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Land, Climate, Energy, Agriculture and Development in the Sahel
Synthesis paper of case studies under the Sudano-Sahelian Initiative for Regional Development, Jobs, and Food Security

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Land, Climate, Energy, Agriculture and Development in the Sahel

Synthesis paper of case studies under the Sudano-Sahelian Initiative for Regional Development, Jobs, and Food Security

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Abstract

This paper synthesizes a set of national case studies conducted in the Sahelian countries during 2019-2020 as a collaboration between national universities and research institutes, and the Center for Development Research (ZEF), University of Bonn, with contributions from the Agrhymet Regional Centre, Permanent Interstate Committee for Drought Control in the Sahel (CILSS). These case studies provide up-to-date knowledge and critical insights on the nexus of land degradation, climate change and energy in the Sahel. The current synthesis paper highlights their major findings and provides cross-cutting and cross-regional analytical conclusions. First, the synthesis paper explores current trends in the Sahel region on land use and land degradation, energy use and supply, climate change projections and impacts, as well as their interactions and links to agricultural growth, food security, poverty reduction, and peace in the region. Second, technological, socio-economic and policy solutions at the nexus of land, water, energy and climate challenges that enable environmentally sustainable and socially inclusive rural development in the Sahel are discussed, including their interactions and implications for peace and stability in the region. The findings show that such socio-economic solutions as improving access to markets, strengthening social safety nets, increasing investments to transport and energy infrastructures, promoting land tenure security, expanding off-farm employment opportunities can greatly contribute to rural development in the Sahel, particularly by aiding climate change resilience and sustainable land management. Key technological innovations highlighted across the case studies include expanding irrigation and adopting water use efficient irrigation techniques, crop diversification, expanding agricultural mechanization, investing into restoring and rehabilitating degraded lands through reforestation, afforestation and agroforestry practices. The key lessons learnt from ongoing national policy initiatives for sustainable development highlight the importance of active stakeholder consultation and participation in policy formulation, institution of effective policy monitoring and assessment mechanisms, and avoiding of excessive reliance on external sources of funding for the successful implementation of sustainable development policies and programs. Based on these findings, the synthesis paper proposes an agenda for applied research to provide guidance to and accompany promising development strategies in and for the region.

Keywords: Sahel, water-energy-food security nexus, food insecurity, land degradation, climate change adaptation, development policies, job creation, infrastructure, conflicts, future research agenda

JEL codes: O1, O2, O3, Q1, Q2, Q4, Q5, J43

Acknowledgments

This synthesis paper and the underlying country case studies from the Sahel region were supported by the German Federal Ministry for Development Cooperation (BMZ) under the Program of Accompanying Research for Agricultural Innovation (PARI), which is gratefully acknowledged.

The authors express their deep appreciation and thanks to the participants of the virtual workshop on "Rural Development, Agricultural Livelihoods and Job Creation in the Sahel Region", conducted jointly by the Center for Development Research (ZEF), University of Bonn, and the Agrhymet Regional Center of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) from 22-26 June 2020, for their valuable feedback, comments and suggestions to this paper and the underlying case studies.

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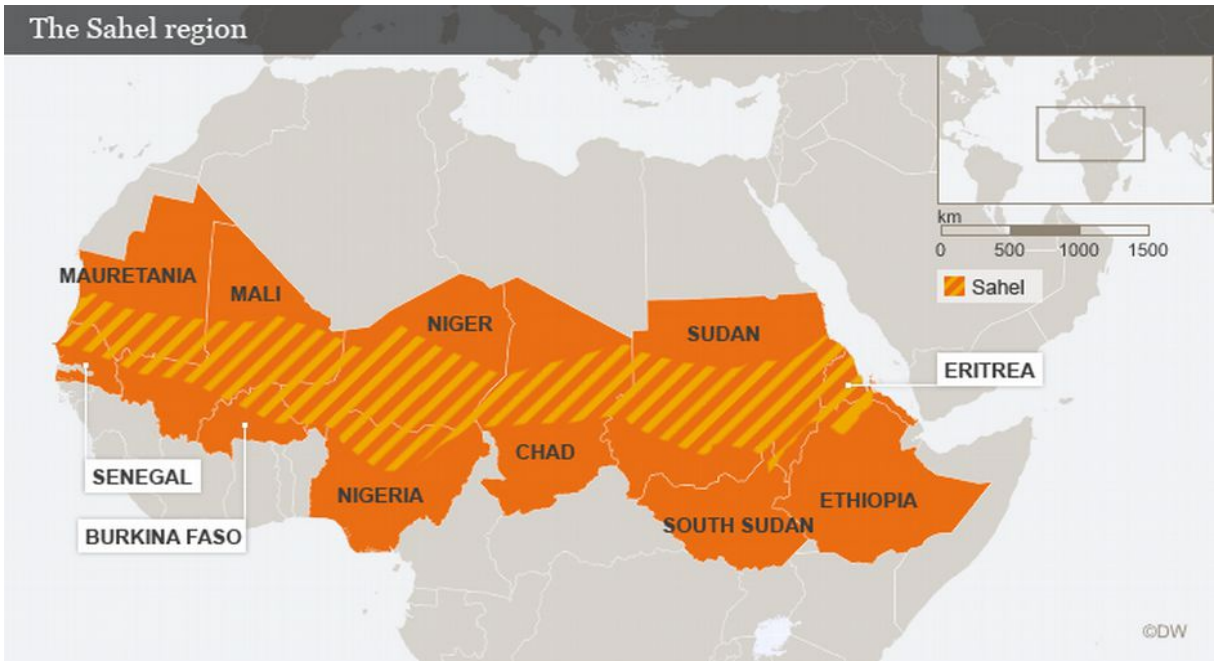
1 Background and problem definition

The Sahel region, as defined here, is home to a half billion people. It stretches through the heart of Africa, from the Atlantic Ocean on the western coast to the Red Sea on the eastern coast. This economically and culturally diverse semi-arid region separates the hyper-arid Sahara, the largest desert in the world, to its North, from lush savannas and tropical forests to its South. The Sahel region is spread over 11 countries: Senegal, Mauritania, Mali, Burkina Faso, Niger, Nigeria, Chad, Sudan, South Sudan, Eritrea, and Ethiopia (from west to east) (Figure 1).

Figure 1: The Sahel region



Source: Deutsche Welle (2019).

Poverty has been declining in the Sahelian countries over the last two decades due to rapid economic growth exceeding 6% annually. Nevertheless, about 42% of the population in the region are still below the international poverty line and the Sahelian countries are classified by the World Bank as low-income countries (Table 1).

Low agricultural productivity, vulnerability to extreme weather, income inequality and conflicts/insecurity are major causes of poverty in the region (Olayide, 2020: Nigeria case study; Sylla et al., 2020: Burkina Faso case study; Admassie and Abebaw, 2020: Ethiopia case study). Unemployment and under-employment levels are high, particularly among the younger generation. Although the share of agriculture in the Sahelian gross domestic products is declining, it still represents one third of the aggregate regional product and continues to play a major role in employment (40-80% of the active labor force), making the regional economies and livelihoods very vulnerable to climate change. Furthermore, most of crop production area in the Sahel is rainfed (> 85%), with limited irrigated agriculture. Biomass remains the major source of household energy across the region (Adamou et al., 2020: Niger case study; Coulibaly, 2020: Mali case study). This high dependency on biomass for energy has led to massive deforestation, loss of soil nutrients and organic matter. Most of the countries in the region are in the bottom ranks of the Human Development Index (HDI) (UNDP. 2019). The most recent FAO assessment under the Global Information and Early Warning System included all the Sahelian countries among those facing critical food insecurity problems, with some facing widespread lack of access to food, while some others are confronted with severe localized food insecurity. The key causes behind this food insecurity situation in the region are droughts and civil

conflicts.[1] The major drivers of conflicts across the region are competition for land and water resources, as well as political, religious and ethnical differences (Figure 2) (Olayide et al., 2020: Nigeria case study; Osman and Mohamed, 2020: Sudan case study).

Tab 1: Key socio-economic characteristics of the Sahelian countries

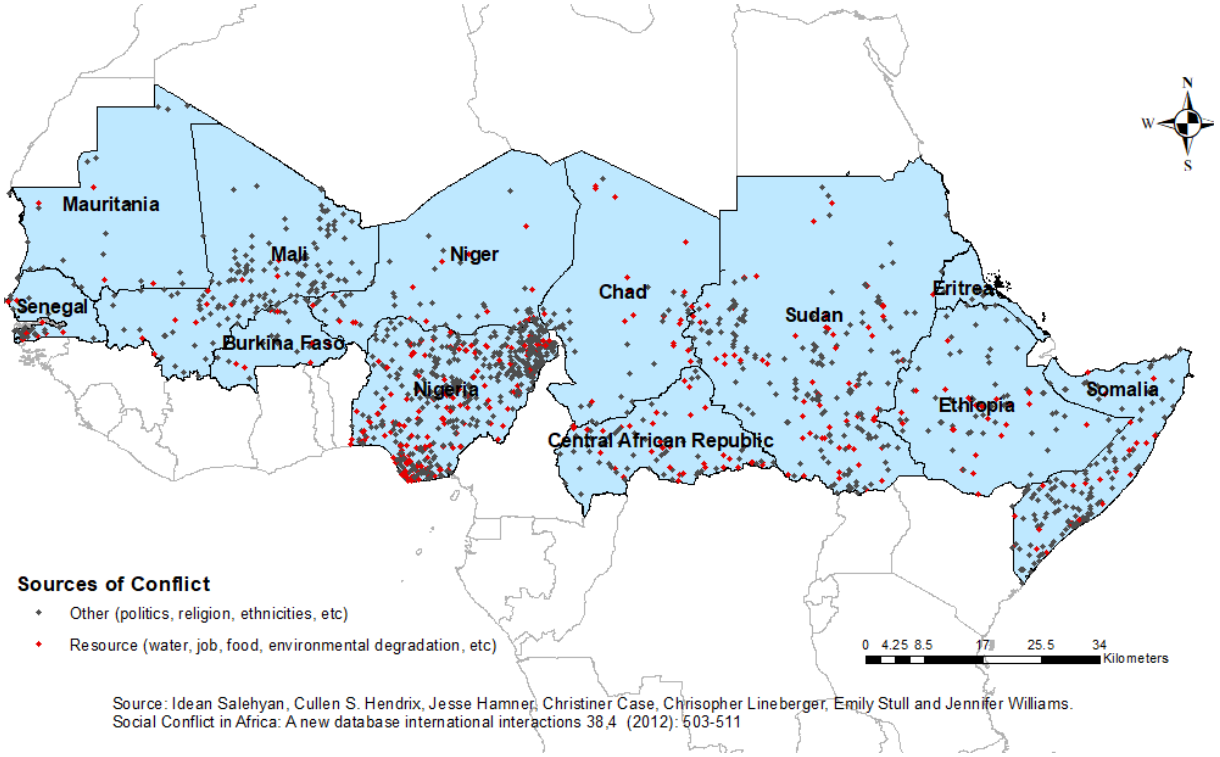
Country	Population (2018, in millions)	GDP per capita (2018, current USD)	Poverty headcount ratio at 1.90 USD a day (% of population, various years[2])	Share of agriculture, forestry, and fishing in GDP (%, 2018)	Main exports
Senegal	16	1522	38	17	fish, groundnuts, petroleum products, phosphates, cotton
Mauritania	4	1189	6	26	iron ore, petroleum, gold, copper, gypsum, fish
Mali	19	900	41	39	gold, cotton
Burkina Faso	20	715	38	28	gold, cotton, livestock, sesame
Niger	23	414	45	39	uranium ore, livestock, cowpeas, onions
Nigeria	196	2028	54	21	petroleum and petroleum products, cocoa, timber
Chad	15	728	38	45	petroleum, cattle, cotton, gum arabic
Sudan	42	977	13	32	gold; petroleum and its products; cotton, sesame, livestock
South Sudan	11	1120	43	10	petroleum
Eritrea	4	396	53	14	zinc, copper, precious metal ore
Ethiopia	109	772	24	31	coffee, qat, gold, leather products, livestock, oilseeds
The Sahel region	**459**	**1345**	**42**	**31**	**petroleum, metals and agricultural products**

(World Bank Open Data, https://data.worldbank.org/, accessed on 10.06.2020; the national case studies cited in Box 1.)

[1] http://www.fao.org/giews/country-analysis/external-assistance/en/

[2] Based on latest available data, mostly between 2009-2018.

Figure 2: Major sources of conflicts across the Sahel region



The Sahel is among the regions of the world confronted with the most severe problems of land degradation. Unsustainable cropping practices, grassland degradation, conversion of grasslands to croplands and deforestation were identified as the major forms of land degradation in the region (Nkonya et al., 2016). Climate change is projected to amplify these degradation processes (Mirzabaev et al., 2019). Land degradation, climate variability and change represent major underlying threats to rural livelihoods in the Sahel (Nkonya et al., 2016). Sustainable and peaceful development of the region critically depends on finding solutions to advance economic growth, human development, and food security. In this regard, sustainable land management, climate change adaptation, expanding access to clean, modern, and renewable energy sources, and investments into human capital in the Sahel are essential entry points for achieving these objectives, including peace and security, through their acceleration of agricultural growth rates. Agricultural growth is the most effective source of poverty reduction in the Sahel due to the concentration of unskilled and low-income labor in agriculture. The Sahelian countries have designed a big number of policies and strategies, such as the African Union (AU) program on Comprehensive Africa Agriculture Development (CAADP), the Great Green Wall (GGW) initiative, Silencing the Guns in Africa, the Malabo Declaration on Accelerated Agricultural Growth, Agenda 2063, and many others, to address land degradation, enhance agricultural productivity, adapt to changing climate, and to sustain peace processes and critical peace operations. However, the overall investments in sustainable land management, land restoration activities and agricultural productivity growth remain low. Therefore, it is particularly important not to lose sight of these fundamental challenges defining the future of the region in the post-COVID world.

Box 1: The National Case studies and other key publications

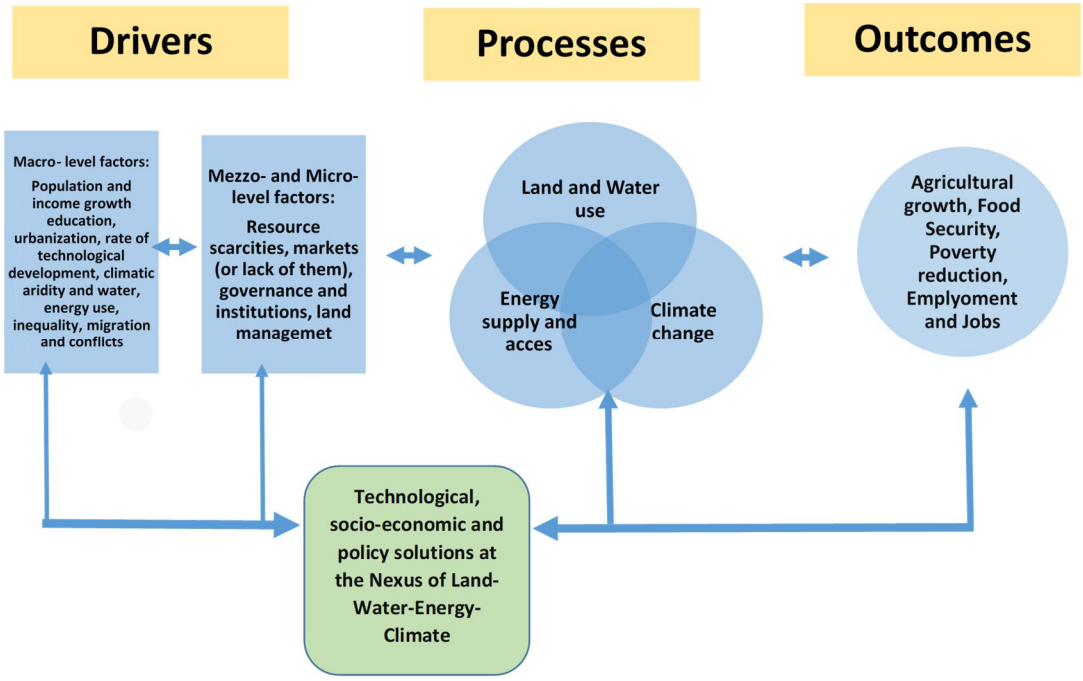
- Mouhamadou Bamba Sylla, Kangbéni Dimobe, Safietou Sanfo (2020) Burkina Faso - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 197 (Sylla et al., 2020).
- Assefa Admassie, Degnet Abebaw (2020) Ethiopia - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 198 (Admassie and Abebaw, 2020).
- Ousmane Coulibaly (2020) Mali - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 199 (Coulibaly, 2020).
- Rabani Adamou, Boubacar Ibrahim, Abdou Latif Bonkaney, Abdoul Aziz Seyni, Mamoudou Idrissa, Nassourou Bello (2020) Niger - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 200 (Adamou, 2020).
- Olawale Emmanuel Olayide (2020) Nigeria - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 201 (Olayide, 2020).
- Amy Faye, Mohamadou Dièye, Pape Bilal Diakhaté, Assane Bèye, Moussa Sall, Mbaye Diop (2020) Senegal - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 202 (Faye et al., 2020).
- Abdelrahman Khidir Osman, Adil Mohamed (2020) Sudan - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper 203 (Osman and Mohamad, 2020).
- Malabo-Montpellier Panel (2018a). WATER-WISE: Smart Irrigation Strategies for Africa.
- Malabo-Montpellier Panel (2018b). MECHANIZED: Transforming Africa's Agriculture Value Chains.
- Malabo-Montpellier Panel (2019). ENERGIZED: Policy innovations to power the transformation of Africa's agriculture and food system.
- CILSS (2016). Landscapes of West Africa – A Window on a Changing World. U.S. Geological Survey EROS, 47914 252nd St, Garretson, SD 57030, UNITED STATES.
- United Nations Convention to Combat Desertification (UNCCD). 2019. The Global Land Outlook, West Africa Thematic Report, Bonn, Germany.

The main objective of this paper is to synthesize a set of accompanying national case studies conducted in the Sahelian countries during 2019-2020 as a collaboration between national universities and research institutes and the Center for Development Research (ZEF), University of Bonn (Box 1), with contributions from the Agrhymet Regional Centre, Permanent Interstate Committee for Drought Control in the Sahel (CILSS). The case studies reviewed existing scientific literature, government documents such as policy and administrative reports, as well as project documents. These case studies provide up-to-date knowledge and critical insights on the nexus of land degradation, climate change and energy in the Sahel region. They also identify policy entry points and investment opportunities that will help in advancing economic growth, food security, and job creation in the region. The current synthesis paper highlights their major findings and provides cross-cutting and cross-regional analytical conclusions. Based on these case studies and the discussions during the virtual workshop on "Rural Development, Agricultural Livelihoods and Job Creation in the Sahel Region", conducted jointly by the Center for Development Research (ZEF), University of Bonn, and the Agrhymet Regional Center (CILSS) from 22-26 June 2020, this synthesis paper proposes an applied research agenda to provide guidance to and accompany promising development strategies in and for the region.

2 Conceptual underpinnings

The conceptual framework in Figure 3 depicts the interactions highlighted in the case studies and this synthesis paper. It shows that various drivers at macro-, mezzo- and micro-levels affect the interlinked processes of climate change, energy supply and access, and land and water use. On the positive side, there are many technological, socio-economic and policy solutions which can operate at the nexus of these overlapping challenges strengthening the resilience and adaptive capacities of rural communities against climate change, while simultaneously contributing to climate change mitigation, and facilitating the attainment of other sustainable development goals (SDGs), particularly addressing land degradation and expanding access to clean energy (Mirzabaev et al., 2019).

Figure 3: The conceptual framework



Source: The authors.

Certainly, land-climate interactions may also have trade-offs and negative externalities on various facets of sustainable development, e.g. large-scale bioenergy development and resulting food insecurity (Smith et al., 2019), or competition for resources leading to conflicts. Similarly, strengthening human capital building and higher education, including tertiary education, is key for boosting job creation, particularly in the non-farm sector, in this resource-constrained region. The role of research is to identify such synergies and trade-offs and assist the creation of enabling policy environments.

Following this conceptual framework, the case studies and the synthesis paper first explore current trends in the Sahel region on land use and land degradation, energy use and supply, climate change projections and impacts, as well as their interactions and links to agricultural growth, food security, poverty reduction, and peace in the region. Second, technological, socio-economic and policy solutions at the nexus of land, water, energy and climate that enable environmentally sustainable and socially inclusive rural development in the Sahel are discussed, including their interactions and implications for peace and stability in the region. Next, key lessons learnt from ongoing national policy initiatives for sustainable development are highlighted. Finally, based on the insights from these three sections as well as stakeholder consultations during the virtual workshop described in the introduction, an agenda for applied research is proposed.

3 Land use and land degradation

Land degradation is defined across the case studies as "a negative trend in land condition, caused by direct or indirect human-induced processes, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans" (Olsson et al., 2019: 349-350). The Sahel region experienced a series of widespread droughts and resulting desertification during the 1970s, however, wetter climate and ensuing greening conditions have been observed in the Sahel since 1990s (Brandt et al., 2015; Leroux et al., 2017; Sylla et al., 2020: Burkina Faso case study; Adamou et al., 2020: Niger case study).

At the same time, greening does not necessarily mean land improvement, as it can be caused by invasive plants encroachment and accompanying decreases in species richness and biodiversity (Admassie and Abebaw, 2020: Ethiopia case study). Major land use changes in the region since the 1970s included the rapid expansion of cropland areas and population settlements, and decreases in forests, grasslands, and water bodies (Hiernaux et al., 2009; Aladejana et al., 2018). Although there is considerable debate about the expansion of the Sahara Desert based on annual rainfall, Thomas and Nigam (2018) indicated that the Sahara expanded by 10% over the 20th century (e.g., Osman and Mohamad, 2020: Sudan case study).

More recent land use and land cover changes between 2001 and 2018 based on remotely sensed data corroborate the findings on greening across the Sahel (Table 3). During this period, grasslands expanded in the region by 13 million ha, whereas the barren areas, i.e. those areas with no more than 10% vegetative cover and the remainder being bare soil, sand and rock, declined by 8.6 million ha. Another major difference between 2001 and 2018 across the region is the reduction of cropped areas, in total by 0.7 million hectares for the entire region. Cropland decline occurred in most countries, except for Nigeria and Senegal, and to a lesser extent Niger and Mauritania, where cropped areas increased between these years. This is contradictory to the impression that cropped areas have been constantly increasing in the region. At the same time, an important caveat to bear in mind is that the MODIS dataset does not include fallowed land under croplands, but summarizes these under other land uses, e.g. grasslands. Even as such, this is an important indicator for the changes of actually cropped areas between 2001 and 2018. More detailed studies are needed to identify the reasons behind these cropland changes, whether they are due to intensification of agricultural production or land degradation. However, indirect evidence indicates that unsustainable land management practices may be playing an important role (Nkonya et al., 2016). These land use and land cover changes are at the regional level, with specific regions of the Sahelian countries often experiencing divergent trends. In Burkina Faso, for example, although overall cropped areas declined, the area under croplands strongly increased in the central and southern parts of the country (Sylla et al., 2020: Burkina Faso case study). The year-to-year variations in the extent of biomes is given in Figure 4. Figure 4 shows that the changes between 2001 and 2018 represented in Table 2 are part of a broadly consistent pattern of annual changes between these years, and not some odd product of selecting these years as the baseline and end-line for comparison.

Tab 2: Changes in land use and land cover between 2001 and 2018

Land use and land cover in 2001, in thousand ha	Land use and land cover in 2018, in thousand ha								**Total**
	Forest	Shrubland	Woodland	Grassland	Wetland	Cropland	Settlement	Barren lands	
Forest	4,607	1	778	1,394	87	98	4	0	**6,969**
Shrubland	6	17,783	3	7,631	3	11	3	380	**25,819**
Woodland	173	0	1,725	434	5	190	5	0	**2,531**
Grassland	1,392	2,535	845	365,000	228	16,710	111	1,914	**388,735**
Wetland	33	0	3	186	1,636	10	6	4	**1,879**
Cropland	105	2	115	17,384	12	67,268	149	7	**85,041**
Settlements	0	0	0	0	0	0	1,255	0	**1,255**
Barren lands	0	1,017	0	9,853	47	4	5	465,000	**475,927**
Total	**6,315**	**21,338**	**3,469**	**401,882**	**2,018**	**84,292**	**1,537**	**467,306**	
Net gain/loss	**-654**	**-4,481**	**937**	**13,147**	**139**	**-749**	**282**	**-8,621**	

Notes: See Box 2 for the definition of these biomes. Despite high resolution of pixel size (25 hectares), this MODIS LUCC database underrepresents cropped areas due to usually small farm sizes across the Sahel and frequent interspersion of cropped areas within larger biomes.
(MODIS LUCC database (at 500 meters' resolution)[3]; Friedl et al. 2019)

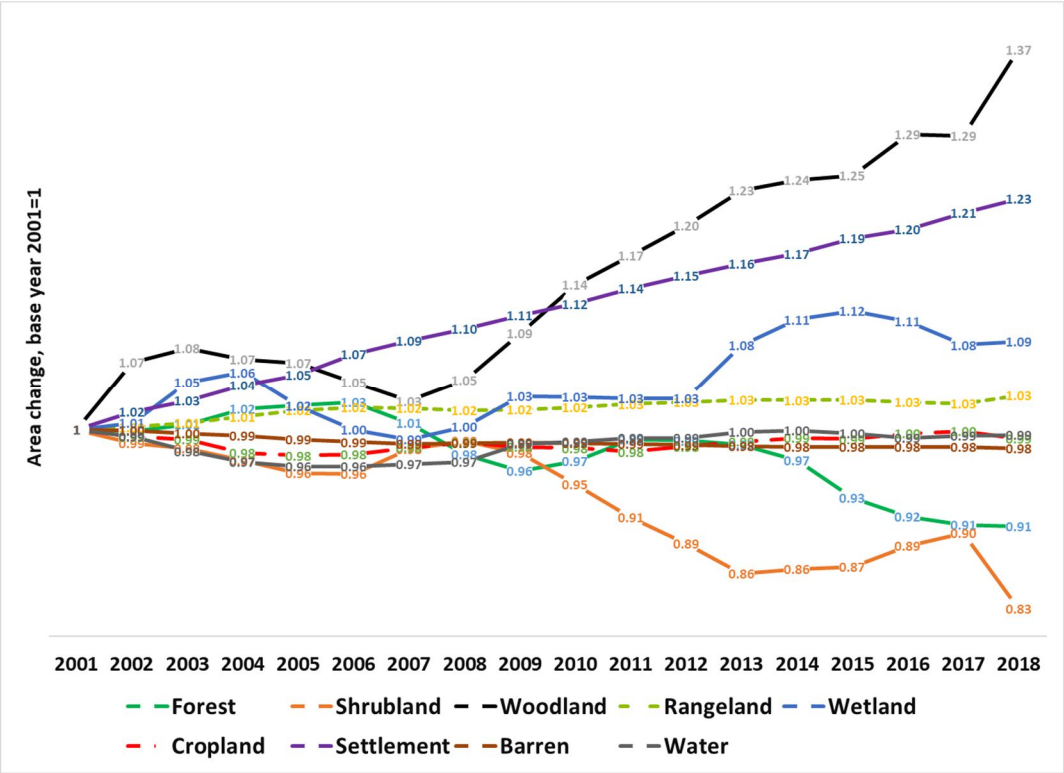
Box 2: Definition of biomes used in the study

Biome	**International Geosphere-Biosphere Program (IGBP) definition**
Forests	Woody vegetation with height >2m & covering at least 60% of land area.
Shrubland	Vegetation with mainly shrubs or short trees (shrubs) of less than 2m. Canopy of shrublands is fairly open and allows grasses and other short plants to grow between the shrubs.
Woodland	Biome with tree cover of 5-10%, with trees reaching a height of 5m at maturity.
Grassland	Lands with herbaceous types of cover. Tree and shrub cover is less than 10%.
Cropland	Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops are classified as forest or shrubland.
Barren lands	Barren or sparsely vegetated (bare soil and rocks) are lands with exposed soil, sand or rocks, with less than 10% vegetation cover throughout the year.
Settlements	Land covered by buildings and other man-made structures.
Wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present either in salt, brackish, or fresh water.

Note: For more definitions, please see http://earthobservatory.nasa.gov/Experiments/Biome/vocabulary.php.

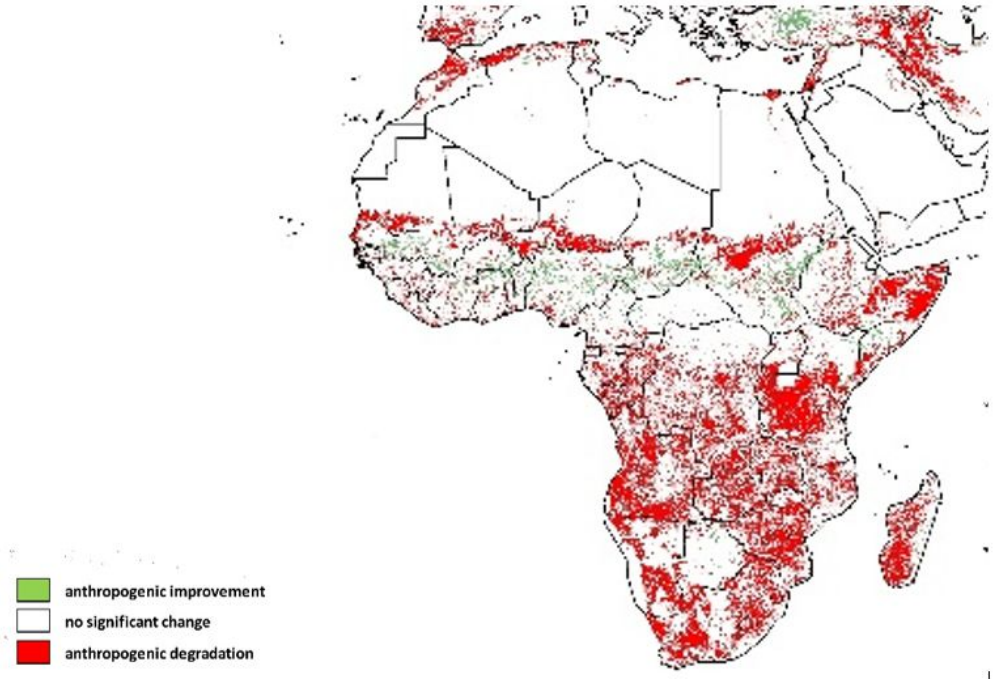
[3] https://lpdaac.usgs.gov/products/mcd12q1v006/, accessed on 05.06.2020.

Figure 4: Annual changes in land use and land cover in the Sahel region (base year is 2001 = 1)



Notes: See Box 2 for the definition of these biomes. Despite high resolution of pixel size (25 hectares), this MODIS LUCC database underrepresents cropped areas due to usually small farm sizes across the Sahel and frequent interspersion of cropped areas within larger biomes.
Source: based on MODIS LUCC database (at 500 meters' resolution); Friedl et al. (2019).

Figure 5: The extent of land degradation and improvement in Africa and the Sahel



Source: Le et al. (2016).

The analysis done by Le et al. (2016) identified a mixture of land degradation and land improvement over the Sahel region with a clear pattern of land degradation at the edges of the Sahara Desert (the Sahelian bioclimatic zone) and more spread out land improvement in the southern parts of the region (Sudanian bioclimatic zone) (Figure 5). Analysis of land degradation, based on vegetation trends, showed that highest levels of land degradation occurred over grasslands (Table 4). On aggregate, the annual costs of land degradation in the Sahel region are estimated to be close to an equivalent of 20 billion USD annually in terms of lost ecosystem services from land. On the positive side, each dollar invested into land restoration and rehabilitation in the region was estimated to yield, on average, about 5 dollars of returns within a 30-year period (Nkonya et al., 2016).

Loss of vegetative cover due to land degradation, particularly in the northern parts of the Sahel region, is intensifying dust storms with considerable negative impacts on human health (Adamou et al., 2020: Niger case study). Although the origin of dust and sandstorms in the region is predominantly natural (coming from the Sahara Desert), assessments show that human activities are further amplifying these dust and sandstorms (Mirzabaev et al., 2019).

Tab 3: Area of vegetation-based land degradation by land use and land cover (km2) between 1980s and early 2000s, and annual cost of land degradation (billion USD 2007)

Country	Cropland	Mosaic vegetation-crop	Forested land	Mosaic forest-shrub/ Grass	Shrub land	Grassland	Sparse vegetation	Annual cost of land degradation
Senegal	9280 (13%)	9216 (20%)	1920 (8%)	1088 (12%)	1344 (3%)	2112 (20%)	1408 (36%)	0.4
Mauritania	768 (13%)	7872 (39%)	N/A	11648 (46%)	0 (0%)	56960 (52%)	8832 (32%)	0.3
Mali	5824 (5%)	9152 (12%)	192 (2%)	8832 (19%)	3648 (4%)	48192 (34%)	7872 (22%)	2.2
Burkina Faso	7104 (6%)	4544 (7%)	128 (5%)	2176 (11%)	2496 (6%)	3200 (19%)	1216 (13%)	1.8
Niger	3328 (21%)	12800 (49%)	64 (100%)	8000 (49%)	0 (0%)	138176 (55%)	4992 (17%)	0.8
Nigeria	12160 (4%)	14784 (10%)	20736 (11%)	1728 (7%)	9984 (5%)	9216 (18%)	640 (21%)	5.2
Chad	5440 (5%)	3840 (5%)	3392 (6%)	5504 (8%)	4992 (4%)	41920 (33%)	2688 (13%)	2.4
Sudan	26624 (17%)	41472 (26%)	5696 (4%)	49664 (16%)	17344 (6%)	108608 (43%)	25408 (23%)	1.7
Eritrea	320 (7%)	448 (5%)	N/A	2304 (18%)	192 (25%)	1216 (6%)	3264 (12%)	0.2
Ethiopia	35904 (18%)	30976 (19%)	9984 (16%)	59776 (27%)	37824 (20%)	7808 (14%)	45888 (32%)	4.3

(Le et al., 2016; Gebreselassie et al., 2016; Mussa et al., 2016; Sow et al., 2016; Nkonya et al., 2016)

The key drivers of land degradation are population growth leading to increased demand for food and fuelwood (cf. all the case studies indicated in Box 1). Poor agro-sylvo-pastoral practices, such as the slash-and-burn system, land tenure insecurity, as well as lack of access to markets, extension services, and credit are also important drivers of land degradation in diverse settings across the region (Moussa et al., 2016; Sow et al., 2016; Gebreselassie et al., 2016; Nkonya et al., 2016). Mono-cropping of cash crops (especially cotton) in several Western African countries has led to depletion of soil fertility and secondary soil salinization (Sylla et al., 2020: Burkina Faso case study; Coulibaly, 2020: Mali case study).

Low productivity associated with subsistence farming has led to soil fertility mining and soil degradation in many parts of the Sahel. This has also brought about a more rapid expansion of cropping to marginal lands with fragile soils (Ogunlela and Ogungbile, 2006), leading to new cycles of land degradation, exacerbating conflict dynamics such as intense competition over land and water resources between pastoralists and sedentary farmers (Olayide, 2020: Nigeria case study; Admassie and Abebaw, 2020: Ethiopia case study).

4 Energy supply and use

Populations in the Sahel region use a wide range of energy sources including fuelwood, charcoal, liquefied petroleum gas (LPG), electricity generated using both fossil fuels and modern renewable energy sources, primarily hydro- and solar power. However, fuelwood represents a predominant share of the total energy use across the region (Table 4) (cf. all the case studies indicated in Box 1). The energy transition trajectories in the Sahel are closely following the "energy stacking" paradigm, where traditional biomass is heavily relied on even when access to other sources of energy is slowly expanding. The access to electricity in the region varies substantially, but remains low overall (Table 4). Extensive use of traditional biomass for cooking is resulting in major health issues through indoor air pollution, particularly for women and children. Growing use of fossil fuels is also rapidly increasing the air pollution in the Sahel's major cities.

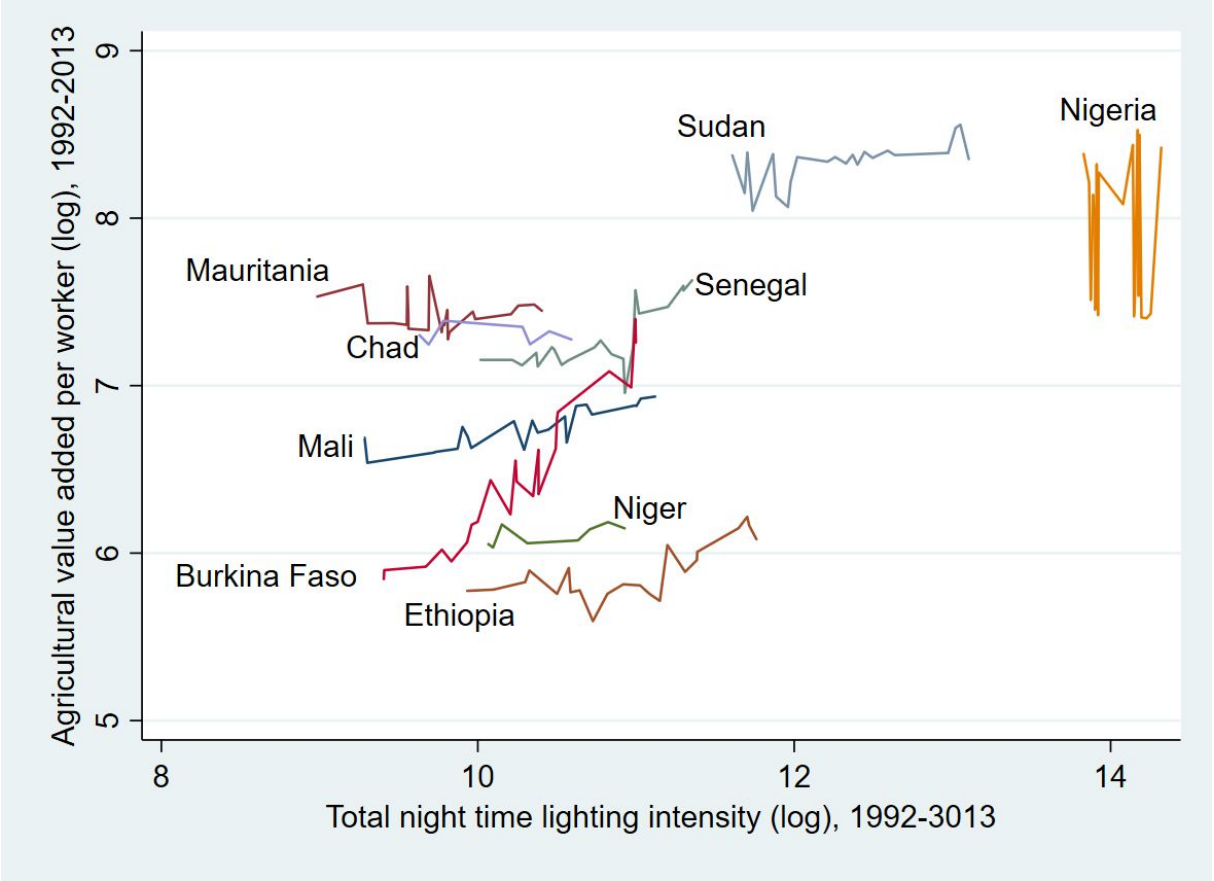
Tab 4: Energy profile of the Sahel region

Country	Share of biomass in energy supply (%)	Access to electricity (% of the population, 2018)	Access to electricity in rural areas (% of the rural population, 2018)	Share of population with access to clean cooking (%)
Senegal	57	67	44	31
Mauritania	60	45	1	50
Mali	76	51	25	<5
Burkina Faso	80	14	5	15
Niger	78	18	12	9
Nigeria	82	57	31	9
Chad	93	12	3	6
Sudan	78	60	47	45
South Sudan	>95	28	24	<5
Eritrea	80	50	35	<5

(World Bank Open Data, https://data.worldbank.org/, accessed on 10.06.2020)

Remotely sensed satellite data on night-time lighting intensity, which is a good proxy for electricity access, shows substantial improvements across the region since the 1990s (Figure 6). Particularly high rates of electricity expansion are observed in Ethiopia, Mali, Senegal and Sudan. However, growing electricity access rates were not always accompanied by a similarly fast growth in agricultural labor productivity. Only in Burkina Faso, Mali and Ethiopia agricultural labor productivity grew in tandem with expanding access to electricity. One reason for this is that despite of the expansion of electricity access, there is still a considerable gap in electricity access in rural areas (Table 4).

Figure 6: Dynamics of access to electricity (horizontal, with night-time lighting intensity as proxy) and agricultural value added per worker (vertical)



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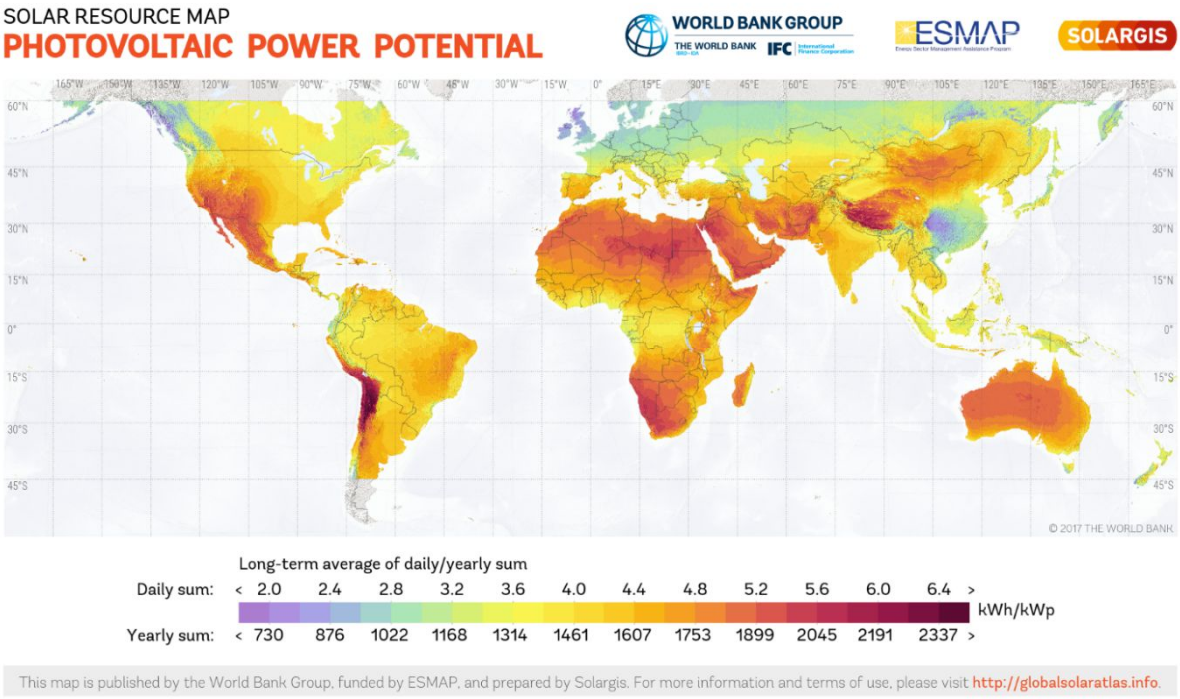
Source: NOAA - Version 4 DMSP-OLS Nighttime Lights Time Series[4], FAOSTAT[5].

Most of the electricity access is concentrated in capital cities and other urban areas, hence, the access rates to electricity in rural areas are significantly lower. Often the quality of electricity access in many of those areas with grid connection is highly unreliable. Many electricity utilities in the region are not viable without heavy government subsidies despite growing electricity prices charged to consumers (Sylla et al., 2020: Burkina Faso case study; Adamou et al., 2020: Niger case study). This is due to losses in transmission, distribution and bill collection, as well as overstaffing of public electricity utilities (Trimble et al., 2016).

The Sahel region has substantial potential for renewable energy production, particularly through harvesting solar energy (Figure 6). In many locations across the region, the use of renewable energy sources as part of decentralized local grids can be less costly than electricity-generation using fossil fuels. Moreover, a large-scale installation of wind and solar farms in the Sahara Desert was even projected to create a positive climate feedback through increased surface friction and reduced albedo, doubling precipitation over the neighbouring Sahel region with resulting increases in vegetation (Li et al., 2018). Renewable energy development can also create substantial employment generation opportunities in the Sahel region. In fact, many governments across Africa identify the renewable energy sector as the major action area for creating “green jobs”. This particularly concerns year-round employment generation for young people in the agricultural sector (Malabo-Montpellier Panel, 2019).

[4] https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html, accessed on 01.02.2020
[5] http://www.fao.org/faostat/en/, accessed on 01.02.2020

Figure 7: Solar power potential across the world and the Sahel region



Source: World Bank, ESMAP, Solargis, https://globalsolaratlas.info, accessed on 04.05.2020.

The expansion of decentralized mini-grid installations based on renewable energy sources could be a cost-effective solution for providing access to clean energy for remote communities. Despite this potential, current levels of use of clean renewable energy in the region are very low. The adoption of renewable energy-based technologies by people suffering from poverty is particularly low due to their limited financial resources. Indeed, wealthier households use more modern and cleaner appliances such as improved stoves for cooking needs. In contrast, poor and rural households use more biomass (wood and charcoal) to meet their cooking needs. Other factors include the lack of a financial framework to promote access to renewable energy, and the poor access to information on credit to access renewable energy (Faye et al., 2020: Senegal case study; Sylla et al., 2020: Burkina Faso case study; Ali and Mohamad, 2020: Sudan case study). As indicated earlier, insecurity in the region is one of the key development challenges hampering long-term planning and progress on essential development, including climate action.

In the recent past, there were also high hopes regarding the expansion of cultivation of energy crops for biofuels (e.g. jatropha). However, biofuel production in many countries of the region did not develop successfully because of the vulnerability to fluctuating oil prices as well as low yields of grains which have compromised the cost effectiveness of entire value chains (Mirzabaev et al., 2015).

5 Climate change

Climate change has become one of the major development challenges in the Sahel region. The effects of climate change are highly pronounced in the Sahelian countries due to their high vulnerability and low adaptive capacities. Even in terms of the exposure to climate change, the Sahel region has an inherently variable climate with long cyclical periods of wet and dry weather. In the past, a wet period was identified between 1940-1970 and a dry period between 1971-2000 (Lebel and Ali, 2009; Lodoun et al., 2013). Consequently, the 1970s and 1980s were marked as the now infamous drought episodes in the Sahel, which claimed the lives of millions of people through hunger and malnutrition (Mahoo et al., 2013).

In more recent years, most of the region has recorded precipitation recovery. However, these precipitation amounts are lower than during the previous wet period (Sylla et al., 2016). In addition, precipitation has intensified and led to extreme precipitation events frequently causing floods (Nka et al., 2015; Panthou et al., 2018; Tazen et al., 2018). The increase in surface flow despite the relative drop in precipitation (Mahé et al., 2005), called the 'Sahelian paradox', is a phenomenon that has been observed in many watersheds in the region (Sylla et al., 2020: Burkina Faso case study; Adamou et al., 2020: Niger case study). To illustrate, Burkina Faso experienced three flooding events per year during the period of 1986-2016, increasing to five flooding events per year since 2000 (Tazen et al., 2018). Flooding also contributed to soil erosion as well as to the loss of human and animal life. In Niger, flooding affected 1.7 million people between 1999 and 2015 (Fiorillo et al., 2018). These climatic changes caused crop yield and production losses of about 10–20% for millet and 5–15% for sorghum in West Africa (Sultan et al., 2019).

Even during the current relatively wet period across the Sahel, short-term drought spells are frequent. Rainfall is also increasingly becoming erratic compared to past long-term averages. In Ethiopia, rainy seasons are contracting, reducing the amount of seasonal rain available for crop production (Funk et al., 2012). Droughts, coupled with irregular and unreliable rainfall, have significant impacts on food security through their effects on crop yields and livestock productivity as well as their indirect effects on food prices, asset depletions, malnutrition and migration (Admassie and Abebaw, 2020: Ethiopia case study). Even today, drought, along with conflicts, remains a key driver of food insecurity across the Sahel region. Droughts are frequently accompanied by other hazards. For example, in 2009, the drought in Niger was compounded by locust infestation, leading to approximately 805 million USD of losses, which corresponded to 30% of the GDP of Niger (World Bank, 2017).

The vulnerability to climate change is also reflected in migration in West Africa. Water stress often leads to internal migration and conflict between farmers and pastoralists (Olayide, 2020: Niger case study). Conflicts constrain pastoralists' mobility and affect agricultural production and market access by disrupting supply routes. Droughts in Nigeria were shown to have triggered conflicts over the distribution of water and posed major challenges for water handling and management (Olayemi, 2016). Anyadike (2009) also reported that drought related conflicts resulted in the death of over 200,000 people and the displacement of more than two million people in Nigeria. In addition, recent scientific studies are pointing out several other related scenarios, including how climate change or climate variability and development challenges amplify the risks to a country's peacefulness by acting as a threat multiplier. These empirical findings suggest that climate change can induce adverse impact on resource availability (i.e. natural resources) and resource governance mechanisms, especially by exacerbating competition over resources (Diffenbaugh & Burke, 2019). Poverty and economic shocks, which are the main drivers of conflicts, are also climate change sensitive (Oppenheimer et al., 2015).

Projected climatic changes for the Sahel point at the intensification of warming all over the region and substantial increases in dry spell length and more frequent intense precipitation events (Sylla et al., 2016). In many northern sections of the Sahel, precipitation is projected to decrease, while some increases are projected for the southern parts of the Sahel. Droughts and floods are forecast to increase in intensity and frequency. Heatwaves and heat stress are projected to substantially increase

in future climates to reach dangerous risk levels for human health but also for agriculture and water resources (Russo et al., 2016; Sylla et al., 2018). As a consequence, substantial yield losses in maize, millet and sorghum are projected in 1.5°C and 2°C global warming scenarios even under higher fertilizer use (Faye et al., 2019). Tesfaye et al. (2015) showed that the number of food insecure people in Ethiopia alone could increase by up to 2.4 million people by 2050 as a result of the impact of climate change. The climate change effects on human health are manifested through climate-sensitive diseases, food and waterborne illnesses. The diarrheal disease rate is high across the Sahel region due to lack of improved sanitation facilities and related hygiene measures. Higher temperatures and elevated flood risks under climate change may enhance pathogen transmission and increase water-borne diseases (Mellor et al., 2016). In terms of water resources under future climates, projections reveal an increased risk of water deficit (10%-40% of decrease of water availability) in most river basins, and particularly in the Volta river basin (30%-60% of decrease) under 1.5°C and 2°C global warming scenarios (Sylla et al., 2018) and will amplify insecurity and competition in the region. Land fisheries are affected by increasing temperatures, more saline water and deoxygenation of lakes, harming fish reproduction, survivability, and virility.

6 Solutions: technologies, infrastructures, institutions and policies

There are a considerable number of technologies and practices that can be used for the sustainable intensification of agricultural productivity in the Sahel region. Major socioeconomic solutions, policy options, and sustainable land and water management technologies consistently highlighted in all of the case studies, are discussed below. A key aspect of these response options is their cross-cutting impacts affecting sustainable land management (SLM) and climate change adaptation simultaneously, often also with strong implications for energy supply and use. At the beginning of this paper, it was highlighted that SLM and climate change adaptation can serve as guiding frameworks for regional development, agricultural growth and employment creation in the Sahel. These response options discussed below embody concrete entry points of action to promote SLM, climate change adaptation and improved supply and access to energy.

6.1 Socio-economic, infrastructural and policy solutions

There are many socio-economic, institutional, and policy solutions, such as livelihood diversification, securing land tenure, improving access to credit and markets, community collective action, and infrastructure development, etc. that could promote SLM and facilitate climate change adaptation in dryland areas around the world, including in the Sahel region (Mirzabaev et al., 2019).

Access to markets, including input, output, and credit markets, was found to increase the income and consumption of households suffering from poverty (McDemott et al., 2015). In a similar vein, Grosh et al. (2008) highlighted the role of **social safety nets** in increasing the livelihoods of households, who in addition to suffering from poverty are exposed to climate shocks. Their study showed that income redistribution policies in favor of households suffering from poverty increase their investment capacity and enable them to cope with unexpected shocks. Particularly, well designed public works programs promote environmental conservation while at the same time creating jobs, improving infrastructure, and empowering people suffering from poverty, including women and youth (Sakketa and von Braun, 2019). According to Yang (2006), Yang and Choi (2007) and Arezki and Bruckner (2012), **remittances** provide private insurance against negative shocks for households in developing countries. Remittances complement households' income deficit when the domestic financial sector is inefficient (Admassie and Abebaw, 2020: Ethiopia case study) and also play an important role for intra-seasonal consumption smoothing (Adamou et al., 2020: Niger case study**). Improved access to crop and livestock insurance** could help smoothen risks and shocks from extreme weather events (Olayide, 2020: Nigeria case study).

Infrastructure development. Expanding access to energy in the Sahel region does not need to exclusively come from extending centralized electricity grids. The use of decentralized mini-grids, based on solar, wind and mini-hydropower could provide an alternative and viable option for providing access to electricity in remote rural areas of the region (Malabo-Montpellier, Panel 2019; Coulibaly, 2020: Mali case study). Policy options and instruments to facilitate the expansion of access to electricity and other sources of clean energy, such as biogas, which were successfully implemented in several countries in Africa are: setting energy sector development targets and providing targeted programmatic support to achieve those objectives (e.g. in Ethiopia), and the liberalization of the energy sector combined with incentives for private power producers (e.g. in Senegal) (Malabo-Montpellier Panel, 2019). Improving market access would require **investments into transportation infrastructures** (roads, railroads, ports, etc.). Such investments into transportation infrastructures may have significant multiplier effects for job creation, rural development and reducing poverty. Most of the countries of the Sahel are affected by economic water scarcity, despite sufficient physical availability of water resources. Hence, overcoming this economic water scarcity requires **investments**

into water infrastructures (not only for irrigation, but also for safe potable water access and sanitation in rural areas) (Sylla et al., 2020: Burkina Faso case study).

Promoting land tenure security. Land tenure insecurity is a major hindrance for investments into sustainable land management in the Sahel (e.g. Adamou et al., 2020: Niger case study). The Sahelian countries have diverse land tenure regimes with frequently overlapping or conflicting tenure rights. For example, in Senegal, access to land in rural areas is governed by the law on the National Domain (1964). Under this law, farmers are not owners of their land (Faye et al., 2020: Senegal case study). Nkonya et al. (2016) point out that when farmers do not own the land they cultivate; they have no incentive to safeguard its quality.

Off-farm job creation. Off-farm livelihood diversification strategies increase the resilience of rural households against land degradation and extreme weather events, such as droughts (Admassie and Abebaw, 2020: Ethiopia case study). Moreover, it can provide the funds to invest into SLM (Mirzabaev et al 2019). Access to non-agricultural employment is especially important for poorer pastoral households as their small herd sizes make them less resilient to droughts (Lybbert et al., 2004). Government action is needed to increase access to off-farm jobs especially for women and marginalized social groups who often lack education and social networks.

Collective action at the village level strengthens the resilience strategies of members and reduces their level of vulnerability (Diop et al., 2010; Diouf, 2014). The work of Diop et al. (2010) highlighted the various initiatives of local communities for the diversification of agricultural practices and sources of income. Thus, they have shown that collective action can facilitate crop diversification with the introduction of new crops. Community led actions in the region also include household drinking water supply (Sylla et al., 2020: Burkina Faso case study), building farm ponds for supplemental irrigation and livestock, crops diversification, development of soil and water conservation techniques (Coulibaly, 2020: Mali case study), cereal banks, delimitation and development of pastoral areas (e.g. see Admassie and Abebaw, 2020: Ethiopia case study), control of bush fires and uncontrolled logging; delimitation and monitoring of village forests (cf. the case studies). Resorting to the social capital embedded in centuries-old social, religious and cultural links between neighbouring countries (such as transhumant herders) in the region is also vital for both the sustainable use of natural resources and the restoring of peace in conflict zones. For instance, the populations from the border areas of Mali and Mauritania have maintained strong political, religious, economic and social ties (such as blood ties and marital alliances) which enabled both to utilize border areas for trade, and provided access to fodder and water for livestock herding by the nomadic Mauritanian herders on the Mali side. However, the outbreak of the Mali crisis has changed this situation making transhumant routes in the region more difficult. As a result, border trade has weakened and conflicts are occurring more frequently between the two countries (Bodian et al., 2020).

Carbon trading refers to the selling and buying of reductions in greenhouse gas emissions, called carbon credits (Gueye, 2019). The mechanism allows developed countries to buy emission reduction from developing countries or invest in emissions reduction projects in those countries (Gueye, 2019). It constitutes the main channel through which developing countries such as those in the Sahel region participate in the international carbon markets. Nevertheless, carbon trading approaches remain extremely underutilized in the region (Admassie and Abebaw, 2020: Ethiopia case study; Faye et al., 2020: Senegal case study). The cooperative approaches under Articles 6.2-6.3 of the Paris Agreement as well as the sustainable development mechanism under Articles 6.4-6.7 could be employed by the Sahelian countries for participating in the international carbon trading. The additional revenues earned could thus be spent for promoting sustainable development of the region (Faye et al., 2020: Senegal case study). However, this requires adjusting the national legislation and regulations in order to create adequate conditions for potential investors.

Promoting regional collaboration is needed to enhance broad-based solutions to ensure sustainable peace in the region. The drivers and consequences of conflicts in the region are complex and interconnected, which is why regional collaboration and innovative solutions are needed to address

these multifaceted challenges while balancing security and development priorities. This in turn depends on the strength of state institutions and governance structures, which are often weak in the region. Therefore, addressing the problems of structural governance is key in aligning and reorienting international interventions for development, jobs and food security. This would be effective by involving a variety of actors and sectors in meeting the needs and aligning with the priorities of local communities. This also suggests that addressing the insecurity in the region and advancing development outcomes require integrated development interventions and regional solutions in a coordinated manner among governments, international development partners and other actors. In addition, responses to climate change and land degradation restoration measures need to be "conflict-sensitive" and should not result in generating new tensions (Olayide, 2020: Nigeria case study).

6.2 Technological solutions

Expanding irrigation is an essential climate change and climate variability adaptation strategy to secure farmers' livelihoods and their food security in semi-arid zones of the Sahel region (van Wesenbeeck et al., 2014; Sanfo et al., 2017). The extent of irrigated areas in the region is expanding, but nevertheless remains limited. Irrigation extension potential is sensitive to irrigation costs and crop prices (Xie et al., 2014). The growth of irrigation investments needs to be considered in the wider context of productivity increases (Coulibaly, 2020: Mali case study), rural development (Xie et al., 2017), and urbanization (Barbier et al., 2011). Expanding irrigation in the Sahel region requires close collaboration between farmers, the private sector and governments, with support measures ranging from tax cuts for importing irrigation equipment and technologies to capacity building and extension for farmers (Malabo-Montpellier Panel, 2018a; Admassie and Abebaw, 2020: Ethiopia case study). Needless to say, regulations for water use in agriculture are needed to avoid negative ecological consequences, such as overuse of water (Malabo-Montpellier Panel, 2018a). Surface irrigation is the most widespread form of irrigation in the region, with low but slowly growing levels of more water-efficient irrigation applications such as sprinkle and drip irrigation. Sprinkler and drip irrigation are more water-efficient and also frequently lead to higher crop yields than surface irrigation (Diouf et al., 2018). Key barriers for wider adoption of sprinkler and drip irrigation technologies are high upfront costs, skill requirements and in certain locations low water quality. Often, irrigation is made possible in the Sahel by **rainwater harvesting** in impluviums, ponds, sand dams, micro-catchments, and underground tanks (Fox et al., 2005; Sanfo et al., 2017; Adamou et al., 2020: Niger case study). Depending on topography, the main techniques of rainwater harvesting are: trays arrangement (Half-moons, Nardi Trenches, Benches), slope arrangement (Manual trenches, Filtering dykes), landscaping of glacis (Stony cords, Filtering dykes, Zaï), and development of the lowlands (Thresholds for water spreading, Micro-dams) (Sylla et al., 2020: Burkina Faso case study). **Sustainable use of groundwaters for irrigation** is a hitherto under-tapped source for irrigation expansion in the Sahel. For improved synergies, groundwater use for irrigation can be combined with the deployment of solar panels which could provide electricity for both groundwater pumping and for other rural household and business needs (Faye et al., 2020: Senegal case study).

Crop diversification is a wide-spread strategy used by smallholder farmers to mitigate agricultural risks at farm level (Sylla et al., 2020: Burkina Faso case study; Admassie and Abebaw, 2020: Ethiopia case study). Poverty and lack of financial resources often prevent Sahelian farmers from subscribing to crop insurance schemes. To cope with climate hazards, farmers have developed various crop diversification strategies (Lawin and Tamini, 2017), such as intercropping, catch crops, relay cropping, diversified crop rotations and improved fallow (Pereira, 2017; Tittonell and Giller, 2013). Catch cropping consist of the cultivation between two main annual crops while relay cropping consists of growing two crops of different species on the same plot, the second crop being planted just before the harvest of the first crop. Crop diversification is often combined with expanding irrigation, allowing to grow vegetables, irrigated rice and other commercial crops (Faye et al., 2020: Senegal case study). Mono-cropping of cotton practiced in several countries in the region is falling short of enhancing the well-being of smallholder farmers (Coulibali, 2020: Mali case study). In addition, mono-cropping's contribution to

rural livelihoods is hampered by high per unit costs of production (FAO, 2014; Gautam and Andersen, 2016). The poor access to agricultural inputs, credit and equipment are important obstacles to crop diversification in those countries with strong mono-cropping legacies, such as Mali. Mono-cropping results in soil degradation and causes declines in production of the main cash and food crops (cotton, maize, millet, sorghum) and livestock (Sylla et al., 2020: Burkina Faso case study). The outcomes are often lower income, food insecurity and poverty among smallholder farmers and herders.

Agricultural mechanization has important potential to increase output and improve agricultural incomes and thus contribute to sustainable economic growth and transformation (Malabo-Montpellier, Panel 2018b). Its relationship with land degradation and agricultural mechanization is complex. On the one hand, the use of heavy agricultural machinery can lead to soil compaction. Excessive tillage, particularly in such dryland environments, often results in soil erosion. On the other hand, improved agricultural productivity and profitability can allow to invest more funds in sustainable land management measures. Currently, access to agricultural machinery in the Sahel remains very low. Less than 5% of the households in the region have access to tractors, while the major types of farm implements remain light tools such as cutlasses, hoes, and axes. Moreover, not all farming households use farm animal power (Kirui, 2019). Although individual ownership of agricultural machinery is currently prevalent across the Sahel countries, mainly among large-scale farmers, there are important opportunities in developing leasing services and setting up rural business for providing mechanization services (ploughing, land levelling). The potential for mechanization is not just limited to tractors (Malabo-Montpellier Panel, 2018b). Entire agricultural value chains across the Sahel region will benefit from mechanization, with more emphasis on post-harvest and processing technologies helping to reduce significant shares of food loss occurring due to a lack of processing and post-harvest management (Malabo-Montpellier Panel, 2018b). Thus, mechanization of the food sector in the Sahel can be a source of job creation and not necessarily come at the cost of job losses. The impact of agricultural mechanization also varies depending on the local context. Higher agricultural mechanization rates were associated with higher agricultural growth rates in Ethiopia, Mali, and Niger, while they did not lead to higher agricultural growth in Burkina Faso, Senegal, and Sudan (Malabo-Montpellier Panel, 2018b).

Adoption of drought resistant crop cultivars is another climate change adaptation strategy with low but slowly increasing adoption rates in the region. Research and crop breeding organizations across the Sahelian countries regularly churn out an impressive array of drought-resistant and early maturing varieties of crop cultivars. However, many factors such as a lack of farmer participation in breeding, high costs, and elevated demands for fertilizers are impeding wider adoption of drought-resistant varieties in many areas in the Sahel (Adamou et al., 2020: Niger case study).

Conservation agriculture involving minimum tillage, maintenance of crop residues and appropriate crop rotations is a drought-smart sustainable land management (D-SLM) technology with important potential in the region. Competition with livestock feeding for crop residues, a lack of direct seeding machinery, and also a lack of knowledge about conservation agriculture benefits are major obstacles for the adoption of conservation agriculture practices. In many other settings across the world, a key advantage of conservation agriculture were fuel savings. Low levels of mechanization in the region often make conservation agriculture a profitable proposition mostly for large-scale farms. Moreover, weed management requirements under conservation agriculture relying on chemical herbicides further limit the immediate spread of this technology in the region. Still, in some parts of the region, e.g. Burkina Faso, farmers have a long history of practicing conservation agriculture-based technologies under rainfed conditions (e.g. reduced tillage, soil cover by crops or residues, crop diversification) (Sop et al., 2012; Zougmoré et al., 2000: Sylla et al., 2020: Burkina Faso case study). Kassie et al. (2009) have shown that the adoption of conservation agriculture practices increased crop productivity in Tigray, Ethiopia (Admassie and Abebaw, 2020: Ethiopia case study). Despite its economic and environmental benefits, the number of analyses of farmer-level costs and benefits of conservation agriculture in the Sahel region is still limited.

Agroforestry is the integration of trees in agriculture systems (Bayala et al., 2002). It is an approach that aims to achieve high levels of productivity by harnessing ecosystem services provided by trees (Kuyah et al., 2019), while at the same time contributing to climate change adaptation and mitigation. Agroforestry is one of the examples of technologies that have been successfully used for soil and water conservation across the Sahel region. It can improve yield depending on the tree species (Sawadogo, 2011). In the northern part of Burkina Faso, farmers manage (protect and regenerate) trees on their farms as a source of food, fuelwood and traditional medicine (Sawadogo et al., 2001). Trees in agroforestry parklands enhance soil fertility as greater yields have been observed around trees like *Faidherbia albida*. As a form of agroforestry, defensive living hedges are used to fight against cattle wandering and human incursions into fields and market gardens but also to delimit plots to avoid land conflicts (Sylla et al., 2020: Burkina Faso case study). Assisted natural regeneration initiatives were promoted in many countries in the Sahel with mixed results. Although preserved trees play important roles in agricultural systems, they can also exert a competition for growth resources on associated staple food crops in the Sahelian zone where the quality of soils is poor and rainfall is low. Studies have been conducted on the interactions between the agroforestry of fruit trees and crops in Burkina Faso. For instance, studies by Bayala et al. (2002) in the country showed that under the canopies of Shea butter tree (*Vitellaria paradoxa*) and African locust bean (*Parkia biglobosa*) the productivity of local sorghum (in terms of grain yield) was reduced by 50 to 70%, respectively, compared to the farms where there were no trees. This result indicates that the practice of agroforestry can have a negative effect on the productivity of some crops depending on the tree species and their management.

Rotational grazing in rangelands contributes to their sustainable use and helps to avoid overgrazing. According to Kagone (2001), the use of rotational grazing could increase the carrying capacity during the rainy season maintaining a high quality of re-growths. Rotational grazing is also practiced through distant transhumant pastoralism in the region, but often only when nearby pastures are already overgrazed (Olayide, 2020: Nigeria case study). However, tensions are becoming more frequent due to an imbalance between agricultural and pastoral areas, semi-subsistence livestock raising and larger-scale commercial livestock fattening operations, and often result in deadly conflicts. Other practices for sustainable rangeland and livestock management include the **supplementary feeding of breeding ewes, mineral supplementation, lamb and kid fattening and the seeding of pastures with forage legumes and grasses to improve their botanical composition and condition.**

Addressing invasive bush encroachment involves actions that help prevent the encroachment of invasive tree and shrub species in savannas, which suppress palatable plant species (e.g herbaceous plants) (Ward, 2005). Bush encroachment control consists of shifting plant communities dominated by trees species (e.g. woodland, tree savanna) by herbaceous vegetation to create a favorable habitat for grazers (Angassa and Oba, 2008). In the savanna ecosystems of Burkina Faso, different bush control methods such as hand removal of trees, use of fire (Zida et al., 2007), tree harvesting coupled with fire and grazing (Sawadogo et al., 2005, 2002), and fire combined with grazing (Sawadogo et al., 2005) are often used to increase the production of herbaceous species and their diversity. Several other bush encroachment control techniques were also identified, such as tree cutting, staining and uprooting (MEECC, 2014).

Afforestation and reforestation activities are not new in the Sahel region, but in fact were carried out at various scales since the 1930s. If in the past, afforestation and reforestation actions were primarily done through government forestry departments. Over time they have become increasingly caried out in a more "participatory" way involving local communities. For this reason, the Sahelian countries have designed a large number of policies and strategies, particularly the African Union (AU) strategy on the Great Green Wall (GGW), to address land degradation, enhance agricultural productivity, and adapt to the changing climate. The GGW is a colossal flagship effort that aims to restore degraded ecosystems by planting locally suitable native trees and grasses stretching coast to coast across the Sahel. The total length of the GGW was estimated to reach 8,000 km from West Africa to the Horn of Africa and the planned width varies between 100 and 200 km. Originally a tree planting initiative, the program has

evolved into Africa's response to climate change and a broader development programming tool (Sacande, 2008).

6.3 Evaluation of existing major policies and investments

The Sahelian countries have a wind range of national programs and policies aimed at increasing agricultural growth and environmental sustainability in order to achieve the SDGs (cf. all the case studies indicated in Box 1). Some of these national strategies are outcomes of international processes and are hence applied in all countries of the region. This specifically concerns national climate change adaptation plans (NAP), the Intended Nationally Determined Contribution to climate change mitigation (INDC), and action programs to combat desertification and safeguard biodiversity, i.e. under the three so called Rio Conventions of the United Nations. Moreover, the Comprehensives Africa Agriculture Development Program (CAADP) under the auspices of the African Union is another initiative adhered to and applied by all countries of the region, which commits the individual countries to increasing government spending on agriculture to match 10% of their GDP by 2020. Most countries of the region also have poverty reduction strategies to guide their national activities and their collaboration with the World Bank and International Monetary Fund. National drought preparedness policies are also found in most countries of the region and frequently frame the countries' collaborations with UNCCD and WMO.

Each country also has more specific sectoral strategies, particularly on agriculture (crop and livestock), energy, and forestry. The major purpose of the national policies in the agricultural sector is to enhance production, productivity and competitiveness of food and cash crops. This often involves providing access to markets, agricultural services and inputs, improving value chains and post-harvest processing, as well as capacity building and development (cf. all the case studies indicated in Box 1). To illustrate, the Agricultural Growth Program in Ethiopia pursues strategies to raise agricultural productivity and production by enhancing market performance and aiding value addition. The implementation of the two phases of this program in Ethiopia highlighted the key role played by the activities on linking farmers to markets and farmer training centers. At the same time, the program faced considerable challenges in terms of poor quality of market infrastructures and a lack of locally suited agricultural technologies (Admassie and Abebaw, 2020: Ethiopia case study). Similarly, Burkina Faso's National Program for Land Management had the objective of reducing poverty and boosting agricultural growth through sustainable land and water management. However, the success of this program was considerably limited due to difficulties related to resolving issues of land tenure insecurity (Sylla et al., 2020: Burkina Faso).

There are several cross-cutting lessons coming from the diverse experiences of policy formulation and implementation in the Sahel. For country after country, the lack of access to credit and capital is emerging as one of the key hindrances to agricultural development in the region. Agricultural development programs require increased and more effective public and private partnerships as well as the active participation of a wide range of stakeholders. Lack of engagement of all relevant stakeholders early on in the designing process of many programs was found to be a limiting factor in the implementation of many programs in the region, for example the Climate Resilient Green Economy Strategy in Ethiopia (Admassie and Abebaw, 2020: Ethiopia case study). To be successful, these programs need to be conceived and driven by stakeholder interactions. The predominance of national funding for the core elements of these programs is critical for their sustainability. Currently, many national strategies are underfunded and lack in implementation. Often, this is an outcome of over-ambitious planning which is intrinsically linked to a high reliance on uncertain development funding by the international community.

Many conflicts across the region are also hindering the successful implementation of these programs and preventing long-term investments into rural development. Addressing these conflicts and their root causes is a critical element for the success of development policies (e.g. see Olayide, 2020: Nigeria case study). There are many interconnections, i.e. synergies and trade-offs, between policies on

climate change, land, water and energy. Available synergies across these sectors need to be used to reduce investment costs. Lower investment costs will increase the chances of successful implementation of the programs. Many national policies set out with hugely ambitious scopes and timelines. Often, they fail to achieve their purposes because the intended funding for these programs does not fully materialize (e.g. see Faye et al., 2020: Senegal case study). A lack of monitoring and evaluation systems was suggested to be a major hindrance to the full implementation of the Niger's Socio-economic Development Policy (2012-2015). Finally, improving political stability, investing in monitoring and evaluation, and increasing government effectiveness are found to be other prerequisites for improving policy implementation in the region (cf. all the case studies indicated in Box 1).

7 Conclusions

Climate variability and change, land degradation, lack of access to energy, instability and associated challenges continue to hinder sustainable development in the Sahel region, including efforts to reduce poverty and ensure food security. Thus, most immediate action needs to involve measures to address conflicts and enhance drought preparedness and resilience. Efforts to address development challenges such as climate change and land degradation need to be "conflict-sensitive" and should not result in generating new tensions. There is a need for locally driven recommendations which provide a basis for engaging in evidence-based actions for SLM, climate change adaptation, peace and development in the region. This includes promoting numerous regionally tested climate change adaptation and SLM technologies and practices, creating enabling institutional and policy environments for their adoption, as well as making use of indigenous conflict resolution mechanisms and supporting the participation of women and youth in key economic activities. SLM, climate change adaptation, and renewable energy expansion are the highest return areas for investments toward achieving SDGs. Investments into soft and hard infrastructures can provide substantial multiplicative effects for job creation and economic growth in the region. Improving policy formulation and implementation can be achieved by setting achievable objectives with guaranteed (mostly own) funding and accompanying the policy implementation with strong monitoring and evaluation. It is important not to lose sight of these critical issues for regional development in the post-COVID world, since investments into these areas may be undermined by the COVID-19 pandemic, as resources and priorities may be shifted away from these crucial development arenas in the Sahel region.

8 Agenda for applied research

The national case studies, regional cross-cutting analysis and stakeholder consultations during the virtual workshop highlighted that for attaining **the overall goal of prosperous, food and nutrition secure and peaceful Sahel**, policy and action-oriented research is needed on the **following specific objectives**:

1) Identifying and harnessing the synergies across the land-water-energy-food security nexus in order to promote agricultural growth, rural development and job creation, particularly for youth and women;

2) Accelerating climate change adaptation and building resilience against extreme weather events, particularly droughts. Developing mechanisms for the use of climate change mitigation measures to generate revenues through tapping into international carbon trading;

3) Examining how conflict risks are affected and exacerbated by human and environmental stressors (and vice-versa) and understanding the strengths and weaknesses of the current, including indigenous, conflict resolution mechanisms;

4) Exploring the impacts of investing into soft and hard infrastructures on economic growth and employment generation;

5) Improving policy formulation, monitoring and implementation.

Realizing these objectives requires investments into accompanying research and technical support, as well as into improving human and institutional capacities in the region. There are five key strategic areas where development investments could generate substantial multiplicative effects and high returns for achieving the objectives stated above. These areas and the more specific actions they include are summarized below in the form of five work packages.

Work package 1. Harnessing the synergies of the land-water-energy-food nexus

1.1. Assessment of synergies and trade-offs across the land-water-energy-food nexus in the Sahel region for agricultural intensification and rural development;

1.2. Integrated water-land-energy use modelling for optimal spatial allocation of investments in sustainable agricultural intensification;

1.3. Evaluation of decentralized energy solutions and centralized grid access for post-harvest processing and rural employment;

1.4. Spatially explicit modelling of land restoration impacts on sustainable development and their distributional effects on different socio-economic groups;

1.5. Analysis of the impacts of improved adoption of agricultural innovations, including potential trade-offs, synergies and impacts on agricultural labor markets, poverty reduction and food security.

Work package 2. Climate change adaptation and carbon trading

2.1. Analysis of observed impacts of climate change and extreme weather events and assessment of their economic and social costs in the Sahel region;

2.2. Creation of a toolbox of climate-smart technological, institutional and policy solutions;

2.3. Foresight modelling of future climate risks as an interaction of hazards, exposure and vulnerability in the Sahel;

2.4. Investments into drought risk mitigation: Modelling of drought risk reduction and adaptation using the options from the solutions toolbox under 2.2.;

2.5. Elaboration of effective mechanisms for carbon trading through land restoration and rehabilitation activities.

Work package 3. Conflicts and insecurity

3.1. Collate data on ecological, economic and political stresses on peace in the Sahel region;

3.2. Analyse drivers and impacts of conflicts in the Sahel region;

3.3. Analyse the strengths and weaknesses of the current, including indigenous, conflict resolution mechanisms;

3.4. Test alternative conflict resolution mechanisms through field experiments and focus group discussions.

Work package 4. Generating jobs and green growth by investing in soft and hard infrastructures

4.1. Ex post and ex ante assessments of the impact of infrastructural investments on economic growth and job creation in the Sahel region:

- Soft infrastructure (vocational training, health care, and other public services),
- Hard infrastructure (roads, railways, mobile phone and internet networks);

4.2. Support the design of national schemes to strengthen the symbiotic linkages between rural areas and secondary towns through investments into infrastructure and public services. Secondary towns are increasing rapidly in the region and represent a considerable potential for local employment to the rural youth.

Work package 5. Enhancing policy implementation

5.1. Policy implementation research: evaluating barriers and opportunities for enhancing policy formulation, implementation and monitoring;

5.2. Development of effective analytical and monitoring tools that countries can use for improved policy implementation.

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