al 2010). ISFM has an advantage over the conventional soil fertility management since it simultaneously increases profit, yield, SOM, and enhances long-term productivity compared to practices, which use only inorganic fertilizer (Vanlauwe et al 2010; Nkonya and Kato 2020). ISFM is even cheaper when agroforestry is used as the organic input since it could provide up to 80% of the recommended fertilizer rates in East and Southern Africa (Akinnifesi et al 2010). ISFM which incorporates agroforestry reduces or completely eliminates the labor-intensive challenge of transporting manure and other house refuse from homestead or animal kraal to crop plots. It also addresses the challenge of manure production, which farmers with few or no livestock face. Other combinations of organic and inorganic could significantly contribute to restoration of degraded lands.

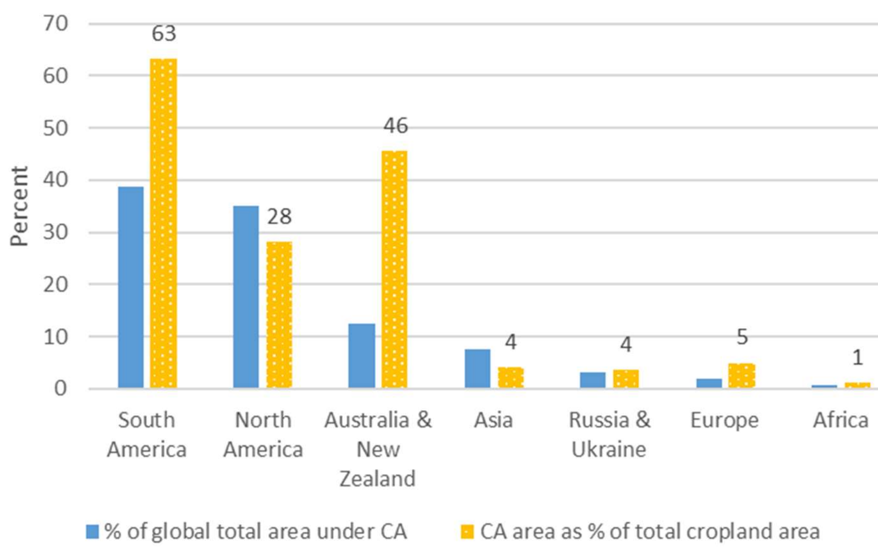
*Technologies for addressing declining soil organic matter (SOM) and compaction***:** SOM is one of the indicators used by UNCCD to monitor achievement of SDG15.3 (IRP 2019). Low-cost soil fertility management practices have been shown to work in low-income countries – which have experienced the highest loss of SOM (Zomer et al 2017). Farmer managed natural regeneration (FMNR), tree planting and protection have been used successfully on agricultural lands in the drylands of the Sahelian region (Carey 2020; Reij et al 2009). The practices reduce soil erosion, increase soil carbon, soil fertility and provide solid bioenergy and other non-timber forest products to poor households (Bayala et al 2020). Additionally, the FMNR and agroforestry practices have higher profit, and increase food and nutrition security (Montagnini, and Metzel 2017; Bayala et al 2020; Sharma et al 2016). In the tree planting programs, use of native trees have been shown to be more successful than those which use exotic tree

(Hänke et al 2016). One of the reasons for the success of using native trees is their higher survival rate and adaptation to local ecological conditions.

The low-cost FMNR and other agroforestry practices are is important given that drylands – which are defined as climatic zones with the ratio of the long-term mean precipitation to potential evapotranspiration, is smaller than 0.65 – account for 40% of global land area and are home to 40% of the global population (Cherlet et al 2018).

In high and middle-income countries with highest level of mechanization, adoption of conservation agriculture (CA) has increased rapidly in the last two decades (Figure 4). Conservation agriculture is a practice that minimizes soil disturbance, maintains permanent soil cover and diversification of plant species. CA increases SOM, soil fertility in general and reduces soil erosion by up to 75% on gently sloping soils (Panagos et al 2018).

Figure 4: Adoption of conservation agriculture across regions



Source: Extracted from Kassam et al (2019).

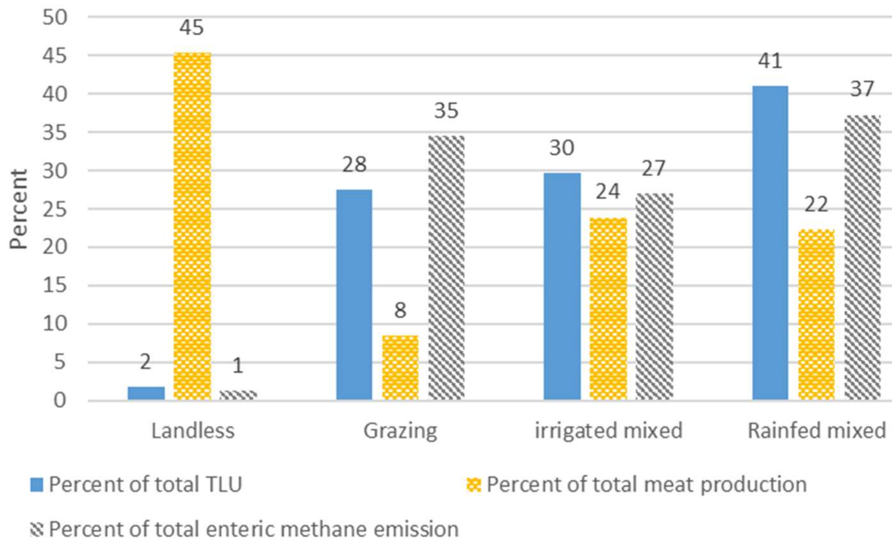
Technologies for addressing overgrazing. Low-cost technologies for addressing overgrazing is rotational grazing. Bogaert et al (2017) observed that soil carbon stored in rotational grazing plots was 19% higher than on continuously grazed plots. A global review also found that rotational grazing increased soil carbon by 25% (Byrnes et al 2018). Rotational grazing is possible on drylands, which have expansive rangelands. Rotational grazing is becoming less amenable in mixed crop-livestock systems and in areas with high human population density. This suggests for other livestock feeding systems.

Intensification could reduce the area expansion to meet increasing meat and milk demand. Livestock production in high-income countries have been shifting to intensive systems, which depend on high-energy feeds in zero-grazed animals. For example, even though zero-grazed livestock (landless) system accounts for only 2% of total tropical livestock unit (TLU) population in the world, it produces 45% of meat (Figure 5).

Livestock production systems contribute significantly to total GHG emission and this challenge needs to be taken into account when addressing livestock-related land degradation. The two most important

GHG emission from livestock are nitrous oxide (N_2O) and methane (CH_4). Animal manure contribute 30% to 50% of the global agricultural nitrous oxide emission (Oenema et al 2005) and 12% to 41% of total agricultural methane emission (Chadwick et al 2011). Ruminants produce about 3.3 Gt CO_2-equivalent annually (van Middelaar et al 2011). Rainfed mixed and grazing systems account for highest enteric methane emission (Figure 5).

Figure 5: Contribution of production systems to total livestock population and enteric methane emission (Percent)



Notes:

- Grazing: grass only production systems, in which livestock production is the only production system.
- Rainfed mixed system – livestock and crop production, in which >90% of non-livestock production is rainfed.
- Irrigated mixed:>10% of non-livestock production is irrigated.
- Landless:<10% of DM fed to livestock comes from feedstocks.

Source: computed from Steinfeld et al (2006).

Multi-pronged approaches are required to address the GHG emission and environmental pollution. Breeding programs have generated animal breeds with up to 20% less enteric methane emission (González-Recio 2020). Strategies are used for increasing feed conversion efficiency – which in turn reduces Nitrogen (N) and Phosphorus (P) in excreta. Livestock solid waste –i.e., slurry, farmyard and poultry manure management – could contribute to reducing GHG emission and environmental pollution. Open pit disposal and excessive application of manure on farm lead to high GHG emission. Strategies which have been used to reduce N_2O and CH_4 emission include nitrification inhibition, incorporation of manure into farm and modification of feeding strategies (Chadwick et al 2011).

Ending deforestation and restoring degraded forests (SDG15.2).

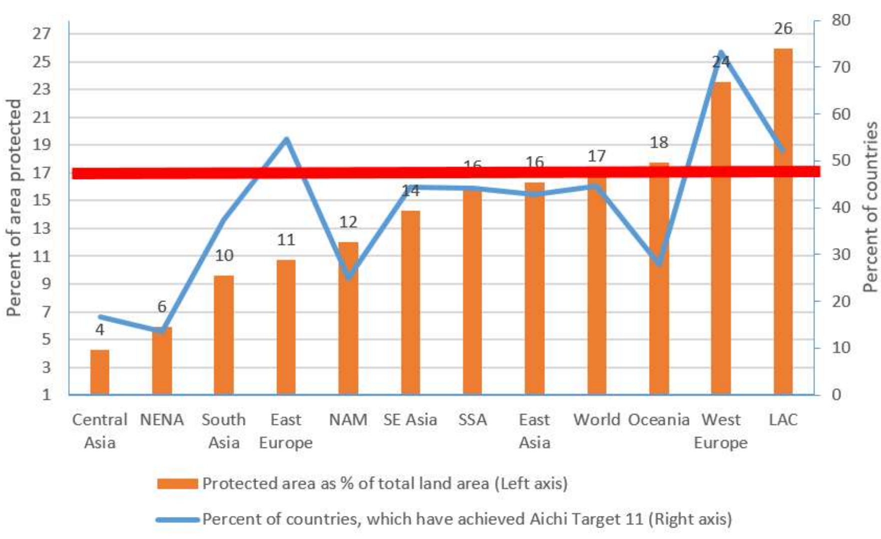
Deforestation is most serious in SSA and South America – where the largest share of forests are publicly owned or under community management (FAO 2020). Addressing deforestation and forest degradation requires tree-planting and protection programs. As discussed earlier, planting indigenous trees have always been successful than using non-native species (Hua et al 2015). Using native trees avoids the risk of disrupting local ecosystems. Additionally, trees with multiple functions are more likely to be widely adopted than single-purpose trees (Benz et al 2020).

Protection of biodiversity:

Aichi target 11 and SDG15.1 set goals to protect biodiversity through protected area and other strategies. Specifically, Aichi Target 11 sets a goal of protected area to be 17% of total land area by 2020. At global level, this target has been achieved, but 55% of the countries in the world have not yet achieved the target (Figure 6). The biodiversity protection is largely a national level policy strategy. The key to successful conservation programs have been strong local institutions and incentives. Such incentives will help investors and other actors to internalize many externalities that negatively affect biodiversity (Altenburg & Assmann 2017). Market-based strategies – such as biodiversity offsets and co-management and benefit sharing with communities surrounding protected areas have been more successful in promoting and expanding protected areas (Buschke et al 2019). Co-management with surrounding communities have also been successful in countries with strong local institutions (Oldekop et al 2016; Shafer 2020). For example, poaching in Mburo national park in Uganda decreased significantly after community involvement which was implemented through its program of neighbors as partners (Ullah and Kim 2020; Infield and Namara 2001). Other programs which have been successful are those which indigenous people or local people are given full control of management and benefits, but under conditions of protecting biodiversity. For example, 25,000 ha of northern part of Kruger National Park in South Africa was given to local Makuleke tribal group and has since been managed sustainably (Brockington et al., 2008).

Private and community game reserves ecotourism have been shown to contribute to biodiversity conservation in both in high and low-income countries (Soares 2019). However privately owned community game reserves have high operational costs due to their small size (Quintas-Soriano, et al 2020; Lee and Du Preez 2016).

Figure 6: Achievement of Aichi Target 11 across regions



Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.
Source: World Bank raw data - https://data.worldbank.org/indicator/ER.LND.PTLD.ZS

Strategy for implementing land restoration and protection

Strategy 1: Land tenure

The strategies for protecting lands heavily gravitates around the land tenure system, institutions and policies. Studies have shown that landowners are more likely to invest in long-term land improvement if they have secure land tenure (Abdulai et al 2011; de Soto 2001). For example, a study in Peruvian indigenous communities showed that giving titles to indigenous people significantly reduced deforestation (Blackman et al 2017). The definition of secure tenure is contextual. Majority of land owners in developing countries do not have formal land title, yet they have been observed to invest as much as those with formal title if they perceived security of land ownership (Barrows and Roth 1990). This suggests the major driver of long-term land improvement investment is perception of security, regardless of formal land titling (Lawry et al. 2014). However, effectiveness of land tenure security is conditional on other factors discussed below in strategy 2, 3 and others.

Strategy 2: Improvement of agricultural marketing and other rural services in low-income countries

: Rural services play a pivotal role in adoption of improved technologies and market participation. The most critical rural services, which have direct impact on agriculture, include all-weather roads, agricultural extension and veterinary services, agricultural market infrastructure, agricultural water, access to credit, and communication infrastructure technology. Studies have shown higher adoption rate of sustainable land management practices in countries with good rural services (Barrett et al 2002; UNEP 2019; IPBES 2018). Controlling for other confounding factors, Kihiu and Amuakwa-Mensah (2017) observed that access to markets increased investment in grazing land improvement in Africa.

Decisions by landowners to increase and/or continue investing in land improvement is driven by expected returns from such investments. Remunerative returns are enhanced when the producers have access to markets to buy inputs and sell their produce. This is possible when transaction costs are not prohibitively high. Poor market access increase transaction costs and reduce the returns and could significantly reduce incentives to invest in in land improvement even when land tenure is secure.

The agricultural extension service plays key role in all countries since land management knowledge is dynamic – requiring constant communication between farmers and extension agents. For example, Agricultural education on the benefits of no-till and conservation agriculture have also been shown to be very effective in increasing adoption of CA and other tillage practices in Europe (Awada et al 2014).

Investing in rural market improvement has its synergistic advantage since it addresses the overarching poverty reduction programs, which is given the highest priority in most low-income countries (Singh and Chudasama 2020). Access to information technology has helped to increase access to financial inclusion, agricultural extension services and market participation. For example, over 60% of adults in SSA have a mobile phone account and about 45% have smart mobile phones (GSMA 2020). The strategies for facilitating effectiveness of information technology is to enhance coverage in remote area, strengthen regulations to ensure mobile financial services are reliable and are not used for illegal and extortionary operations. Effective regulations are even more important given that extortionary mobile financial services are likely to harm more severely poor and less-educated users. However, governments need to avoid over-taxing mobile service. For example, recently Uganda introduced social media tax which decreased mobile money transfer and phone internet use in general (GSMA 2020).

Strategy 3: Land Policies, institutions and Strategies, which create incentives for investment in land improvement:

Land policies: Without incentives for communities and individual farmers, achievement of sustainable forest and wilderness management may not be achieved even when there are secure land tenure and good market access (Bennett et al 2018). National and district-level land policies and institutions need to be designed in a way, which creates conducive environment and incentives for investment in land improvement. Land and soil policies formulation in developing and middle-income countries have seen an increase in recent years following the severe land degradation and food security challenges. Land tenure, land planning and subsidy policies are among the most prominent land and soil policies which have driven investment strategies in developed and developing countries.

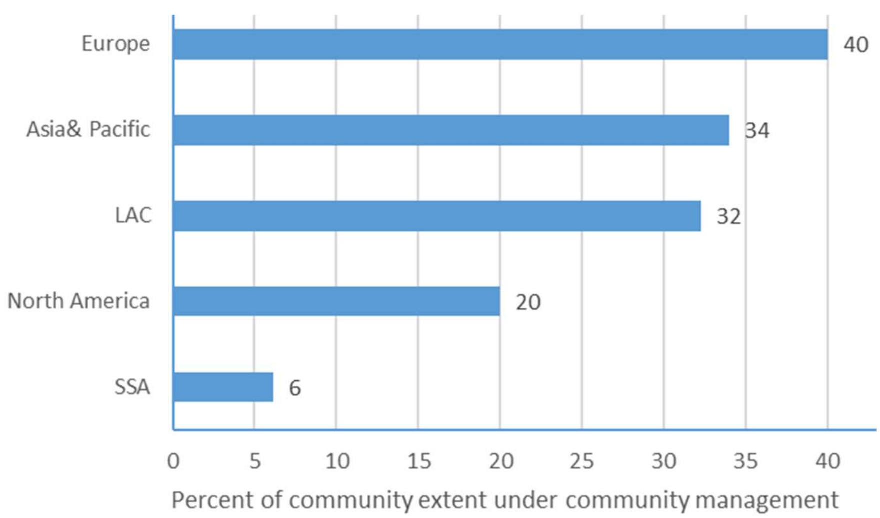
Subsidies to farmers have been widely used around the world to incentivize farmers to adopt sustainable land management practices. In the European Union, subsidies – or more specifically payment for ecosystem services have been implemented through the common agricultural policy (CAP) – which rewards farmers who adopt sustainable land management practices (Pe'Er et al 2019). In the US, the Conservation Reserve Program (CRP) is one of the most ambitious programs aimed at incentivizing farmers and ranchers to to comply with environmental regulations and guidelines for controlling soil erosion, protecting ecosystems, water and other environmental enhancement programs (Schulte et al 2017; Bigelow and Hellerstein 2020). This is done by paying landowners to fallow environmentally sensitive croplands for 10 to 15 years, after which farmers could reenroll their cropland or choose to plant crops or other uses (Bigelow and Daniel Hellerstein 2020). The CRP program has helped to improve biodiversity conservation though some negative effects have also been observed (Schulte et al 2017; Lituma and Buehler 2020).The Great Green Wall (GGW) in 1978 to combat desertification in northern China. The GGW created multiple enabling factors – including National Bureau to Combat Desertification, the National Desertification Monitoring Centre, and research and training centers and a forest academy (Jiang 2016). As a result of the large-scale investment in conducive environment, GGW increased tree cover from 5% in 1980 to 12.4% in 2012 and the total area planted with trees increased by about 27 million ha (Sternberg et al 2015). Additionally, the government has invested about $4billion between 1978-2007 to implement the GGW and to compensate farmers who are willing to plant trees to replace other land uses (Ibid).

In SSA, input subsidies have dominated soil improvement programs. The early efforts of subsidies did not target properly the needy farmers and disrupted development of more efficient private input market development (Jayne et al 2013). However, recent programs – dubbed as smart-subsidies made efforts to target poor farmers and to work through private input market systems (Jayne and Rashid 2018). Consequently, they become more successful improving food security in the short-term. However, the smart input subsidies still do not effectively support adoption of organic soil fertility management, which could contribute to climate change mitigation (Jayne et al 2018). The subsidy programs could be improved further by treating them as payment for ecosystem services. For example, the subsidies could be made on condition that a farmer has adopted easily verifiable adoption of organic soil fertility management practice, which sequester significant amount of carbon. Examples of easily verifiable organic soil fertility management practices include agroforestry and soil and water conservation structures (Nkonya et al 2018). Conditional fertilizer subsidies have been shown to be acceptable to smallholder farmers in Malawi (Marenya et al 2014).

On deforestation and restoration of degraded forests, the public good nature of forests and wilderness in general – collective management policies have shown to be more effective and efficient than individual or central government management (Poteete et al 2010). This means, the key strategy for achieving SDG15.2 is to enhance forest policies, which give mandate to local institutions to manage forests and for the local people to benefit from forest resources. Prime examples of impact of farmer groups on forest management articulated by Ostrom's eight principles for managing common pool resources (commons) (Ostrom 1990; Ostrom 2008). Long-term research by the International Forest Research Institute (IFRI) have shown forest resource managed collectively in Africa, India and other parts of the world were more sustainably managed than those managed by central government or by individual farmers. Additionally, a recent FAO review of community forest management showed its effectiveness (Gilmour 2016). Similarly, extensive review by Roe et al (2008) showed community-based natural resource management (CBNRM) in Africa significantly improved forest and wilderness compared to individually managed approach.

A recent approach, which better articulates community-forest management, is the Forest and Landscape Restoration (FLR) program. FLR operates on proven approaches of community involvement in decision-making and implementation and equitable benefit sharing (Gichuki et al 2019; Höhl et al 2020). FLR implemented on public land calls for long-term resource commitment and technical support to reflect the long-term of nature of tree life cycle (Ibid). Forest ownership plays key role in implementing FLR. Community forest management has been increasing in developing countries, but is at its lowest level in SSA (Figure 7) – where severity of deforestation is high. The strategies to enhance community forest management is required to help reduce deforestation and wilderness losses.

Figure 7: Share of forest extent owned by community across regions

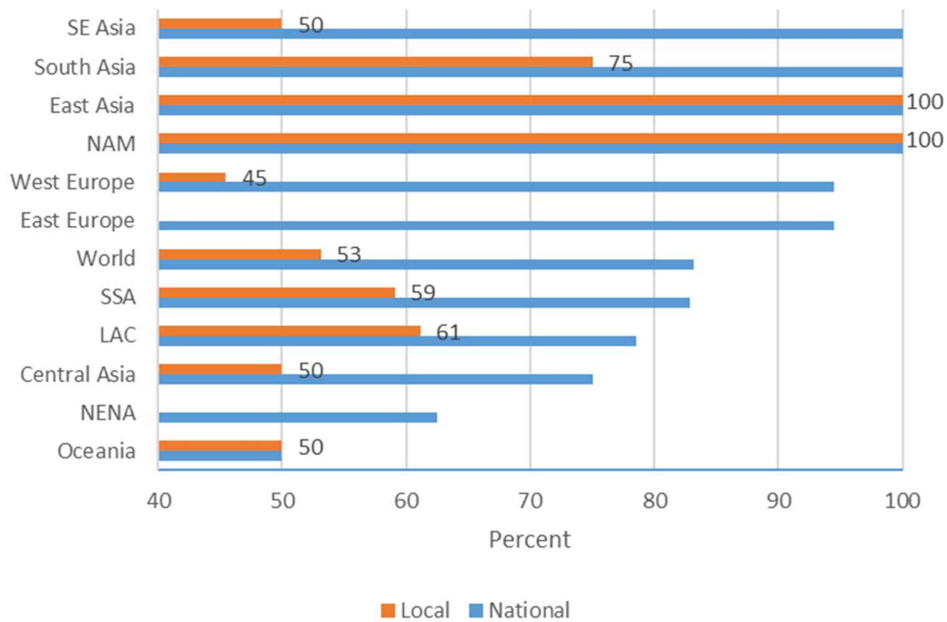


Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.

Source: Calculated from Gilmour 2016.

Addressing degradation on existing forests is equally important. Strong policies and investment commitments from public and private sources are required to address forest degradation. Like the case of deforestation discussed above, local communities play key role in addressing forest degradation. Figure 8 shows that about 60% of countries in SSA and LAC – where deforestation is highest – have sustainable forest management (SFM) policies at local level. This is a good indication that there is strong political will at achieving SFM. However, policies are just the first step to ending deforestation and achieving SFM. There are good policies, which remain on paper and are never implemented. The discussion below shows the effective approaches in implementing good policies and strategies.

Figure 8**:** Sustainable Forest Management Policies at National and Local level



Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.
Source: Extracted from FAO (2015)

Enhancing government effectiveness: Government effectiveness is defined as the quality of policy formulation and implementation, as well as quality of public and civil services and the degree of independence from political pressure (Kaufmann et al 2010). Government effectiveness is a major driver of land restoration and protection (Nkonya et al 2016). A good example is Niger - the country – which reported the lowest human development index (HDI) in 2019 (UNDP 2019). After experiencing severe deforestation, the Nigerien government passed the *Rural Code* statute, which gave land owners mandate to manage resources at local level (Carey 2020; Stickler 2012). Additionally, the 2004 forestry law gave landowners tree tenure for trees on their farmland (Adam, et al. 2006; Abdoulaye et al, 2005; Carey 2020). These and other changes improved Nigerien government effectiveness at a much higher rate than other countries in West Africa (Moussa et al 2016). The tree tenure incentivized landowners to plant and protect trees. The value of timber and non-timber forest products increased significantly, since deforestation created severe shortage (Specht et al 2015). There was no expensive government programs in implementing tree planting, and protection program (Carey 2020), yet Niger succeeded in significantly reducing deforestation. Such institutional changes and incentives contributed to the regreening of the Sahel (Herrmann, et al 2005). The success story in Niger demonstrates that other countries – with higher HDI – could do even better. The results from Niger demonstrated the key role that incentives play in achieving sustainable forest and tree management even among the poorest landowners. Accordingly, the 2018 New York Declaration observed the key role which governance plays in forest protection (UNDP 2018). Governance is weakest in sub-Saharan Africa (SSA) and South Asia where land degradation is more severe. Governance is highest in West Europe, North America and East Asia (World Bank 2019) where land degradation is lowest (Table 1).

One of the most important strategies for increasing government effectiveness is decentralization and strengthening local institutions. As discussed earlier, giving mandate to local communities to manage natural resources is more effective than centralized management. A study covering eastern and western African countries at different levels of decentralization showed higher propensity of local communities to enact natural resource byelaws and regulations than in countries with lower degree of decentralization (Nkonya et al 2015). Similarly, a study in Uganda showed that compliance with byelaws and regulation enacted by local councils was significantly higher than those enacted by higher authorities (Nkonya et al 2008). Ceddia et al (2014) also found that good governance was significantly correlated with agricultural intensification, which in turn led to contraction of agricultural land – resulting in sustainable intensification in South America.

In middle and high-income countries where government effectiveness is high, the strong local institutions play pivotal role in implementing participatory natural resource management. For example, more than 95% of European Union forests are managed and governments effectively regulate human intervention (EEA 2016). Over 60% of EU's forests are privately owned, but managed under government regulations (Ibid). Even though the largest share of forest area is under private ownership, the policies and regulations have been very effective because they were formulated collaboratively and with strong stakeholder participation and consensus building. The policies take into account the profit incentives of businesses and environmental objectives of the government and civil societies (Ibid).

Strategic options for sustainable and cost-effective infrastructure and settlement pattern

The land-specific technologies for achieving sustainable and cost-effective infrastructure and settlement pattern include:

Sustainable urban planning Technologies.

Innovations in remote sensing and high-resolution data have allowed planners to accurately develop greener cities (Hernández-Moreno 2009). Additionally, computer modelling have allowed planners to assess environmental impact of settlement development strategies. Environmental monitoring and evaluation have always been one of the overarching challenges in planning sustainable settlement and these new technologies are contributing to addressing this challenge. Such technologies and data will also help to address a serious land degradation challenges. For example, road construction in urban and rural areas could cause serious erosion if not constructed in a way, which incorporates the hydrological and topographical features. Construction of roads that do not cause soil erosion is limited in developing countries due to limited human and financial resources (Seutloali and Beckedahl, 2015). The cheap or freely available remote sensing data have allowed developing countries to use high-resolution topographical and hydrological data, which could help in designing and constructing roads that don't cause oil erosion or encroach on critical habitats (Ibid).

Construction accounts 40% of the natural resources extracted in high-income countries and 70% of the electric energy consumption (Franzoni 2011). This means, technologies for construction material have the potential to significantly reduce the negative environmental impacts of buildings. For example, super-hydrophobic cement is more durable and it changes its microstructure to make it absorb and reflect light – an attribute which could replace streetlights (Johnsson,). Similarly, LED (Light Emitting Diode) are being replaced with more energy efficient OLED (Organic LED). These are some of the examples of many innovations which are being used to build greener cities.

Metro and regional transportation system technologies:

A significant number of innovations are coming into market, with favorable environmental impacts. Among these are self-healing concrete – which reduce number of energy-intensive repairs, vehicle to vehicle (V2V) communication, vehicle to infrastructure communication (V2I) and many others have been shown to increase road safety, energy-saving and other benefits (Hock et al 2019). Google map and other navigation technologies have also helped drivers to avoid traffic – which waste both time and energy (Choi et al 2016; Hay et al 2011). The Technologies of Personalized Transit (TPT) and Intelligent Transportation Systems (ITS) have been used to address the growing challenges of congested and unsafe urban transportation systems (Bekiaris 2019). Some ITS technologies have designed to minimize environmental impacts of transportation and energy consumption (Bento et al 2019; Barth and Boriboonsomsin 2009).

Technologies for addressing soil sealing:

Using permeable material for building pavement, roads and other infrastructure could help in addressing the growing soil-sealing problem. A study in Europe has shown that addressing soil sealing by using permeable material and green infrastructure and water harvesting strategies are more effective than mitigation and compensation (EU 2012).

Strategy 1: Integrated and Green Urban and Infrastructure Development

Green city planning has also gone beyond environment – as equity, inclusive and participatory planning and city management – are increasingly being included (Hatch 2019; Plastrik and Parzen. 2013). The inclusive, participatory strategy creates incentive mechanisms to encourage sustainable land use and protection of the environment and is consistent with SDG 11.3.1 "*Enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement*" and SDG 11.3.2: "…. *direct participation structure of civil society in urban planning and management that operate regularly and democratically.*" The inclusive and participatory planning creates understanding and justification of taking into account sustainable urban planning and it ensures that all key stakeholder needs are considered in zoning. The stakeholder involvement in planning and managing the urban socio-economic dynamics have been shown to significant contribute to creating green cities (Hölscher et al., 2019; EGC 2020). Such cities have implemented strict zoning – which protects open space, forests, wildlife habitat, and watershed health[1]. For example, city centers are growing greener in high-income countries – contributing the improved urban biodiversity (Salvati et al 2016).

Empirical evidence have shown that multi-pronged, inclusive and collaborative urban planning have reduced the negative effects of urban growth on land degradation in the Mediterranean regions of southern Europe and northern Africa (Salvati et al (2014). In developing countries – which are experiencing the most serious urban planning challenges, there are success stories, which demonstrate that even poor countries could achieve SDG13.1. Kigali city designed the Smart City Master Plan, which lays out sustainable urban development plans that meets the economic and social needs of the fast growing country (UN Habitat 2015). The city masterplan developed pedestrian and cycling corridors to enhance green public transit system. The private sector, local government, NGOs, civil society and investors are participating in this Kigali Master Plan implementation. In 2008, Kigali won the UN Habitat Scroll of Honor for successfully reducing slums, modernizing refuse collection, wastewater management, and providing housing. One of the most interesting feature was the dedication of one day for cleaning the city – all of which have made the city one the cleanest in sub-Saharan Africa. One of the most interesting feature – which reflects consideration of the predominance of agricultural sector in the country's economy, the Master Plan integrated urban and peri-urban horticulture. With guidance from the United Nations Food and Agriculture Organization (FAO), authorities are promoting production of fresh fruits and vegetables in well-designed zones. Incorporation of horticultural production in the city planning has contributed to increasing urban food and nutrition security as well as boosting farmers' incomes.

Transport planning is key to achieving green cities. The transportation system allows metro and sub-urban residents to be sustainably connected. This is possible when the transport system plans prioritizes modes of transportation, which minimizes GHG emission. For example, giving mass transit system fast lane space – which is becoming common even in developing countries. Additionally, transportation system planning need to plan for non-motorized transportation (walking, bicycle lanes, etc), which have both health and environmental benefits (Poswayo et al., 2019). These strategies will contribute to achieving SDG3.6 – which aims to reduce by half road fatalities and injuries by 2020. Likewise, the strategies will contribute to achieving SDG11.2 – which aims to increase access to safe and affordable, accessible and sustainable transportation and improving road safety in urban areas.

Success of these programs will be realized if there is strong monitoring, evaluation mechanism, and incentive mechanism for those who perform better in achieving green city and infrastructure programs. Unfortunately, there is limited monitoring and evaluation of green infrastructure development and reward mechanisms in low- and middle-income countries (Schäffler and Swilling 2013). As shown above, such shortcomings could be used to using remote sensing data.

Strategy 2: Market-Driven Smart Sustainable Urban and Infrastructure:

The market-based approach in urban planning internalizes the environmental costs to ensure the market-oriented population assigns monetary value to natural resources and environment in decision-

[1] The European Green Capital is based on 12 environmental indicators: Climate Change Mitigation; Climate change adaptation; Sustainable Urban Mobility; Sustainable Land Use; Nature and Biodiversity; Air Quality; Noise; Waste; Water; Green Growth and Eco-innovation; Energy Performance and Governance (EGC 2020).

making processes (Dale and Hamilton 2007). This requires careful studies to determine the footprint of infrastructure and settlement development. The need for education and awareness creation also plays a key role in informing inhabitants and building sense of pride and environmental responsibility (Caramaschi 2014).

The market-based approach in infrastructure and settlement planning is illustrated by the experience in Canada, which have shown that market-based approaches to developing sustainable infrastructure and settlement patterns work better than non-market forms of planning.

As articulated earlier, new technologies play pivotal role in operating market-oriented urban operations and in helping businesses to respond to fast-changing business environment.

Strategy 3: Strong –Rural-urban food system:

An international policy pact on rural-urban collaboration to ensure sustainable food systems was established in 2015 under the Milan Urban Food Policy Pact (MUFPP) (Clinton et al. 2018). It challenges urban policy makers and planners to enhance sustainable natural resource use and management, food safety and security food policies (Forster et al. 2015). Such objectives could be achieved through designing food supply and distribution systems, which reduce food waste, as well as coordinating the food supply and demand (Ibid). MUFPP is especially important in low-income countries – where road and marketing infrastructure bears the hallmark of export crop history, which ignored the food crop and livestock marketing system (Balat et al 2008; Mendes et al 2014). Under MUFPP and similar programs, the need to create a strong rural-urban relationship is growing as food tastes and preferences are changing fast in response to growing middle-class in urban areas (Hirvonen et al 2020; Béné et al 2019). Such changes creates a conducive environment for implementing bold strategies for realizing sustainable rural-urban food systems.

The urban food system has responded to this new dynamics through a fast growth of supermarkets, which cater for the middle-income population (Reardon and Hopkins 2006). Unfortunately, the smallholder have not responded to the growing urban demand for high quality agricultural produce. This has forced the supermarkets to be importing high quality food – denying the smallholder farmers to exploit the emerging market. This means, smallholder farmers in developing countries need to be organized in groups to help them meet the high quantity and quality demand of urban consumers (Bizikova et al 2020; Balat et al 2008).

The roads and market infrastructure discussed in strategy 1 above need to facilitate better connection between rural producers and urban consumers, in a way, which promote better access to domestic markets, which – as discussed earlier contributes to adoption of land improvement technologies. The ICT technologies which are currently widespread in rural areas should also be utilized to connect farmers to the urban market and for promoting collective marketing, all of which have been shown to enhance adoption of sustainable land management practices. The combination of the green and smart rural-urban transportation and marketing infrastructure coupled with organized farmers will contribute to land protection (Bizikova et al 2020).

Change diets to less meat and more plant-based food: Meat carbon footprint is quite high. A kilogram of grass-fed cattle produces 60 kgCO_2-equiv (Poole and Nemecek 2018). In general, plant-based food carbon footprint is 10-50 lower than animal-based food (Ibid). This suggests that promoting plant-based diets will significantly reduce food carbon footprint (Smith et al 2019). This strategy will contribute to achieving SDG13 of reducing the warming of 1.5°C. However, it will involve tradeoffs with SDG1 on food security (Smith et al 2019). For example, Frank et al (2017) estimated that reducing global warming to 1.5 °C, could result to a loss of 110–285 kcal per capita per day in 2050 – increasing population with malnutrition by 80-200 million people. Such tradeoffs need to be taken into account as countries design their strategies for rural-urban food systems.

Non-agricultural activities in urban and rural areas

In this section, we concurrently discuss the technologies and strategies to highlight their strong relationship. The focus on land since terrestrial water aspects are covered by Rosegrant paper in this volume.

Strategy 1: Eliminating soil pollution

Polluter-pays principle strategy has been used effectively in high income countries include (FAO 2018). Robust monitoring and evaluation (M&E) strategies are required to accurately determine liability and diffusion of pollution. However, lack of data and M&E remains a challenge in many countries (UNEP 2018). Data and M&E approaches for determining impacts of projects impacts on *Environmental impact assessment (EIA):* Strong EIA is required to ensure new investments do not pollute the environment. EIA in many countries are under the Ministry of environment. Compliance with EIA recommendations heavily relies on a wide range of other ministries and departments – including the justice, law enforcement and others. Coordination of the ministries and department is critical in making EIA recommendations enforceable.

Remediation and management of polluted soils. Remediation is required for cases whose pollution could be reversed. If irreversible, strategies need to be used to manage polluted soils to contain its negative environmental and health effects. Database and M&E would help in implementing of such challenges (UNEP 2017). As part of strategies to prevent soil pollution, is to integrate non-tradable ecosystem services in planning and development in general (UNEP 2017).

Strategy 2: Nonfarm activities in rural areas

Non-farm activities in rural areas are closely interlinked with land and agricultural production. Current efforts of rural industrialization – which many developing countries are pursuing, are crucial in modernizing the agricultural sector – which has limited processing and consequently high post-harvest losses. Ensuring that rural non-farm activities and industrialization support sustainable agricultural production, processing and consumption is key to land protection. Studies have shown that non-farm activities help farmers afford investing in landscape conservation (e.g. Barrett et al 2002; Issahaku and Abdul-Rahaman, 2019; Tanui et al 2013). With increasing population in urban and rural areas in developing countries, the need to diversify from agriculture to nonfarm activities could lead to a win-win-win result – reducing the pressure on land, creating employment and reducing post-harvest losses. If done in a coordinated way, such strategy could lead to sustainable land management.

Studies have shown that increasing access to credit, ICT and electricity enhances entrepreneurship and start-up of nonfarm activities (Alemu and Adesina 2017; Reardon et al 2007). Access to these resources help rural communities to exploit the demand-pull factor (Lebhart 2002; Möllers 2006). The rural non-farm activities are attractive to the youth and other vulnerable groups since they could easily adopt ICT technologies which help run small businesses as well as exploiting the growing high quality food and agricultural demand. The non-farm activities and rural industrialization will also help the youth to avoid the distress-push factors, in which rural population are pushed into poorly paying urban jobs – a phenomenon which is currently prevailing in many countries (UNESCO 2018).

Strategy 3: Green industrial revolution:

The European Union has recently announced its Green Deal (EGD) while South Korea has announced its Green New Deal (GND). Additionally, Germany is planning to restructure its energy and transportation sectors to make them greener. The United Kingdom has also announced its Green Industrial Revolution. Among other goals, the country will ban use of petrol and diesel cars by 2030. The Netherlands, Norway, France, the UK, Sweden, and Ireland have also announced plans to end petrol and diesel cars at different years spanning from 2025-40. These and other initiatives are demonstrating the new direction of decarbonization of industries and transportation sectors. Achievement of these objectives will heavily rely on manufacturing. As shown in section 1, SDG9 (industries, innovations & infrastructure) is directly connected to SDG15 through the raw material used for manufacturing. The Manufacturing sector has great potential for helping the world not to exceed the planetary boundaries (Altenburg, & Assmann 2017). Manufacturing could help to produce labor-saving technologies which could help land users to adopt sustainable land management practices and technologies.

Other strategies have been designed to achieve a greener industrial sector. The discussion below examines two strategies, which could help non-agricultural sectors to contribute to land protection and restoration of degraded lands

(i) ***Circular economy*****:** Innovations in organic recycling and reuse are gaining traction. Recycling has the potential to reduce natural resource use in all countries. Recycling strategies are driven by innovations, which decrease the cost of recycling practices. Recycling will reduce the landfill disposal which is contributing to the solid waste pollution and GHG emission. Education, regulations and incentives increase recycling among consumers in high-income countries.

(ii) ***Bio-economy*****:** Increasing bio-efficiency increases the value and duration of use of natural resources in the economy. Bio-economy also seeks to substitute fossil fuel energy with renewable resources (Heimann 2019). There are tradeoffs, which need to be taken into account. For example, biofuels could contribute to decarbonization but at the same time could lead to reduction of biodiversity and compete with food security objectives (Smith et al 2019). Efforts to educate consumers and enforce labeling and certification has been shown to be effective in changing consumer behavior (Price 2014).

(iii) *Incentive mechanism to reward green technologies*: Electric car programs are currently growing fast. The current large fuel subsidies – which in 2015 was US$5.2 trillion – or 6.5% of global GDP Globally) (Coady et al 2019)[2] – could be used to incentivize generation and operation of green technologies

[2] The countries providing subsidies (with value in brackets are: China ($1.4 trillion), United States ($649 billion), Russia ($551 billion), European Union ($289 billion), and India ($209 billion) (Coady et al 2019).

Scenarios for SDG15 and Aichi Target 11

The discussion in this section examines two scenarios of achieving SDG15 and Aichi Target 11. The baseline scenario assumes business as usual (BAU) when no action is taken to combat the ongoing land degradation. The optimistic scenario assumes that strategies in the three areas discussed above are implemented simultaneously to exploit their synergistic attributes in an effort to address land degradation and protect non-degraded lands.

Scenarios for SDG15.1 and Aichi target 11

Forest BAU: Since 1990, deforestation has claimed about 30% of global forest cover and 20% of standing forest has been degraded (Griscom et al 2017). The rate of deforestation has been increasing in tropical areas - especially in sub-Saharan Africa (SSA) and Latin America (FAO and UNEP 2020). Forest areas in temperate countries have increased – leading to the global total forest area to increase of forest area by 23.6 million ha (Mha) between 2000-10 and by 3.1 Mha between 2011-19 (Ibid). One notable upside captured by the new assessment is that the area of forest in protected areas globally has increased by 191 million hectares since 1990 and now 18 percent of the world's forests are located within protected areas, and South America is home to the highest share of protected area. This suggests the SDG15.2.1 and Aichi Biodiversity targets to protect at least 17% of terrestrial area by 2020 has been surpassed at global level. The deforestation rate fell by about 40% from 7.8 Mha per year in 1990–2000 to 4.7 Mha per year in 2010–2020 (FAO 2020). Since 2015 when the SDG2030 were adopted, the annual rate of deforestation decreased by 17% from 12 Mha in 2010-15 to 10 Mha in 2015-20 (Ibid). However, the global level achievement is hiding the regional level challenges – especially in SSA and Latin America, where forest area has declined in the last decade (Ibid).

Optimistic goal: The optimistic scenario is to completely eliminate deforestation and ensure sustainable forest management (SFM). The Bonn Challenge aims to bring 150 million hectares of deforested and degraded land into restoration by 2020 and 350 million hectares by 2030 (FAO & UNEP 2020). The focus will be in the tropical areas – especially SSA and Latin America – where deforestation is still high. Natural regeneration is cheapest approach and it is not surprising that 93% of forest area is based on natural regeneration and only 7% is planted forest (FAO 2020). As discussed earlier, designing policies and strategies, which give incentives to land users to invest in forest restoration, have worked in Niger and Europe.

Agriculture

Scenarios for SDG15.3 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.

Agricultural land degradation BAU: Under BAU**,** about 25% of the agricultural land area is degraded (Le et al 2016). Le at (2016) masked agricultural land, which receives large quantities of fertilizer and other inputs to mask degradation. Excluding areas with high input intensity, Table 3 shows that at global level, degraded cropland area as share of total cropland area will increase from 40% in 2020 to 50% in 2030 under BAU. Degradation of grassland is more severe. At the global level, grassland degradation is expected to increase from 52% in 2020 to 66% in 2030 under BAU. The NENA region reported the highest rate of cropland and grassland degradation while Europe (both east and west) reported the lowest cropland degradation.

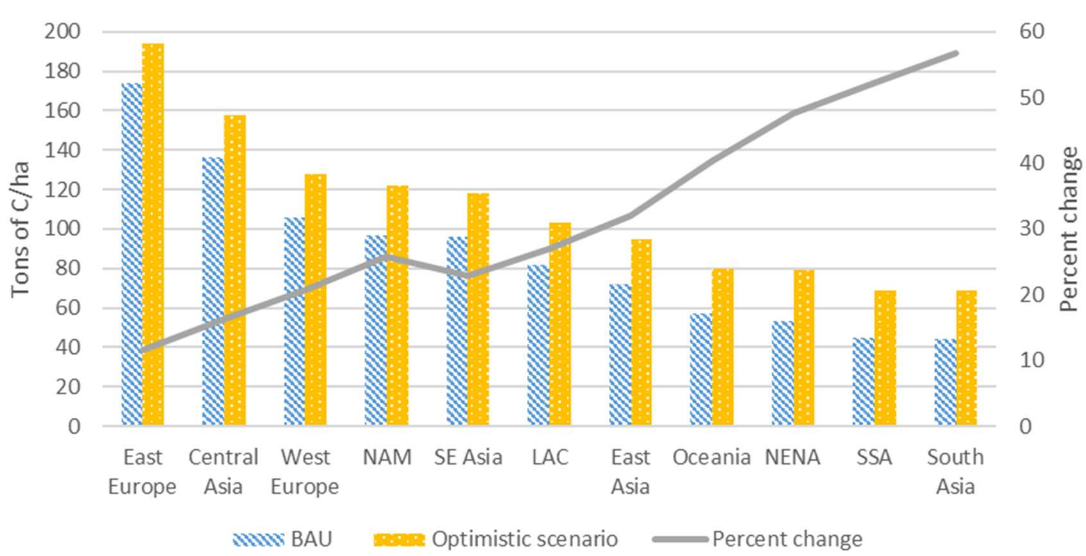
Table 3: Trend of cropland and grassland degradation, 2020 – 2030 under BAU

	Cropland		Grasslands	
	2020	2030	2020	2030
	Percent degraded			
East Europe	21	26	22	28
West Europe	22	28	32	40
NAM	27	34	70	88
Oceania	27	34	55	70
SSA	35	44	52	66
South Asia	36	46	55	70
LAC	40	50	38	48
World	40	50	52	66
East Asia	48	60	38	48
Central Asia	51	64	35	44
SE Asia	51	64	55	70
NENA	71	90	82	95

Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.
Source: Computed from Le et al (2016).

Optimistic scenario: The optimistic scenario is consistent with the SDG15.3 of zero net land degradation. This implies restoration of all degraded cropland and grasslands. The strategies for achieving such optimistic scenario is dependent on how countries will design strategies for achieving such restoration.

Figure 9: Cropland soil organic carbon (SOC) under BAU and optimistic scenario across regions



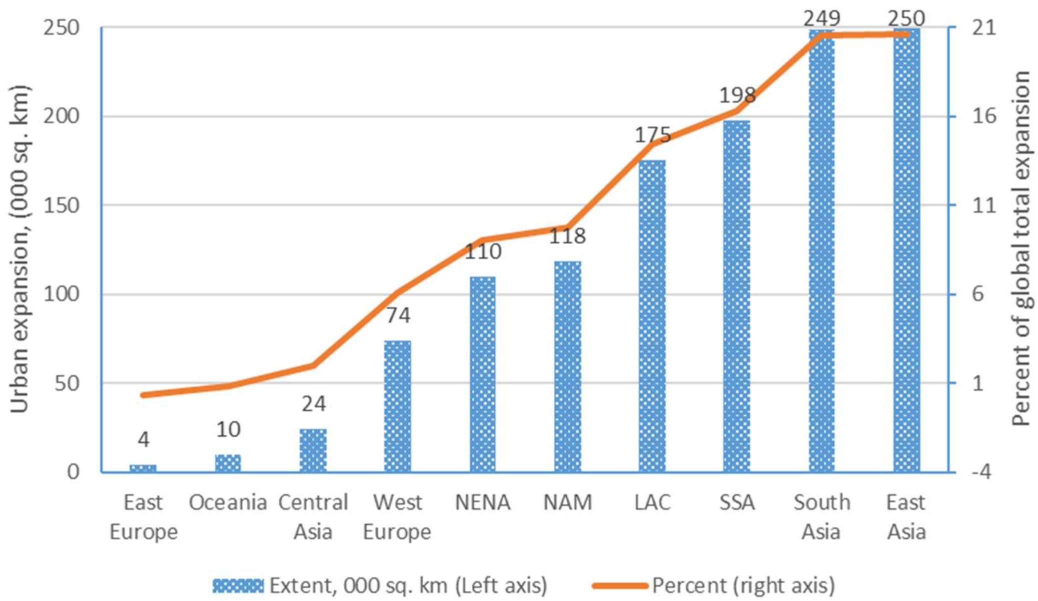
Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.
Source: Extracted from Zomer et al 2017.

Restoration of soil carbon is one of UNCCD's indicator of SDG15.3. Figure 9 shows the baseline and optimistic scenarios of increasing soil carbon across regions. East Europe, Central Asia and West Europe has the lowest gap between BAU and optimistic scenario, while South Asia and sub-Saharan Africa have the widest gap. Technologies and strategies for helping countries achieve the optimistic scenarios have been discussed in the sections above.

Scenarios for sustainable and cost-effective infrastructure and settlement pattern

BAU: Under BAU, urban expansion will increase as shown in Figure 10.

Figure 10**:** Urban expansion in 2030 under BAU



Notes: (All regions are as defined by the United Nations): SE Asia=Southeast Asia; LAC=Latin America & Caribbean countries: SSA=sub-Saharan African countries; NENA=Near East and North Africa; NAM=North America.

Source: Extracted from Seto et al 2012.

Built-up areas account for about 0.6% of land surface and expected to reach 2% by 2050 if the current uncontrolled expansion is not checked (IPBES 2019). If current urban population growth remain stable, built up areas in 2050 is expected to triple in developing countries and increase by 30% in developed countries from their levels in 2000 (Ibid).

Optimistic goals of reducing urban expansion and sprawl:

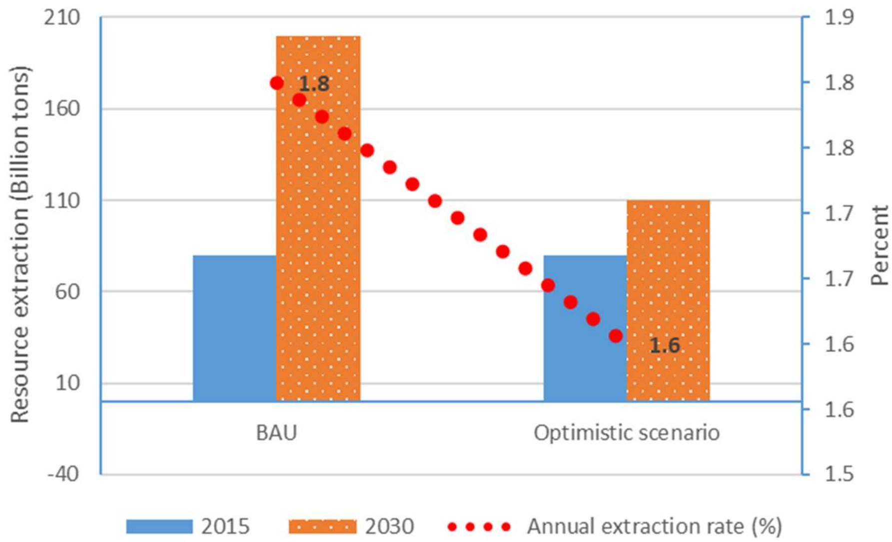
A study by UNDP-IRP (2018) showed that if all multiple strategies are applied, urban land use could be reduced by about 20 to 40% - depending on the country. The same strategies could reduce GHG emission from cities by 40% to 60% (Ibid).

Scenarios for non-agricultural sectors

BAU: Extraction of resources poses the danger of exceeding the planetary boundaries. The current annual resource extraction is increasing at a rate of 1.8% (Figure 11).

Optimistic scenario: Combined efforts circularity and bio-economy will help reduce the resource extraction from the baseline of 1.8% annual growth to 1.6%, which will lead to a reduction of annual resource extraction from 200 billion tons to 110 billion tons (Figure 11). This will significantly reduce soil pollution and other environmental effects. Additionally, reduced resource extraction will contribute to achieving the Aichi target 11 and other SDGs.

Figure 11**:** Global annual resource extraction and growth rate under BAU and optimistic scenario, 2015-30



Source: Extracted from IRP (2019).

Conclusions: Priority Strategic Options

Prioritization of strategic options is required to help countries to quickly and simultaneously achieve multiple Sustainable Development Goals (SDGs) and Aichi Target 11. The strategy for achieving SDG15.3 – net zero land degradation – will increase agricultural productivity – thus directly enhance food and nutrition security; increase soil carbon sequestration and household income. This in turn will directly contribute to achievement of SDG2 – zero hunger; SDG3 – good health and wellbeing; SDG13 – climate change mitigation; and SDG1 – no poverty. Widespread adoption of these technologies is conditional on existence of policies and strategies, which build an efficient market infrastructure and incentives that, reward the adopters of sustainable natural resource use and management. Secure land tenure, and strong local institutions are also required to facilitate farm and community level adoption of sustainable land management (SLM) practices and achievement of SDG5 – gender equality. Additionally, exploiting the information technology and other innovations offers a big potential for enhancing diffusion of the SLM practices.

On the infrastructure and settlement dimension, the priority is on enabling inclusive and participatory planning. This will allow all stakeholders to have a sense of ownership of the planning, management and governance processes of infrastructure and settlements. In turn, this will lead to achievement a number of targets of SDG9 on industry, innovations and infrastructure as well as SDG7 – affordable and clean energy. Similarly, the nonagricultural sector have the potential to generate technologies which will increase adoption of SLM practices as well as reducing its resource extraction, which in turn will facilitate achievement of several targets of SDG11 – sustainable cities and communities. The discussion below summarizes priority technologies and strategies for achieving the relevant SDGs in each of the three dimensions – agriculture, infrastructure and settlement and non-agricultural activities.

Agriculture: Selection of the technologies which could be used to achieve SDG15.3 need to be based on their effectiveness, and existence of strong supporting rural services. For the low-income countries – where land degradation is most severe, integrated soil fertility management (ISFM), and agroforestry practices are low-cost practices which not only increase agricultural productivity, but reduce use of inorganic fertilizers, which are expensive and have the potential to pollute water and the environment in general. Conservation agriculture is another low-cost practice with significant environmental benefits related to reduction of GHG emission and enhancing long-term soil productivity.

Combatting deforestation and forest degradation heavily gravitates around policies and institutions, which provide incentives for land users to securely invest in long-term tree planting and protection. This includes secure land tenure, local institutions to effectively manage community forests and national forests in which surrounding communities participate in management and benefit sharing.

For livestock, intensification has socio-economic and environmental benefits that even smallholder farmers in developing countries have been able to realize. For example dairy productivity among smallholder farmers in Kenya is among the highest in developing countries (FAO 2011). However, intensification need to be accompanied by proper strategies for reducing the GHG emission and environmental pollution of solid waste – a challenge that is more serious in high-income countries.

Infrastructure and settlements: Emerging sustainable urban planning technologies have a large potential to build sustainable infrastructure and settlement. Innovative technologies – such as electric and/or hybrid cars, navigation systems and other innovations have been shown to simultaneously reduce GHG emission and accidents, improve mobility efficiency and coordinate complex transport systems – even in among poor communities in remote areas. For example, the information technology, and remote sensing are enhancing participation of the youth and other vulnerable groups – even those in poor communities in remote areas. Likewise, remote sensing and drone technologies are helping to capture low-cost or free longitudinal databases, which are highly relevant for monitoring and evaluation of the environmental processes – which in most cases change slowly. Additionally, impacts of interventions on the environment have a long have long-lag periods – thus highlighting the importance of capturing longitudinal data at low-cost.

Effectiveness of infrastructure and settlement planning heavily gravitates around inclusive and participatory approaches in which all stakeholders are involved. Inclusive and participatory planning creates sense of belonging, understanding and justification of taking into account sustainable urban planning and it ensures that all key stakeholder needs are considered in zoning. The stakeholder involvement in planning and managing the urban socio-economic dynamics have been shown to significant contribute to creating green cities

Non-agricultural activities: Manufacturing and other non-agricultural activities lead in innovations for preventing the world from exceeding the planetary boundaries. Additionally, these sectors account for a big share of resource extraction. Incentives for creating and adopting sustainable natural resource use and management are required to help their widespread adoption. Innovations in circular economy and Bioeconomy will help in reducing the resource extraction, which in turn will enhance achievement of a number of SDGs. As for the other dimensions discussed above, inclusive and participatory governance have shown to be very effective in all countries.

References

FAO. 2011. Dairy development in Kenya. Online at http://www.fao.org/3/a-al745e.pdf

Hirvonen, K., Bai, Y., Headey, D. and Masters, W.A., 2020. Affordability of the EAT–Lancet reference diet: a global analysis. *The Lancet Global Health*, 8(1):e59-e66.

Abdoulaye, T., and G. Ibro. 2006. Analyse des Impacts Socio-economiques des Investissements dans la Gestion des Ressources Naturelles : Etude de Cas dans les Regions de Maradi, Tahoua et Tillabery au Niger. Niamey et Amsterdam: Centre Regional d'Enseignement Specialise en Agriculture et l'Universite Libre d'Amsterdam.

Abdulai, A., Owusu, V. and Goetz, R., 2011. Land tenure differences and investment in land improvement measures: Theoretical and empirical analyses. *Journal of Development Economics*, 96(1):66-78.

Adam, T., C. Reij, T. Abdoulaye, M. Larwanou, and G. Tappan. 2006. Impacts des Investissements dans la Gestion des Resources Naturalles (GRN) au Niger: Rapport de Synthese. Niamey, Niger: Centre Régional d'Enseignement Specialise en Agriculture.

Akinnifesi F, Ajayi OC, Sileshi G, Chirwa PW, Chianu J (2010). Fertiliser trees for sustainable food security in the maize-based production systems of east and southern Africa a review. *Agronomy for Sustainable Development* 30:615–629

Alemu, A.E. and Adesina, J.O., 2017. In Search of Rural Entrepreneurship: Non-farm Household Enterprises (NFEs) as Instruments of Rural Transformation in Ethiopia. *African Development Review*, 29(2):259-271.

Altenburg, T., & Assmann, C. (Eds.). (2017). Green Industrial Policy. Concept, Policies, Country Experiences. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE).

Anderson, D.M., Glibert, P.M. and Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*, 25(4):704-726.

Angel, S., Parent, J., Civco, D. L., & Blei, A. (2010). The Persistent Decline in Urban Densities: Global and Historical Evidence of 'Sprawl'. Lincoln Institute of Land Policy. Retrieved from http://www.lincolninst.edu/publications/working-papers/persistent-decline-urban-densities

Angel, S., Parent, J., Civco, D. L., Blei, A., & Potere, D. (2011). The dimensions of global urban expansion: Estimates and projections for all countries, 2000-2050. *Progress in Planning*, 75(2):53–107. https://doi.org/10.1016/j.progress.2011.04.001

Anthem, P. (2020). Risk of hunger pandemic as coronavirus set to almost double acute hunger by end of 2020. World Food Programme Insight. Retrieved from https://perma.cc/ELB4-XMD5.

Arcardis. 2018. Citizen Centric Cities The Sustainable Cities Index 2018. Online at https://www.arcadis.com/media/1/D/5/%7B1D5AE7E2-A348-4B6E-B1D7-6D94FA7D7567%7DSustainable_Cities_Index_2018_Arcadis.pdf

Asner, G., & Archer, R. (2010). Livestock and carbon cycle. In H. Steinfeld., H. A. Mooney, F. Schneider & L. E. Neville (Eds.), Livestock in a changing landscape. Drivers, consequences and responses (pp. 69–82). Scientific Committee on the Problems of the Environment (SCOPE): Island Press.Balat, J., Brambilla, I. and Porto, G., 2008. Realizing the gains from trade: Export crops, marketing costs, and poverty. The World Bank.

Barbero-Sierra, C., Marques, M., & Ruíz-Pérez, M. (2013). The case of urban sprawl in Spain as an active and irreversible driving force for desertification. *Journal of Arid Environment*. 90: 95-102.

Barrett, C.B., Place, F., Aboud, A. and Brown, D.R., 2002. The challenge of stimulating adoption of improved natural resource management practices in African agriculture. Natural resource management in African agriculture, 31:1-21.

Barrows, R. and Roth, M., 1990. Land tenure and investment in African agriculture: Theory and evidence. *The Journal of Modern African Studies*, 28(2):265-297.

Barth, M. and Boriboonsomsin, K., 2009. Environmentally beneficial intelligent transportation systems. *IFAC Proceedings Volumes*, 42(15):342-345.

Bayala, J., Sanou, J., Bazié, H.R., Coe R., Kalinganire A.,& Sinclair F. L. 2020. Regenerated trees in farmers' fields increase soil carbon across the Sahel. *Agroforest Syst* 94:401–415. https://doi.org/10.1007/s10457-019-00403-6

Bekiaris, E.D., 2019. Optimization and personalization technologies and algorithms for future transportation systems. *European Transportation Research Review* 11:39-42.

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J.P. and Smith, P., 2013. Livestock greenhouse gas emissions and mitigation potential in Europe. *Global Change Biology*, 19(1):3-18.

Béné, C., Oosterveer, P., Lamotte, L., Brouwer, I.D., de Haan, S., Prager, S.D., Talsma, E.F. and Khoury, C.K., 2019. When food systems meet sustainability–Current narratives and implications for actions. *World Development*, 113:116-130.

Bento, L.C., Parafita, R., Rakha, H.A. and Nunes, U.J., 2019. A study of the environmental impacts of intelligent automated vehicle control at intersections via V2V and V2I communications. *Journal of Intelligent Transportation Systems*, 23(1):41-59.

Benz, J.P., Chen, S., Dang, S., Dieter, M., Labelle, E.R., Liu, G., Hou, L., Mosandl, R.M., Pretzsch, H., Pukall, K. and Richter, K., 2020. Multifunctionality of forests: A white paper on challenges and opportunities in China and Germany. *Forests*, 11(3):266-289.

Bigelow, D. and Hellerstein, D., 2020. In Recent Years, Most Expiring Land in the Conservation Reserve Program Returned to Crop Production. *Amber Waves*: The Economics of Food, Farming, Natural Resources, and Rural America, 2020(1490-2020-868).

Bizikova, L., Nkonya, E., Minah, M., Hanisch, M., Turaga, R.M.R., Speranza, C.I., Karthikeyan, M., Tang, L., Ghezzi-Kopel, K., Kelly, J. and Celestin, A.C., 2020. A scoping review of the contributions of farmers' organizations to smallholder agriculture. *Nature Food*, 1: 620–630. Doi https://doi.org/10.1038/s43016-020-00164-x

Byrnes, R.C., Eastburn, D.J., Tate, K.W. and Roche, L.M., 2018. A global meta-analysis of grazing impacts on soil health indicators. *Journal of environmental quality*, 47(4):758-765.

Blackman, A., Corral, L., Lima, E.S. and Asner, G.P., 2017. Titling indigenous communities protects forests in the Peruvian Amazon. *Proceedings of the National Academy of Sciences*, 114(16):4123-4128.

Blais, P. 2011. Perverse cities: hidden subsidies, wonky policy, and urban sprawl. UBC Press.

Bogaerts, M., Cirhigiri, L., Robinson, I., Rodkin, M., Hajjar, R., Junior, C.C. and Newton, P., 2017. Climate change mitigation through intensified pasture management: Estimating greenhouse gas emissions on cattle farms in the Brazilian Amazon. *Journal of Cleaner Production*, 162:1539-1550.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V. and Bagarello, V., 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature communications*, 8(1):1-13.

Bouwman, L., K.K. Goldewijk, K. W. Van Der Hoek, A.H.W. Beusen, D.P. Van Vuuren, J. Willems, M.C. Rufino, and E. Stehfest. 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences* 110(52): 20882-20887.

Brockington, D., Duffy, R., & Igoe, J. (2008). Nature unbound: Conservation, capitalism and the future of protected areas. London: Earthscan

Buschke, F.T., Brownlie, S. and Manuel, J., 2019. The conservation costs and economic benefits of using biodiversity offsets to meet international targets for protected area expansion. *Oryx,* 53(4):732-740.

Burghardt, W. (2006). Soil sealing and soil properties related to sealing. *Geological Society, London, Special Publications*, 266(1):117–124. https://doi.org/10.1144/GSL.SP.2006.266.01.09

Burchell RW, Shad N A, Listokin D, Phillips H, Seskin S, Davis J S, Moore T, Helton D, Gall M, 1998 The Costs of Sprawl Revisited: Transportation Research Board Report 39 (National Academy Press, Washington, DC).

Cabanatuan, M. (2020). Very unhealthy air blankets Bay Area as historic wildfires spread noxious smoke. San Francisco Chronicle, https://www.sfchronicle.com/california-wildfires/article/Very-unhealthy-air-blankets-Bay-Area-15559693.php.

Çapraz, Ö. and Deniz, A. (2020). Particulate matter (PM10 and PM2.5) concentrations during a Saharan dust episode in Istanbul. Air Quality, Atmosphere & Health. http://doi.org/10.1007/s11869-020-00917-4.

Caramaschi, S., 2014. Public markets: rediscovering the centrality of markets in cities and their relevance to urban sustainable development. *WIT Transactions on Ecology and the Environment*, 191:1187-1197.

Carey The best strategy for using trees to improve climate and ecosystems? Go natural. *Proceedings of National Academy of Sciences* 117(9): 4434–4438

Carter, N., Killion, A., Easter, T., Brandt, J. and Ford, A., 2020. Road development in Asia: Assessing the range-wide risks to tigers. *Science Advances*, 6(18), p.eaaz9619.

CBD (Convention on Biological Diversity). 2020. Global Biodiversity Outlook 5. Montreal.

Cecchini, M., Zambon, I., Pontrandolfi, A., Turco, R., Colantoni, A., Mavrakis, A. and Salvati, L., 2019. Urban sprawl and the 'olive' landscape: Sustainable land management for 'crisis' cities. *GeoJournal*, 84(1):237-255.

Ceddia, M.G., Bardsley, N.O., Gomez-y-Paloma, S. and Sedlacek, S., 2014. Governance, agricultural intensification, and land sparing in tropical South America. *Proceedings of the National Academy of Sciences*, 111(20):7242-7247.

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B. and Misselbrook, T., 2011. Manure management: Implications for greenhouse gas emissions. *Animal Feed Science and Technology*, 166:514-531.

Chambers, R., and R. Conway, 1992. Sustainable rural livelihoods: Practical concepts for the 21st century. IDS Discussion Paper No. 296. Institute of Development Studies (IDS), Brighton

Cherlet, M. Hutchinson C., Reynolds J., Hill J., Sommer S., von Maltitz (eds). 2018: World Atlas of Desertification. 3rd edition. Publication Office of the European Union, Luxemburg, 248 pp.

Choi, J., Hwang, M., Kim, G., Seong, J. and Ahn, J., 2016. Supporting the measurement of the United Nations' sustainable development goal 11 through the use of national urban information systems and open geospatial technologies: a case study of south Korea. O*pen Geospatial Data, Software and Standards*, 1(1):4-12.

Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M. et al. (2018). A global geospatial ecosystem services estimate of urban agriculture. *Earth's Future* 6(1), 40-60. https://doi.org/10.1002/2017EF000536.

Coady, D., Parry, I., Le, N.P. and Shang, B., 2019. Global fossil fuel subsidies remain large: An update based on country-level estimates. *IMF Working Papers*, 19(89):1-39.

Craswell ET, Vlek PL (2013) Mining of nutrients in African soils due to agricultural intensification. In: Lal R, Stewart BA (eds). Principles of sustainable soil management in agroecosystems. CRC Press, Boca Raton, pp 401–422.

Dale a. and J. Hamilton. 2007. Sustainable Infrastructure: Implications for Canada's Future. Online at https://www.crcresearch.org/files-crcresearch_v2/File/SI_Final_Report.pdf

De Soto H. 2001. The Mystery of Capital. London: Bantam Press

De Sy, V., M. Herold, F. Achard, R. Beuchle, J.G.P.W. Clevers, E. Lindquist, and L. Verchot. 2015. Land use patterns and related carbon losses following deforestation in South America. *Environmental Research Letters* 10(12):124004. Online at http://iopscience.iop.org/article/10.1088/1748-9326/10/12/124004/meta; jsessionid=02742B7E3B90ABC1E63EB767AC34A0D9.c2.iopscience.cld.iop.org

Derpsch, R., Friedrich, T., Kassam, A. and Li, H., 2010. Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, 3(1):1-25.

Doygun, H., 2009. Effects of urban sprawl on agricultural land: a case study of Kahramanmaraş, Turkey. *Environmental monitoring and assessment*, 158(1-4):471.

EEA (European Environment Agency). 2016. European forest ecosystems State and trends. Available at https://www.eea.europa.eu/publications/european-forest-ecosystems/download

EGC (European Green Capital). 2020. Expert Panel Technical Assessment Synopsis Report European Green Capital Award 2022. Online at https://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2020/05/EGCA_2022_Synopsis_Technical_Assessment_Report.pdf

Eisenbies, M.H., W.M. Aust, J.A. Burger, and M.B. Adams, 2007: Forest operations, extreme flooding events, and considerations for hydrologic modeling in the Appalachians – *A review. For. Ecol. Manage*., 242, 77–98, doi:10.1016/j.foreco.2007.01.051

EU (European Union). 2012. Guidelines on best practice to limit, mitigate or compensate soil sealing. Online at https://ec.europa.eu/environment/soil/pdf/guidelines/EN%20-%20Sealing%20Guidelines.pdf

FAO. 2020. Global Forest Resources Assessment 2020 – Key findings. Rome. https://doi.org/10.4060/ca8753en

FAO and UNEP. 2020. The State of the World's Forests 2020. Forests, biodiversity and people. Rome. https://doi.org/10.4060/ca8642en

FAO, IFAD, UNICEF, WFP and WHO. 2020. The State of Food Security and Nutrition in the World 2020. Online at http://www.fao.org/documents/card/en/c/ca9692en, accessed October 18, 2020.

FAO. 2019. New standards to curb the global spread of plant pests and diseases. online. Retrieved from https://perma.cc/5VFJ-72XE.

FAO 2018. Soil pollution. Global symposium on soil pollution, May 4-12, 2018. Rome Italy. Online at http://www.fao.org/3/ca0362en/CA0362EN.pdf

FAO. 2015. Global Forest Resources Assessment 2015. Online at http://www.fao.org/3/a-i4808e.pdf.

FAOSTAT. 2019. Food Balances. Raw data online at http://www.fao.org/faostat/en/#data/FBS

Florens, F.V., 2013. Conservation in Mauritius and Rodrigues: challenges and achievements from two ecologically devastated oceanic islands. *Conservation Biology: Voices from the tropics*:40-50.

Forster, T., Egal, F., Escudero, A.G., Dubbeling, M. and Renting, H. (eds.) (2015). *Milan Urban Food Policy Pact. Selected Good Practices from Cities*. Milano: Fondazione Giangiacomo Feltrinelli. Online at https://www.ruaf.org/sites/default/files/MUFPP_SelectedGoodPracticesfromCities.pdf.

Frank, S., Havlík, P., Soussana, J.F., Levesque, A., Valin, H., Wollenberg, E., Kleinwechter, U., Fricko, O., Gusti, M., Herrero, M. and Smith, P., 2017. Reducing greenhouse gas emissions in agriculture without compromising food security? *Environmental Research Letters*, 12(10):105004.

Franzoni E. 2011. Materials selection for green buildings: Which tools for engineers and architects? *Procedia Engineering*, 21:883-890.

Fratkin, E. and Mearns, R., 2003. Sustainability and pastoral livelihoods: lessons from East African Maasai and Mongolia. *Human organization*, 62(2):112-122.

Gao, Y., Skutsch, M., Paneque-Gálvez, J. and Ghilardi, A., 2020. Remote sensing of forest degradation: a review. *Environmental Research Letters*, 15(10):103001.

Gerber, P., Vellinga, T., Opio, C. and Steinfeld, H., 2011. Productivity gains and greenhouse gas emissions intensity in dairy systems. *Livestock Science*, 139(1-2):100-108.

Gichuki, L., Brouwer, R., Davies, J., Vidal, A., Kuzee, M., Magero, C., Walter, S., Lara, P., Oragbade, C. and Gilbey, B. (2019). Reviving land and restoring landscapes: Policy convergence between forest landscape restoration and land degradation neutrality. Gland, Switzerland: IUCN. viii + 34pp

Gilmour, D., 2016. Forty years of community-based forestry: A review of its extent and effectiveness. FAO. Online at http://www.fao.org/3/a-i5415e.pdf

González-Recio O., J. López-Paredes, L. Ouatahar, N. Charfeddine, E. Ugarte, R. Alenda, J.A. Jiménez-Montero. 2020. Mitigation of greenhouse gases in dairy cattle via genetic selection: 2. Incorporating methane emissions into the breeding goal. *Journal of Dairy Science*, 103 (8):7210 DOI: 10.3168/jds.2019-17598

Gozlan R.E., B. K. Karimov, E. Zadereev, D. Kuznetsova & S. Brucet (2019). Status, trends, and future dynamics of freshwater ecosystems in Europe and Central Asia, *Inland Waters*, 9:1, 78-94.

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P. and Woodbury, P., 2017. Natural climate solutions. *Proceedings of the National Academy of Sciences*, 114(44):11645-11650.

GSMA. 2020. The Mobile Money Economy. Online at https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf

Hallegatte, S.; Rentschler, J.; Rozenberg, J. 2019. Lifelines : The Resilient Infrastructure Opportunity. Sustainable Infrastructure. Washington, DC: https://openknowledge.worldbank.org/handle/10986/31805

Hänke, H., Börjeson, L., Hylander, K. and Enfors-Kautsky, E., 2016. Drought tolerant species dominate as rainfall and tree cover returns in the West African Sahel. *Land use policy*, 59:111-120.

Hasse, J.E. and Lathrop, R.G., 2003. Land resource impact indicators of urban sprawl. *Applied geography*, 23(2-3):159-175.

Hatch, J., Cleveland, J., Silano, M. and Fox-Penner, P., 2019. Cities and climate change: Strategic options for philanthropic support. Boston University Institute for Sustainable Energy.

Hay G.J., C. Kyle, B, Hemachandran, G. Chen,,M.M. Rahman, T.S. Fung and J.L. Arvai. 2011. Geospatial Technologies to Improve Urban Energy Efficiency *Remote Sensing* 3(7):1380-1405; https://doi.org/10.3390/rs3071380

Henders, S., U.M. Persson, and T. Kastner. 2015. Trading forests: Land-use change and carbon emissions embodied in production and exports of forest-risk commodities. Environmental Research. *Letters* 10(12):125012. Online at http://iopscience.iop.org/article/10.1088/1748-9326/10/12/125012/meta

Hernández-Moreno, S., 2009. Current technologies applied to urban sustainable development. *Theoretical and Empirical Researches in Urban Management*, 4(4 (13):125-140.

Herrmann, S.M., Anyamba, A. and Tucker, C.J., 2005. Recent trends in vegetation dynamics in the Africa Sahel and their relationship to climate. *Global Environmental Change* 15: 394-404.

Hock P., V. Mogilireddy and A. Vishnu. 2019. Smart Road Technologies Shaping the Future of Transportation. Online at https://pswordpress-production.s3.amazonaws.com/2019/01/Smart-Road-Technologies-PreScouter.pdf

Hocquette, J.F., Ellies-Oury, M.P., Lherm, M., Pineau, C., Deblitz, C. and Farmer, L., 2018. Current situation and future prospects for beef production in Europe—A review. *Asian-Australasian Journal of Animal Sciences*, 31(7):1017-1035.

Hölscher, K., Frantzeskaki, N., McPhearson, T., and Loorbach, D. 2019. “Capacities for urban transformations governance and the case of New York City”. *Cities.* 94: 186-199

Hu, X., Pant, R., Hall, J.W., Surminski, S. and Huang, J., 2019. Multi-scale assessment of the economic impacts of flooding: evidence from firm to macro-level analysis in the Chinese manufacturing sector. *Sustainability,* 11(7):1933-1941.

Hua, F., Wang, L., Fisher, B., Zheng, X., Wang, X., Douglas, W.Y., Tang, Y., Zhu, J. and Wilcove, D.S., 2018. Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015. *Biological Conservation*, 222:113-124.

Infield, M. and Namara, A., 2001. Community attitudes and behaviour towards conservation: an assessment of a community conservation programme around Lake Mburo National Park, Uganda. *Oryx*, 35(1):48-60.

International Disaster Database. 2017. 1. Natural Disasters 2017. Available at https://www.emdat.be

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2018. Thematic assessment of land degradation and restoration. Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services Sixth session, Medellin, Colombia, 18–24 March 2018. Online at https://ipbes.net/meeting-documents

IRP (International Resource Panel) (2019). Global Resources Outlook 2019: Natural Resources for the Future We Want. United Nations Environment Programme. Nairobi, Kenya. Online at https://www.resourcepanel.org/reports/global-resources-outlook.

Issahaku, G. and Abdul-Rahaman, A., 2019. Sustainable land management practices, off-farm work participation and vulnerability among farmers in Ghana: Is there a nexus? *International Soil and Water Conservation Research*, 7(1):18-26.

Jayne, T.S., Mason, N.M., Burke, W.J. and Ariga, J., 2018. Taking stock of Africa's second-generation agricultural input subsidy programs. *Food Policy*, 75:1-14.

Jayne, T.S. and Rashid, S., 2013. Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. *Agricultural economics*, 44(6):547-562.

Jiang, H. (2016). Taking down the "Great Green Wall": The science and policy discourse of desertification and its control in China. In Behnke, R. and Mortimore, M. (eds.). The End of Desertification? Disputing Environmental Change in the Drylands. Berlin: Springer. 513-536. https://link.springer.com/chapter/10.1007/978-3-642-16014-1_19

Johnsson, F., Karlsson, I., Rootzén, J., Ahlbäck, A. and Gustavsson, M., 2020. The framing of a sustainable development goals assessment in decarbonizing the construction industry–Avoiding "Greenwashing". *Renewable and Sustainable Energy Reviews*, 131:110029

Kassam A., T. Friedrich & R. Derpsch (2019) Global spread of Conservation Agriculture, *International Journal of Environmental Studies*, 76:1, 29-51, DOI: 10.1080/00207233.2018.1494927

Kaufmann D, Kraay A, Mastruzzi M (2010) The worldwide governance indicators: methodology and analytical issues. World Bank Policy Research working paper no. 5430. Available at http://ssrn.com/abstract¼1682130

Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-1329-0. License: Creative Commons Attribution CC BY 3.0 IGO

Kihiu, E.N. and Amuakwa-Mensah, F., 2017. Improving access to livestock markets for sustainable rangeland management. *African Journal of Economic Review*, 5(2):75-108.

Krauss, M., Berner, A., Perrochet, F., Frei, R., Niggli, U. and Mäder, P., 2020. Enhanced soil quality with reduced tillage and solid manures in organic farming–a synthesis of 15 years. *Scientific reports*, 10(1):1-12.

Lituma, C.M. and Buehler, D.A., 2020. Cost-share conservation practices have mixed effects on priority grassland and shrubland breeding bird occupancy in the Central Hardwoods Bird Conservation Region, USA. *Biological Conservation*, 244:108510-108513.

Grote U, Craswell E, Vlek P (2005) Nutrient flows in international trade: ecology and policy issues. *Environmental Science Policy* 8: 439–451

Lawry, S., Samii, C., Hall, R., Leopold, A., Hornby, D. and Mtero, F., 2014. The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *Campbell Systematic Reviews*, 10(1):1-104.

Le Q.B., E. Nkonya and A. Mirzabaev. 2016. Biomass Productivity-Based Mapping of Global Land Degradation Hotspots. In: E. Nkonya, A. Mirzabaev and J. von Braun (eds). Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer: 55-84

Leadley, P., Pereira, H.M., Alkemade, R.,Fernandez-Manjarrés, J.F., Proença, V., Scharlemann, J.P.W., Walpole, M.J. (2010) Biodiversity Scenarios: Projections of 21st century change in biodiversity and associated ecosystem services. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 50, 132 pages.

Lebhart, G., 2002. Internationale Migration. Hypothesen, Perspektiven und Theorien. Demographie aktuell. Vorträge - Aufsätze - Forschungsberichte Nr. 19.

Landrigan, P.J., Fuller, R., Acosta, N.J., Adeyi, O., Arnold, R., Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N. and Chiles, T., 2018. The Lancet Commission on pollution and health. *The Lancet*, 391(10119):462-512.

Lee, D.E. and Du Preez, M., 2016. Determining visitor preferences for rhinoceros conservation management at private, ecotourism game reserves in the Eastern Cape Province, South Africa: A choice modeling experiment. *Ecological Economics*, 130:106-116.

Le Quéré, C., Peters, G.P., Andres, R.J., Andrew, R.M., Boden, T.A., Ciais, P., Friedlingstein, P., Houghton, R.A., Marland, G., Moriarty, R. and Sitch, S., 2014. Global carbon budget 2013. *Earth System Science Data*, 6(1):235-263.

Li, M., De Pinto, A., Ulimwengu, J.M., You L., & Robertson R.D. (2015). Impacts of Road Expansion on Deforestation and Biological Carbon Loss in the Democratic Republic of Congo. *Environ Resource Econ* 60:433–469. https://doi.org/10.1007/s10640-014-9775-y

Lindblom, J., Lundström, C., Ljung, M. and Jonsson, A., 2017. Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. *Precision Agriculture*, 18(3):309-331.

Loeks-Johnson, B.M. and Cotner, J.B., 2020. Upper Midwest lakes are supersaturated with N_2. *Proceedings of the National Academy of Sciences*, 117(29):17063-17067.

Lowenberg-DeBoer, J. and Erickson, B., 2019. Setting the record straight on precision agriculture adoption. *Agronomy Journal*, 111(4):1552-1569.

Marenya, P., Smith, V.H. and Nkonya, E., 2014. Relative preferences for soil conservation incentives among smallholder farmers: evidence from Malawi. *American Journal of Agricultural Economics*, 96(3): 690-710.

Montagnini, F. and Metzel, R., 2017. The contribution of agroforestry to sustainable development goal 2: end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. In Montagnini, F. (ed.). *Integrating landscapes: Agroforestry for biodiversity conservation and food sovereignty* (pp. 11-45). Springer, Cham

Moussa B., E. Nkonya, S. Meyer, E. Kato, T. Johnson and J. Hawkins. 2016. Economics of land degradation and improvement in Niger. In: E. Nkonya, A. Mirzabaev and J. von Braun (eds). Economics of Land Degradation and Improvement – A Global Assessment for Sustainable

Development. Springer: 499-540.OECD (Organization for Economic Co-operation and Development) and European Commission (2020). *Cities in the World: A New Perspective on* Urbanization*.* OECD Urban Studies and OECD Publishing. Paris. https://doi.org/10.1787/d0efcbda-en.

Marshall, M.R., Francis, O.J., Frogbrook, Z.L., Jackson, B.M., McIntyre, N., Reynolds, B., Solloway, I., Wheater, H.S. and Chell, J., 2009. The impact of upland land management on flooding: results from an improved pasture hillslope. *Hydrological Processes: An International Journal*, 23(3):464-475.

Mateo-Sagasta, J., Zadeh, S.M., Turral, H. and Burke, J., 2017. Water pollution from agriculture: a global review. Executive summary. Rome, Italy: FAO Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).

Meinzen-Dick, R., Quisumbing, A., Doss, C. and Theis, S., 2019. Women's land rights as a pathway to poverty reduction: Framework and review of available evidence. *Agricultural Systems*, 172:72-82.

Mendes, A.P.F., Bertella, M.A. and Teixeira, R.F., 2014. Industrialization in Sub-Saharan Africa and import substitution policy. *Brazilian Journal of Political Economy*, 34(1):120-138.

Möllers, J., 2006. Außerlandwirtschaftliche Diversifikation im Transformationsprozess. Diversifikationsentscheidungen und -strategien ländlicher Haushalte in Slowenien und Mazedonien. Dissertation, Universität Hohenheim, Stuttgart

Nandwa, S.M. and Bekunda, M.A., 1998. Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. *Agriculture, ecosystems & environment*, 71(1-3):5-18.

Nelson G, Hellerstein D (1997). Do roads cause deforestation? Using satellite images in econometric analysis of land use. *American Journal of Agricultural Economics,* 79:80–88

Nkonya E., Kato E. (2020) Rethinking Agro-Food Sector to Combat Land Degradation and Desertification. In: Leal Filho W., Azul A., Brandli L., Lange Salvia A., Wall T. (eds) Life on Land. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham**.** https://doi.org/10.1007/978-3-319-71065-5_132-1

Nkonya E., F. Place, E. Kato, and M. Mwanjololo. 2015. Climate Risk Management Through Sustainable Land Management in Sub-Saharan Africa. In R. Lal B. Singh, D. Mwaseba, D. Kraybill, D. Hansen and L. Eik (eds.), Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, Springer International Publishing Switzerland. Page 75112. DOI 10.1007/978-3-319-09360-4_5. pp 665

Nkonya, E., J. Pender, E. Kato. 2008. "Who knows who cares? Determinants of enactment, awareness and compliance with community natural resource management regulations in Uganda." *Environment and Development Economics* 13(1):79-109.

Nkonya, E., Karsenty, A., Msangi, S., Souza Jr, C., Shah, M., Von Braun, J., Galford, G. and Park, S., 2012. Sustainable land use for the 21st century. Online at https://agritrop.cirad.fr/566934/

OECD & FAO. 2020. Agricultural Outlook 2020-2029. https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2020-2029_1112c23b-en.

Oldekop, J. A., Holmes, G., Harris, W. E., & Evans, K. L. (2016). A global assessment of the social and conservation outcomes of protected areas. *Conservation Biology*, 30(1):133–141

Olsson, L., H. Barbosa, S. Bhadwal, A. Cowie, K. Delusca, D. Flores-Renteria, K. Hermans, E. Jobbagy, W. Kurz, D. Li, D.J. Sonwa, L. Stringer. 2019: Land Degradation. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Ostrom, E., 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge university press.

Ostrom, E., 2008. The challenge of common-pool resources. *Environment: Science and Policy for Sustainable Development*, *50*(4):8-21.

Oenema, O., Wrage, N., Velthof, G.L., van Groeningen, J.W., Dolfing, J., Kuikman, P.J., 2005. Trends in global nitrous oxide emissions from animal production systems. *Nutrient Cycling in Agroecosystems* 72:51–65.

Panagos P, Standardi G, Borrelli P, Lugato E, Montanarella L, Bosello F (2018) Cost of agricultural productivity loss due to soil erosion in the European Union: from direct cost evaluation approaches to the use of macroeconomic models. *Land Degradation and Development* 29(3):471–484

Plastrik P. and J. Parzen. 2013. Strategic options for philanthropic support. Toward a Sustainable City: The State of Innovation in Urban Sustainability. Online at www.usdn.org.

Poswayo A, Kalolo S, Rabonovitz K*, et al* . 2019. “School Area Road Safety Assessment and Improvements (SARSAI) program reduces road traffic injuries among children in Tanzania.” *Injury Prevention* . **25 :**414-420.

Quintas-Soriano, C., Gibson, D.M., Brandt, J.S., López-Rodríguez, M.D., Cabello, J., Aguilera, P.A. and Castro, A.J., 2020. An interdisciplinary assessment of private conservation areas in the Western United States. *Ambio:*1-13.

Palm, C., Blanco-Canqui, H., Declerck, F., Gatere, L., & Grace, P. (2014). Conservation agriculture and ecosystems services. An overview. *Agriculture, Ecosystems & Environment*, 187:87–105.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G. and Ciais, P., 2011. A large and persistent carbon sink in the world’s forests. *Science*, 333(6045):988-993.

Paresi, M., Melchiorri, M., Siragusa, A. and Kemper, T. (2016). Atlas of the Human Planet 2016: Mapping Human Presence on Earth with the Global Human Settlement Layer.

Parnell, J. A. N., Cronk , Q., Wyse Jackson, P. and Strahm, W. (1989). A study of the ecological history, vegetation and conservation management of Ile aux Aigrettes, Mauritius . *Journal of Tropical Ecology*, 5: 355 – 374.

Pereira, H.M., Leadley, P.W., Proença, V., Alkemade, R., Scharlemann, J.P.W., Fernandez-Manjarrés, J.F. et al. (2010). Scenarios for Global Biodiversity in the 21st Century. *Science* 330(6010), 1496-1501. https://doi.org/10.1126/science.1196624.

Pfaff, A., Robalino, J., Walker, R., Aldrich, S., Caldas, M., Reis, E., Perz, S., Bohrer, C., Arima, E., Laurance, W. and Kirby, K., 2007. Road investments, spatial spillovers, and deforestation in the Brazilian Amazon. *Journal of regional Science*, 47(1):109-123.

Pe'Er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., Bontzorlos, V., Clough, D., Bezák, P., Bonn, A. and Hansjürgens, B., 2019. A greener path for the EU Common Agricultural Policy. *Science*, 365(6452):449-451.

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392):987-992.

Poteete, A.R., Janssen, M.A. and Ostrom, E., 2010. Working together: collective action, the commons, and multiple methods in practice. Princeton University Press.

Prokop, G., Jobstmann, H., & Schonbauer, A. (2011). Overview of best practices for limiting soil sealing or mitigating its effects in EU-27. European Commission, DG Environment. Retrieved from https://publications.europa.eu/en/publication-detail/-/publication/c20f56d4-acf0-4ca8-ae69-715df4745049/language-en

Reardon, T., Berdegué, J., Barrett, C.B. and Stamoulis, K., 2007. Household income diversification into rural nonfarm activities. *Transforming the rural nonfarm economy: opportunities and threats in the developing world,* pp.115-140.

Reardon, T. and Hopkins, R., 2006. The supermarket revolution in developing countries: Policies to address emerging tensions among supermarkets, suppliers and traditional retailers. The European journal of development research, 18(4):522-545.

Reid, W.V., Ali, M.K. and Field, C.B., 2020. The future of bioenergy. Global Change Biology, 26(1), pp.274-286.

Reij, C., Tappan, G. and Smale, M., 2009. Re-greening the Sahel: farmer-led innovation in Burkina Faso and Niger. *Millions fed: proven successes in agricultural development*, pp.53-58.

Ritchie H. (2020) - "Environmental impacts of food production". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/environmental-impacts-of-food'

Rodríguez-Eugenio, N., McLaughlin, M. and Pennock, D. 2018. Soil Pollution: a hidden reality. Rome, FAO. 142 pp.

Roe, D., Nelson, F. and Sandbrook, C. eds., 2009. Community management of natural resources in Africa: Impacts, experiences and future directions (No. 18). IIED.

Rosegrant, M.W., T.B. Sulser, D. Mason-D'Croz, N. Cenacchi, A. Nin-Pratt, S. Dunston, T. Zhu, C. Ringler, K. Wiebe, S. Robinson, D. Willenbockel, H. Xie, H-Y Kwon, T. Johnson, T.S. Thomas, F. Wimmer, R. Schaldach, G.C. Nelson, and B. Willaarts. 2017. Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio. Project Report, Washington DC, USA: International Food Policy Research Institute (IFPRI).

Salvati, L., Tombolini, I., Ippolito, A. and Carlucci, M., 2018. Land quality and the city: Monitoring urban growth and land take in 76 Southern European metropolitan areas. *Environment and Planning B: Urban Analytics and City Science*, 45(4):691-712.

Salvati, L., Karamesouti, M. and Kosmas, K., 2014. Soil degradation in environmentally sensitive areas driven by urbanization: an example from Southeast Europe. *Soil use and management*, 30(3):382-393.

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L. and Panagos, P., 2019. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. *Land Use Policy*, 86:299-312.

Schulte, L.A., Niemi, J., Helmers, M.J., Liebman, M., Arbuckle, J.G., James, D.E., Kolka, R.K., O'Neal, M.E., Tomer, M.D., Tyndall, J.C. and Asbjornsen, H., 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. *Proceedings of the National Academy of Sciences*, 114(42):11247-11252.

Seto, K.C., Güneralp, B. and Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109(40):16083-16088.

Seutloali, K.E. and Beckedahl, H.R., 2015. A review of road-related soil erosion: an assessment of causes, evaluation techniques and available control measures. *Earth Sciences Research Journal*, 19(1):73-80.

Schäffler, A. and Swilling, M. (2013). Valuing green infrastructure in an urban environment under pressure — The Johannesburg case. *Ecological Economics* 86, 246-257. https://doi.org/10.1016/j.ecolecon.2012.05.008

Shafer, C.L., 2020. Arguments for and against IUCN protected area management category VI with a review of state versus community governance. *Journal for Nature Conservation*, 53:125697-125711.

Sharma, N., Bohra, B., Pragya, N., Ciannella, R., Dobie, P. and Lehmann, S., 2016. Bioenergy from agroforestry can lead to improved food security, climate change, soil quality, and rural development. *Food and Energy Security*, 5(3):165-183.

Singh, P.K. and Chudasama, H., 2020. Evaluating poverty alleviation strategies in a developing country. *PloS one*, 15(1):p.e0227176.

Song X.P., Hansen M.C., Stehman S.V., Potapov P.V., Tyukavina A., Vermote E.F., Townshend J.R. (2018). Global land change from 1982 to 2016. *Nature* 560(7720):639–643

Sternberg T., Rueff, H. and Middleton, N. (2015). Contraction of the Gobi Desert, 2000–2012. *Remote Sensing* 7(2):1346–1358. https://doi.org/10.3390/rs70201346.

Stickler, M., 2012. Rights to trees and livelihoods in Niger. Focus on land in Africa. Placing land rights at the heart of development. Available at: www.focusonland.com/download/51c49667b7626.

Smith P., Calvin K., Nkem, J., Campbell D., Cherubini F., Grassi G., Korotkov V., Le Hoang A., Lwasa S., McElwee P., Nkonya E., Saigusa N., Soussana J.F., Taboada M.A. Manning F., Nampanzira D., Arias-Navarro, C. Vizzarri M., House J. Roe S., Cowie A., Rounsevell M., and Arneth A. 2019. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land-degradation and desertification? *Global Change Biology*, 26(3):1532-1575.

Specht, M.J., Pinto, S.R.R., Albuquerque, U.P., Tabarelli, M. and Melo, F.P., 2015. Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. *Global Ecology and Conservation*, 3:200-209.

Stafford-Smith, M., Griggs, D., Gaffney, O. Ullah F., Reyers B., Kanie N., Stigson B., Shrivastava P., Leach M., & O'Connell D. 2017. Integration: the key to implementing the Sustainable Development Goals. *Sustainability Science* 12:911–919. https://doi.org/10.1007/s11625-016-0383-3

Steensland, A. (2020). 2020 Global Agricultural Productivity Report: Productivity in a Time of Pandemics (Thompson, T., Ed.), Virginia Tech College of Agriculture and Life Sciences.

Steensland A., and M. Zeigler. 2017. Global Agricultural Productivity Report. Global Harvest Initiative

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & De Haan, C. (2006).Livestock's long shadow: Environmental issues and options. Rome: United Nations Food and Agriculture Organization

Stickler M. (2019). Rights to trees and livelihoods in Niger. Gates Open Research, focus on land in Africa, Policy brief no. 3. Online at www.focusonland.com

Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G.,. Davidson E.A, Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S. (2013). Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

Tanui, J., Groeneveld, R., Klomp, J., Mowo, J. and Ierland, E.C.V., 2013. Explaining investments in sustainable land management: The role of various income sources in the smallholder farming systems of western Kenya (No. 309-2016-5177). Online at http://www.ageconsearch.umn.edu

Tian, H., Xu, R., Canadell, J.G. et al. A comprehensive quantification of global nitrous oxide sources and sinks. *Nature* 586:248–256

Tittonell P, Leffelaar PA, Vanlauwe B, et al. (2006) Exploring diversity of crop and soil management within smallholder African farms: A dynamic model for simulation of N balances and use efficiencies at field scale. *Agricultural Systems* 91: 71–101.

Townsend, R.2015. Ending poverty and hunger by 2030: an agenda for the global food system. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/700061468334490682/Ending-poverty-and-hunger-by-2030-an-agenda-for-the-global-food-system

Ullah, I. and Kim, D.Y., 2020. A Model of Collaborative Governance for Community-based Trophy-Hunting Programs in Developing Countries. *Perspectives in Ecology and Conservation* (forthcoming).

UNCCD and FAO. 2020. Land Degradation Neutrality in Small Island Developing States. Technical report. Bonn, Germany

UNDP 2019. Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. Online at http://hdr.undp.org/sites/default/files/hdr2019.pdf

UNDP. 2018. Progress on the New York Declaration on Forests Improving Governance to Protect Forests. Online at https://forestdeclaration.org/images/uploads/resource/2018_Goal10_FocusReport_Brief.pdf

UNEP (United Nations Environment Program) (2019). Global environment outlook (GEO-6). Healthy planet, healthy people. Cambridge University Press, Cambridge, UK.

UNEP-IRP. 2018. *The weight of cities. Resource requirements of future urbanization*. United Nations Environment Programme. International Resource Panel. Online: https://www.resourcepanel.org/file/971/download?token=ehOygAQ7

UNDESA 2019a. Global Forest Goals and Targets of The UN Strategic Plan for Forests 2030. Online at https://www.un.org/esa/forests/wp-content/uploads/2019/04/Global-Forest-Goals-booklet-Apr-2019.pdf

UNDESA (United Nations, Department of Economic and Social Affairs) (2019b). World Population Prospects 2019, Volume II: Demographic Profiles.

UN-HABITAT (2015). The city prosperity initiative: 2015 global city report. Nairobi.

UNECE (2015). Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals, 1603 ITU-T L.1603.

UNESCO. 2018. Youth and the 2030 Agenda for Sustainable Development. Online at https://www.un.org/development/desa/youth/wp-content/uploads/sites/21/2018/12/WorldYouthReport-2030Agenda.pdf

UN-Habitat. 2017. Smart City Rwanda Masterplan. Online at https://unhabitat.org/sites/default/files/documents/2019-05/rwanda_smart_city-master_plan.pdf.

UNEP (2018). Assessing Environmental Impacts- A Global Review of Legislation, Nairobi, Kenya.

UNEP (United Nations Environment Programme) (2017). Towards a Pollution-Free Planet Background Report. United Nations Environment Programme, Nairobi, Kenya

United Nations Environment Programme (2019). Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Nairobi: 2651 Cambridge University Press. https://doi.org/10.1017/9781108627146.

UNIDO (United Nations Industrial Development Organization). 2019. Statistical Indicators of Inclusive and Sustainable Industrialization: Biennial Progress Report 2019.Vienna.Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D. and Smaling, E.M.A., 2010. Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook on agriculture,* 39(1):17-24.

van Lierop, P., Lindquist, E., Sathyapala, S. & Franceschini, G. 2015. Global forest area disturbance from fire, insect pests, disease and severe weather events. *Forest Ecology and Management* 352: 78–88.

Van Middelaar, C.E., Berentsen, P.B.M., Dijkstra, J., Van Arendonk, J.A.M. and De Boer, I.J.M., 2014. Methods to determine the relative value of genetic traits in dairy cows to reduce greenhouse gas emissions along the chain. *Journal of Dairy Science*, 97(8):5191-5205.

Van Meerbeek, K. and Svenning, J.C., 2018. Causing confusion in the debate about the transition toward a more plant-based diet. *Proceedings of the National Academy of Sciences*, 115(8):E1701-E1702.

van Wijk, M.T., Merbold, L., Hammond, J. and Butterbach-Bahl, K., 2020. Improving Assessments of the three pillars of Climate Smart Agriculture: current achievements and ideas for the future. *Frontiers in Sustainable Food Systems*, 4:148-161.

Viglizzo, E.F., Frank, F.C., Carreño, L.V., Jobbagy, E.G., Pereyra, H., Clatt, J., Pincen, D. and Ricard, M.F., 2011. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Global Change Biology*, 17(2):959-973.

Wilkinson, J. and Rocha, R., 2009. Agro-industry trends, patterns and development impacts. Agroindustries for Development, Wallingford, UK: CABI for FAO and UNIDO, pp.46-91.

World Bioenergy Association. 2019. Global Bioenergy Statistics 2019. Online at https://worldbioenergy.org/uploads/191129%20WBA%20GBS%202019_HQ.pdf

World Bank. 2020. Projected Poverty Impacts of COVID-19 (coronavirus). Online. Retrieved from https://perma.cc/4JR7-GYU7.

World Bank. 2018. Agriculture value added as percent of GDP. Online at https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

World Bank. 2019. Worldwide Governance Indicators database https://info.worldbank.org/governance/wgi/

World Health Organization (2020a). Air pollution: Air Pollution infographics. https://www.who.int/airpollution/infographics/en/ 2714 (Accessed: 02 April 2020).

WWAP. 2017. The United Nations World Water Development Report 2017: Wastewater, the untapped resource. United Nations World Water Assessment Programme (WWAP).

Xiao, L. et al. 2017: The indirect roles of roads in soil erosion evolution in Jiangxi Province, China: A large scale perspective. *Sustainability,* 9:129, doi:10.3390/su9010129.

Yousefi, S., Moradi, H., Boll, J. and Schönbrodt-Stitt, S., 2016. Effects of road construction on soil degradation and nutrient transport in Caspian Hyrcanian mixed forests. *Geoderma*, *284:*103-112.

Zeng, L. and Ramaswami, A. (2020). Impact of Locational Choices and Consumer Behaviors on Personal Land Footprints: An Exploration Across the Urban–Rural Continuum in the United States. *Environmental Science & Technology* 54(6), 3091-3102. https://doi.org/10.1021/acs.est.9b06024.

Zomer, R.J., Bossio, D.A., Sommer, R. and Verchot, L.V., 2017. Global sequestration potential of increased organic carbon in cropland soils. *Scientific Reports*, 7(1):1-8.

Zuazo H.V. and C.R. Pleguezuelo. 2008. Soil-erosion and runoff prevention by plant covers. A review. Agronomy for Sustainable Development 28 (1):65-86.