MALABO MONTPELLIER PANEL

WATER-WISE

Smart Irrigation Strategies for Africa

A Malabo Montpellier Panel Report

2018

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Foreword

Africa is seeing a surge of interest in irrigation among small-scale farmers as climate change brings more erratic weather. At the same time, a growing population across the continent demands more reliable and continuous supply of food. Elevating irrigation to a top policy priority and bringing irrigation to scale could help ensure the continent's food security in the face of more extreme weather conditions and be an engine of agricultural transformation. Expanding and upgrading irrigation systems – of all types – requires successful partnerships between farmers, governments and the private sector. It will require tax cuts on imported technologies and machines; support for the build-up of an African irrigation technology industry; training of farmers on how to operate irrigation systems; and regulation governing the use of water in agriculture guided by long term cost and benefit considerations, that also take ecological aspects into account. A most important aspect for innovation in irrigation is institutional arrangements including cooperation approaches, not just technical innovations.

Significant lessons can be drawn from interventions in several African countries. The current report – *Water-Wise: Smart Irrigation Strategies for Africa* – summarizes the key findings of a systematic analysis of what six African countries at the forefront of progress on irrigation have done right. It analyzes which institutional and policy innovations were implemented to increase irrigation uptake. Several of these can be brought to scale across the continent to help governments meet the targets and goals under the African Union Agenda 2063 and the Malabo Declaration.

The objective of this report is to identify interventions that work and recommend options for policy and program innovation that allow countries to upgrade or expand current irrigation systems. This strategy should be as diverse as are African countries and agro-ecologies. It may be small-scale and farmer-led or large-scale irrigation systems supported by governments and the private sector. Crucially, any irrigation systems and technologies ought to be designed to fit local environments, and meet the needs of smallholder farmers, while being environmentally sustainable and preserving the natural resource base upon which agriculture depends.

The Malabo Montpellier Panel convenes 17 leading experts in agriculture, ecology, nutrition and food security to guide policy choices by African governments to accelerate progress toward food security and improved nutrition in Africa. The Panel identifies areas of progress and positive change across the continent and assesses what successful countries have done differently. It then identifies the most important institutional innovations and policy and program interventions that can be replicated and scaled up by other countries. The related Malabo Montpellier Forum provides a platform to promote policy innovation by using the evidence produced by the Panel to facilitate dialogue and exchange among high-level decision-makers on African agriculture, nutrition and food security.

Ousmane Badiane

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Co-Chairs, Malabo Montpellier Panel

THE MALABO MONTPELLIER PANEL

The core mission of the Malabo Montpellier Panel, a group of leading African and international experts from the fields of agriculture, ecology, food security, nutrition, public policy and global development, is to support evidence-based dialogue among policy makers at the highest level. The Panel's reports seek to inform and guide policy choices to accelerate progress toward the ambitious goals of the African Union Commission's Agenda 2063, the Malabo Declaration and the global development agenda. The Panel works with African governments and civil society organizations to provide support and evidence-based research that facilitate the identification and implementation of policies that enhance agriculture, food security and nutrition.

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Introduction

Considerable progress has been made across Africa to increase agricultural productivity, reduce poverty, create new employment opportunities, and improve livelihoods. Yet population growth, demographic change, urbanization, and climate change mean that pressure on agricultural systems to make more food available and accessible is growing rapidly.

In many countries across the continent, rainfall is highly variable or insufficient. Yet food production continues to be almost exclusively rain-fed. Where there is only one growing season, farmers are thus more vulnerable to erratic rainfall patterns and droughts, resulting in low yields and incomes. Currently, only 6 percent of arable land in Africa is irrigated[1] and on average the area equipped for irrigation grew by just 1.5 percent between 1990 and 2015.[2] Nevertheless, the potential to increase irrigation is high, in particular in countries south of the Sahara (SSA).[3]

Expanding countries' irrigation potential can improve agricultural productivity on existing land and extend growing seasons throughout the year, which would reduce poverty, food insecurity, and import dependency across the continent. However, expanding and upgrading irrigation systems will require individual and collective action by governments, the private sector, and communities in rural and urban areas.

Fortunately, key lessons can be drawn from successful interventions in several African countries that can be adopted and brought to scale across the continent. This report identifies what these countries have done right, why and how to 'move the needle' in the area of irrigation. In particular, it identifies the most important institutional innovations as well as policy and program interventions that can be replicated and scaled up by other countries to develop and expand irrigation systems.

The report begins with an overview of the challenges on agricultural systems to make more food available and accessible and lays out the potential of irrigation to make agriculture more productive, efficient and profitable for smallholder farmers. A discussion on the potential to expand irrigation across Africa and barriers to uptake including an analysis of the inherent risks and desired outcomes of irrigation forms the next section. The report reviews the traditional and new, innovative small-scale and large-scale irrigation approaches and technologies that have been implemented in Africa, followed by an analysis of the experiences of six African countries that have been particularly innovative and successful in terms of their institutional and policy design for irrigation. The report closes by drawing some key lessons and offering nine recommendations for actions by African governments and the private sector.

Drip irrigation on a vegetable field, Kenya

1. The Challenges

Meeting the increasing demand for food, water and energy as a result of population growth, demographic change, and urbanization is creating pressure on agricultural systems to make more food available and accessible, as well as to produce more diverse and nutritious foods. Agriculture and smallholder farmers are central to this, perhaps nowhere more so than in Africa. This has led to a rapid increase in public sector investments in agriculture by many African countries. While much progress has been made in reducing hunger and improving livelihoods over the last two decades, the pace of growth needs to be accelerated and the reach broadened to bring the high rates of poverty and vulnerability to acceptable levels. Failure to do so will raise pressure on global food supplies and prices and thereby increase the cost of meeting food demand for African countries, in particular for the poor and vulnerable in rural and urban areas.

Any future growth and poverty reduction agenda will require a combination of several interventions, including investment in the technological, policy and institutional innovations required to further accelerate agricultural production. Unlocking Africa's irrigation potential has to be a crucial component of strategies to improving farmers' resilience and livelihoods, and of meeting broader national and international food security and nutrition targets.

BOX 1: Definition of irrigation

Irrigation is the artificial application of water to land for the purpose of agricultural production, where water is either unavailable or insufficiently available. Most water used for irrigation comes directly from a natural water body, including rivers, creeks, lakes, or groundwater, or other water stores, such as dams and rainwater harvesting tools. The water is then transferred to agricultural land, either using gravity diversion methods (for example, through canals or floodwater spreading) or human-powered technologies such as rope-and-bucket or watering cans, or more complex and sophisticated technologies including boreholes, pipes, sprinklers, liquid-fuel engine-driven systems, and solar-powered pumps.[4,5]

Irrigation development can make good business sense: yields from irrigated crops are twice or more in comparison to rain-fed yields on the continent,[6] and under climate change, the benefits of expanding areas under irrigation are estimated to be twice as high as the costs.[7] Furthermore, in the semi-arid and arid regions of Africa, such as the Sahel and the Horn of Africa, rain-fed agriculture means that farmers can work productively only during the short rainy season(s). Access to irrigation can allow farmers to extend the growing season(s) and thus diversify activities, increase productivity levels and incomes. Irrigation can also be an important coping mechanism against the adverse impacts of climate change and can strengthen farmers' resilience in the face of increasingly frequent and extreme weather events.

A mere 6 percent of cultivated land is currently irrigated in Africa, compared to 14 and 37 percent in Latin America and Asia respectively.

However, despite highly variable and, in many countries, insufficient rainfall, food production in Africa continues to be almost exclusively rain-fed, resulting in lower than average yields compared to other developing regions. A mere 6 percent of cultivated land is currently irrigated in Africa,[8,9] compared to 14 and 37 percent in Latin America and Asia respectively. Of this 6 percent, more than two-thirds is concentrated in just five countries—Egypt, Algeria, Morocco, South Africa and Sudan—each of which have more than a million hectares of irrigated land.[10,11]

Fortunately, the potential to increase irrigation in Africa is high, at 47 million hectares.[i] Considering both land and water resources, much of the increase would take place in SSA, where irrigated land could be expanded to 38 million hectares, up from the current 7.7 million.[12]

Importantly, irrigation can have multiple benefits that help to improve the livelihoods and increase the resilience of smallholder farmers and their communities:

- Longer and more growing seasons, providing year-round incomes
- Greater diversity in available crops
- Potential to diversify into livestock and other non-crop activities
- Healthier diets and improved nutrition outcomes
- Higher incomes derived from market sales
- Employment generation in rural areas, particularly in the lean season
- Improved water supply, sanitation, and hygiene
- For women, more opportunities for asset ownership and greater control over resources and time[13]

i Based on FAO Aquastat most recent data for all 54 African countries (no data available for South Africa and Cape Verde). Accessed 15 November 2018.

Fortunately, the potential to increase irrigation in Africa is high, at 47 million hectares. Considering both land and water resources, much of the increase would take place in SSA, where irrigated land could be expanded to 38 million hectares, up from the current 7.7 million.

Yet, there are also costs and risks involved, including social, economic and environmental consequences that need to be taken into account when considering the design or upgrade of irrigation schemes. Any planned irrigation expansion should consider the alternative of investing in rain-fed agriculture. For example, in countries that experience high levels of water stress and already have vast irrigation schemes, further irrigation expansion may not be the answer. Instead, key objectives could include improving water resource management and a focus on water conservation and efficiency.

One strategy for realizing the potential of irrigation is to replicate and scale up interventions that have been successful in African countries. Doing so in a critical mass of countries across the continent could help meet the targets and goals of the African Union Agenda 2063 and the Malabo Declaration. Developing these smart irrigation strategies for Africa will require individual and collective action by governments, the private sector, and communities in rural and urban areas. Irrigation can be a vital investment for improving the livelihoods of smallholders, spurring agricultural growth, and strengthening national economies.

Irrigation investments need to accelerate in Africa. By meeting the need for expanded agricultural production, and by drawing on strengthened capacities as well as promising technologies that facilitate decentralized water-saving approaches, these investments will be attractive to farmers, businesses, and governments.

Farmer holding pumpkin seeds, Malawi

2. The Action Agenda

As this report shows, key lessons and recommendations can be drawn from several African countries that have successfully increased irrigation uptake. By adapting these lessons to countries' specific contexts and scaling them up across the continent, African governments can meet their national and international commitments. The Malabo Montpellier Panel recommends that governments establish a clear policy and regulatory environment, supported by public investments, to catalyze and facilitate private sector engagement and innovation in irrigation. In turn, the private sector could work with national and local governments and research institutions to develop locally suitable technologies, along with finance arrangements to ease access to irrigation equipment for smallholder farmers. The present report has identified the set of policies and practices summarized below that, if brought to scale, could significantly improve the resilience and livelihoods of rural communities and spur overall agricultural growth and transformation in Africa.

GOVERNMENT ACTIONS

ELEVATE IRRIGATION TO A TOP POLICY PRIORITY

1

To meet the targets on irrigation set out in the Malabo Declaration and the Sustainable Development Goals, irrigation needs to be elevated to a top policy and long-term investment priority. Currently, fewer than 10 African countries have dedicated Ministries of Water and Irrigation. By creating Ministries of Water and Irrigation and Departments of Water and Irrigation situated within Ministries of Agriculture, a focused and holistic approach to water management in agriculture and irrigation can be ensured and mainstreamed into agricultural policy making and broader rural development efforts. This needs to be coupled with considerable long-term public investments to expand and upgrade small and large-scale irrigation systems.

SMART REGULATIONS

2

Regulation governing the access to, and use of water and land in agriculture is essential to improving the economic efficiency and environmental effectiveness of irrigation practices and preventing resource depletion and degradation. Smart regulations for water use, including pricing structures that help to secure and save water resources, can be coupled with incentives to promote the dissemination of technologies for the use of treated waste water.

3

To minimize the potential risks of irrigation to human health, including higher rates of waterborne disease and contaminated potable water, regulation governing the regular maintenance of irrigation infrastructure and the use of fertilizers in irrigation systems is needed. Regulation needs to be complemented with significant ongoing investments in the maintenance and repair of irrigation and drainage systems.

PRIVATE SECTOR ACTIONS

INVESTMENT IN SUPPORTIVE INFRASTRUCTURE

4

Increased investments need to be made by the private sector to build and improve distribution networks for irrigation equipment as well as to enhance repair and maintenance facilities. This infrastructure is needed for smallholder farmers in remote areas to be able to harness the opportunities of new irrigation tools and technologies.

INNOVATIVE TECHNOLOGIES

5

The private sector has a crucial role to play in the design, development and dissemination of innovative, smart technologies for irrigation that are locally adapted and improve smallholder farmers' productivity and livelihoods. These technologies could be large-scale, small-scale, or farmer-led innovations that are low-cost.

JOINT ACTIONS

PUBLIC–PRIVATE PARTNERSHIPS (PPPs) AND COOPERATION

6

The strengths of the public and private sectors can complement each other in providing information and advisory services that address the irrigation needs of farmers and rural communities. To take irrigation to scale through effective public–private partnerships, financial securities, smart subsidies, or tax waivers need to be put in place as incentives for the private sector to engage with smallholders. Public-private partnerships can also facilitate the development of locally adapted technologies for the benefit of smallholder farmers and the acquisition at scale of such technologies.

7

Irrigation requires collective action in most circumstances. Incentives for collective action need to be provided, as well as policies for conflict resolution mechanisms at local level.

SKILL DEVELOPMENT AND TRAINING

8

Increased investment in institutional and physical infrastructure for skill development and upgrading is critical. Skills are required to operate, maintain, and repair some of the more advanced and sophisticated irrigation technologies and systems. Without the right set of skills, misuse and mismanagement of machinery can result in water and yield losses and severely hinder the continued use of modern irrigation technologies.

ACCESS TO FINANCE

9

The acquisition of new irrigation systems and equipment by smallholder farmers, including women and youth, requires a supportive fiscal regime where barriers to accessing finance for equipment and services are removed and access to micro-credits and leasing arrangements for irrigation equipment is facilitated. This can be done by lowering sales taxes and minimizing barriers such as import duties on irrigation systems, spare parts, and raw materials for local manufacturing.

3. Current Irrigation Uptake and Potential

Current irrigation uptake

At 1,045 mm per year, Africa receives slightly less precipitation than the global average, and its 6,273 m^3 of internal renewable water resources per capita are similarly just below the global average.[14] However, these values mask huge variability in water availability across the continent. Cameroon, the Central African Republic, Congo, the Democratic Republic of the Congo (DRC), Gabon and Madagascar have the highest water resources per capita per year, ranging from 14,300–205,788 m^3. In contrast, in Libya, Algeria, Djibouti, Tunisia and Egypt, water resources amount to only 110–1,030 m^3 per capita per year.[ii, 15]

At 83 percent, small-scale, farmer-led irrigation systems make up the largest share of irrigated land in many countries in SSA.

Rain-fed agriculture is a risky business for smallholder farmers, especially in areas with high rainfall variability. Yet, irrigated area, as a share of total cultivated area, is currently estimated at a mere 6 percent of arable land in Africa, compared to 37 percent in Asia and 14 percent in Latin America.[16] On average, between 1990 and 2015, the area equipped for irrigation in Africa grew by just 1.5 percent annually, although in some countries, including Zambia, Tanzania and Ghana, irrigation capacity expanded faster.[17] Furthermore, irrigation capacity is unequally distributed across the continent, with 75 percent located in Africa's drylands.[18]

At 83 percent, small-scale, farmer-led irrigation systems make up the largest share of irrigated land in many countries in SSA.[19] South Africa is the one exception, with small-scale irrigation schemes covering less than 50,000 hectares of the 1.3 million hectares under irrigation in 2010.[23]

The potential for irrigation uptake

Under rain-fed farming systems, water productivity – the amount of crop produced per drop of water – tends to be low, as losses from evaporation are high. Rain-fed farming systems also allow just one growing season for smallholder farmers in many African countries, with limited opportunities for productive on- and off-farm employment during the rest of the year. Yet, African countries produce 38 percent of their crops (by value) under irrigation, while 62 percent are rain-fed.[24] Increased levels of irrigation could therefore help to improve agricultural productivity on existing land and extend the productive season throughout the year.[25] Irrigation can also allow farmers to diversify production, with the potential to raise incomes and expand access to, and consumption of, more nutrient-rich crops among farm households.[26] For example, in Senegal, smallholders use flood recession and small-scale irrigation techniques to grow vegetables on plots averaging just 0.2 hectares.[27]

Across the continent there is a high potential to increase the area of land under irrigation.[iii] In 2012, the DRC had the largest irrigation potential with 7 million hectares, followed by Angola and Mozambique with 4 and 3 million hectares each.[28] Although North Africa has almost exhausted its irrigation potential, expansion potential in SSA is significant.[29] Depending on the technology used, the expansion potential for smallholder irrigation is estimated at 30 million hectares for motor pumps, 24 million hectares for treadle pumps, 22 million hectares for small reservoirs, and 20 million hectares

BOX 2: Definitions of irrigation

Small-scale irrigation systems are irrigation initiatives led by smallholders who own and manage an individual plot of land or are part of a community-managed irrigation scheme. Small-scale irrigation therefore includes a variety of irrigation activities, ranging from motor and treadle pumps and surface water diversion to irrigation schemes of several hundred hectares in which individual smallholders participate as users.[20]

Large-scale irrigation systems in SSA are systems that cover areas of 1,000 ha or more. More specifically, large-scale irrigation is defined as any system where there is a formal, usually government sponsored irrigation organization responsible for the development and management of the upper tiers of the distribution system and for the delivery of water to farmers.[21]

Farmer-led irrigation is a process in which small-scale farmers drive the establishment, improvement or expansion of irrigated agriculture, often in interaction with external actors, including the government, private sector, or non-governmental organizations. Farmer-led initiatives cut across existing irrigation types in terms of scale, technologies, crops and governance arrangements.[22]

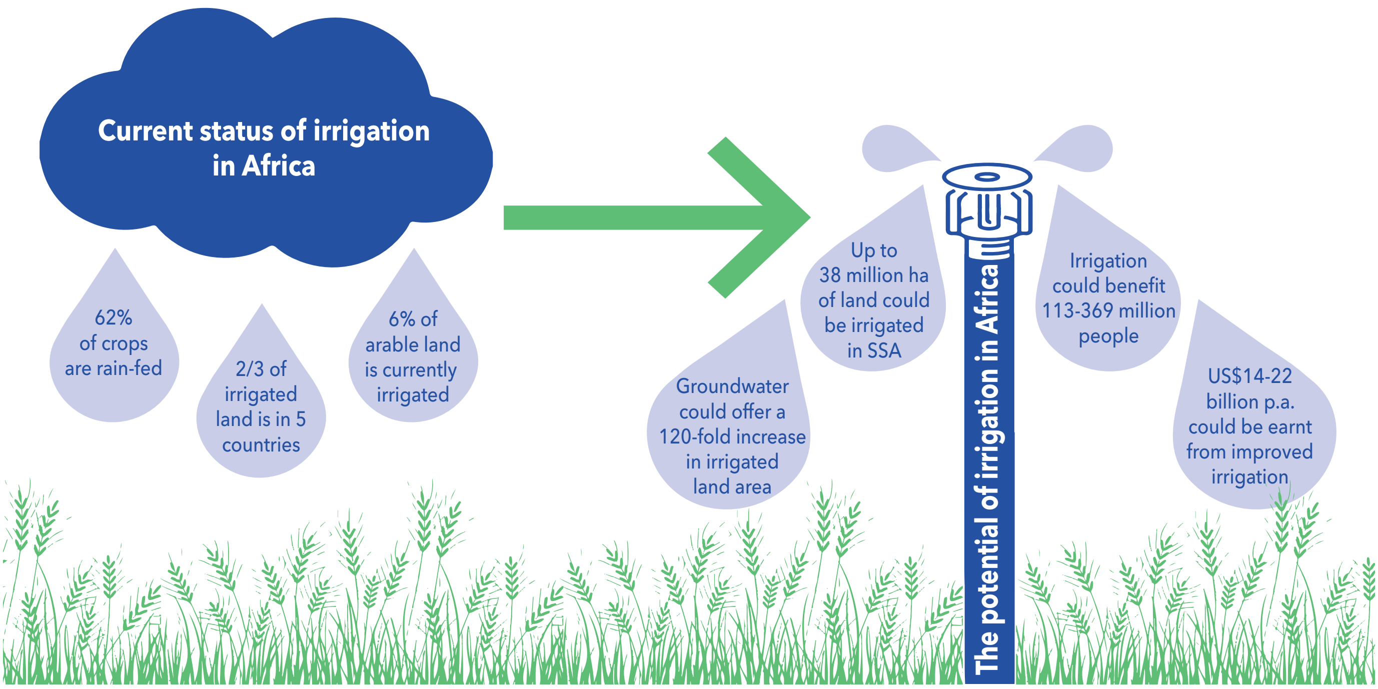
ii Per capita water resources, by country: Cameroon (14,567 m^3), the Central African Republic (32,811 m^3), Congo (205,788 m^3), the Democratic Republic of the Congo (19,449 m^3), Gabon (108,970 m^3), Madagascar (16,269 m^3), Libya (110 m^3), Algeria (329 m^3), Djibouti (337 m^3), Tunisia (438 m^3), and Egypt (706 m^3)

iii Irrigation potential is defined as the area of land that is potentially irrigable (Source: FAO Statistical Yearbook 2014. Africa Food and Agriculture. http://www.fao.org/3/a-i3620e.pdf) for communal river diversions. An estimated 113 to 369 million people in rural areas could be benefitting from these technologies, with net revenues of US$14–22 billion per year.[30]

Furthermore, most existing irrigation schemes in Africa rely on surface water, despite a remarkable potential for using renewable groundwater resources for irrigation. Roughly 78 percent of large- and small-scale irrigation schemes use surface water, while 20 percent make use of groundwater resources. It is estimated that in 13 African countries – Nigeria, Tanzania, Ghana, Zambia, Burkina Faso, Ethiopia, Niger, Kenya, Mali, Mozambique, Rwanda, Uganda, and Malawi—tapping into groundwater could offer a potential 120-fold increase, equivalent to 13.5 million hectares, in the total area under irrigation.[31] However, it is important to note that the development of irrigation potential is done in line with the water status of the country. When plotting water stress[iv] against the extent to which countries have already developed their irrigation potential, three broad groups of countries emerge:

- Countries that have dramatically higher levels of irrigation development and higher levels of water stress. For these countries, key objectives often involve improving water resource management and a focus on water conservation, efficiency, and productivity—rather than further irrigation expansion.
- Countries that have very little irrigation development, and currently experience low levels of water stress—this is common in West and Central Africa. Objectives in these countries include irrigation expansion as permitted by geography, hydrology and requirements for environmental protection.
- Countries that have significant areas equipped for irrigation but experience lower levels of irrigation use or water stress, for example Djibouti, Madagascar and Malawi. In the countries that fit this description, there is either an abundance of water resources, a history of conflicts, or low use of irrigation infrastructure. In cases with low use of infrastructure, policy objectives include improving access to water, addressing institutional issues, in particular land and water tenure, and making improvements in the operation and maintenance of existing infrastructure, rather than further irrigation expansion.[32]

FIGURE 1: Current vs potential status of irrigation in Africa



iv Water stress, or water scarcity, occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of freshwater resources in terms of quantity (aquifer overexploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). Water scarcity can mean scarcity in availability due to physical shortage; or scarcity in access due to the failure of institutions to ensure a regular supply; or a lack of adequate infrastructure. Water stress is defined as an annual water supply below 1,700 m^3 per person. When annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity, and below 500 m^3 is termed absolute scarcity (UN Water, http://www.unwater.org/water-facts/scarcity/#).

While irrigation projects were often unprofitable in the 1970s and 1980s, returns on projects now reach 20 percent in Africa, a figure that is comparable to the rest of the world.

Currently, large quantities of water are lost each year as a result of poor application of irrigation technologies and techniques, limited capacity for water harvesting, and limited use of reusable water resources. This problem may intensify as agriculture in Africa is under pressure to produce more food for a rapidly rising population. As irrigation practices and technologies are brought to scale, it is important that they be designed to use water efficiently and prudently, so as to preserve the natural resource base on which agriculture depends.[33]

While irrigation projects were often unprofitable in the 1970s and 1980s, returns on projects now reach 20 percent in Africa, a figure that is comparable to the rest of the world.[34] This reflects better-designed irrigation projects, dedicated institutions for irrigation and water-resource management, better access to technologies, and market opportunities for high-value products.[35]

Farmers using canals to get water to their plots, Congo

4. Overcoming Barriers to Irrigation Uptake

Although the potential for increasing irrigation across the continent is high and the benefits of irrigation could be substantial, there are a number of barriers and potential risks that hinder irrigation development and expansion. This includes barriers such as poor infrastructure, limited access to finance, insufficient skill development, and insecure land tenure, as well as risks to the environment and human health.

Infrastructure and technologies

Due to a lack of appropriate irrigation technologies and supportive infrastructure, countries are often unable to harness water resources for use in agriculture, even where water is abundant. Increased investments in technologies, supportive infrastructure, and energy provision, adapted to local production systems, are therefore essential to enable a sufficient water supply for crop production and an expansion of land under irrigation.[36] In particular, smallholder farmers continue to struggle to gain access to groundwater aquifers, lacking the required tools and technologies to lift water from deeper water resources.[37] In Mangoma, Tanzania, the introduction of pedal pumps that allowed access to groundwater resources led to a doubling of yields, and over half of farmers were able to diversify their crops.[38]

Due to a lack of appropriate irrigation technologies and supportive infrastructure, countries are often unable to harness water resources for use in agriculture, even where water is abundant.

Skill development

Further advances in irrigation will require equipping farmers and service providers with the skills to design, operate, maintain and repair some of the more advanced and sophisticated irrigation technologies and systems. Without the right set of skills, misuse and mismanagement of machinery can result in water and yield losses and severely hinder the continued use of modern irrigation technologies. Experience from Kenya has shown that a lack of spare parts and repair services forced many smallholder farmers to abandon the use of stand-alone, low-cost drip irrigation kits.[39] Increased investment in institutional and physical infrastructure to expand access to skill development and upgrading is therefore critical. In Morocco, 52 agricultural vocational training centers across the country improve the technical and competitive capacities of agricultural businesses and farms by meeting their need for skill development and by training qualified technicians to service and repair agricultural equipment and tools.[40] In addition, equipping agricultural extension agents with the information and training to provide advice to farmers on how to operate new irrigation technologies is one potential solution. Improved access to spare parts and repair services, particularly in remote areas, is another.

Land tenure

Lack of land tenure security may discourage farmers from making long-term investments or increase land grabbing because of the potential for irrigation. Irrigation uptake therefore requires a transparent land tenure system that guarantees rights for producers, particularly for the most vulnerable, including women and young people. For example, in Uganda, women's land ownership is not clearly defined, which leaves them vulnerable to losing rights and access to their land and limits their incentive to invest in irrigation expansion and sustainable land management practices.[41] In contrast, in Mali, a law passed in 2017 ensures that a minimum of 15 percent of irrigated land is allocated to women and youth.[42,43]

Large scale irrigation with overhead sprinklers, South Africa

Access to finance

Improved access to finance for smallholder farmers and local irrigation equipment manufacturers continues to be a major barrier; both groups typically lack collateral for accessing bank loans. The significant up-front costs of purchasing and installing irrigation systems put most irrigation technologies far beyond the reach of smallholder farmers. Only a small number of farmers hold land titles, which can serve as collateral to facilitate access to credits[44,45] and high interest rates and short repayment periods put additional constraints on farmers' access to credit. In Ghana, where commercial bank credits are made available for agricultural equipment, the interest rates are often prohibitively high, reaching up to 33 percent.[46] Import duties and taxes on irrigation add to the problem by raising overall funding needs. Lowering these duties and taxes would be a major step by governments to ease access to finance and reduce the cost of investing in irrigation for farmers.[v,47]

Returns on investments

Farmers will only make high up-front capital investments in irrigation systems if they can expect positive returns on their investments. Hence, improved access to reliable markets where farmers can sell their produce at higher prices may lower investment risks and incentivize them to make the necessary investment for irrigation. When farmers are better connected to food value chains and able to access markets in nearby towns or the capital city, they can negotiate much better prices for their produce.[48] Storage and processing facilities can further allow them to increase their bargaining power, and ultimately make more profit on what they grow. Together these will incentivize investment in irrigation, particularly by smallholder farmers.[49]

Integrated approaches

Finally, irrigation will be most effective in raising productivity levels—and thus farmers' incomes and livelihoods—when combined with access to other inputs, such as improved seeds, fertilizers and pesticides. In Uganda, it was estimated that only 6 percent of farmers, including those using irrigation, also used improved seeds in 2012. Where improved seeds, fertilizers and pesticides are not readily available, or too expensive, yields may remain well below their potential, despite irrigation.[50,51] Investments therefore need to be targeted toward a combined set of interventions, including fertilizer, advanced seed delivery systems, postharvest processing facilities and access to markets.[52]

The benefits of irrigation are even greater when combined with improved soil management practices.[53] Evidence from Burkina Faso shows that farmers were able to produce 1,700 kg/ha of sorghum when zaï pits (small planting pits) were enriched with both dung and fertilizers, compared to just 200 kg/ha without dung and fertilizer.[54] Similarly, in North East Tanzania, cucumber yields were 203 percent higher and water consumption four times lower with the adoption of practices such as manure application and mulching.[55]

Women fetching water, Ethiopia

v Funding models for irrigation are discussed in detail in Section 8 of this report

5. Trade-Offs of Irrigation: Achieving Desired Outcomes and Addressing Risks

By increasing water supplies and enabling cultivation during the dry season, irrigation can help farmers to extend the growing season(s) and thus diversify activities, increase productivity levels and incomes. Above all, irrigation systems need to be accessible and reliable, so that smallholder farmers can depend on them as a sustainable source of water supply for their agricultural production needs. Irrigation policies need to be inclusive and contribute to improved farmer resilience and livelihoods, as well as to better nutrition, women's empowerment, and employment generation for rural youth. However, without appropriate regulation, competition over water resources and land can lead to conflict between smallholders, large-scale producers, and other downstream users.

Desired outcomes of irrigation

Increased water supply and farm productivity

Available estimates indicate that across SSA small-scale irrigation could boost maize yields by 141–195 percent and paddy yields by 270–283 percent, compared to yields achieved under rain-fed agriculture.[56] In Burkina Faso and Kenya, supplemental irrigation of 60–80 mm helped farmers to double or even triple grain yields to 1 ton and 2.5 tons per hectare for sorghum and maize respectively. After 50,000 tube wells were installed in Nigeria, farmers experienced increases in yields ranging between 65 and 500 percent, with an average return on investment reaching up to 40 percent.[57] Evidence from Niger shows that small-scale irrigation can significantly improve agricultural production and income generation, particularly during dry seasons when households are the most food insecure.[58]

Improved household resilience

Rising global temperatures, changing rainfall patterns, and more extreme weather events sparking more frequent and intense floods and droughts will continue to disrupt the availability and use of water for rain-fed agriculture. Estimates show that, without substantial additional investment in irrigation, the share of people at risk of hunger in Africa could increase by 5 percent by 2030 and by 12 percent by 2050 due to climate change.[59] The reliance of African farmers on rain-fed agriculture makes them particularly vulnerable and susceptible to extreme weather events. Many studies predict a decline in yields for some of Africa's major crops, including rice, maize, sorghum, groundnut and cassava, due to higher temperatures and more frequent droughts. Irrigation offers a critical coping mechanism for farmers to respond to the adverse impacts of climate change. As discussed in Section 6, improvements in agricultural water management and irrigation provide some of the most effective mechanisms for smallholder farmers to adapt to the anticipated adverse impacts of climate change.

Higher incomes and better nutrition

While irrigation has a direct impact on agricultural productivity and income levels, it may also contribute to better nutrition through improved crop diversity for household consumption.[60] Those smallholders using irrigation frequently grow vegetables, fruits, and other cash crops rich in micronutrients during the dry season that also increase household income when they are sold at markets at high prices. For example, through the Bwanje Valley Irrigation scheme in Malawi, participating farmers increased their annual agricultural income by 65 percent and their daily per capita caloric intake by 10 percent. In Burkina Faso, the use of simple irrigation technologies contributed to an increase in vegetable production from 60,000 tons to 160,000 tons within nine years.[61,62] In Tigray, Ethiopia, households that do not use irrigation earn less than half the average income of households that use irrigation – overall average income gains due to access to irrigation ranged between US$145 and US$163 per household per year.[63]

After 50,000 tube wells were installed in Nigeria, farmers experienced increases in yields ranging between 65 and 500 percent, with an average return on investment reaching up to 40 percent.

Women's empowerment

Irrigation policies and programs that pay greater attention to the needs of women farmers have several additional benefits. These include women's enhanced decision-making authority; access to and control over resources including income and food; a reduction in the physical burden or drudgery of farming; and less time spent on fetching water.[64] For example, the introduction of drip irrigation systems in gardens farmed by a cooperative of 45 women in the Kalale district in northern Benin meant that women only had to fetch water once or twice per week, rather than every day. Women also saved up to four hours each day by using modern technologies for watering plant beds.[65] In contrast, in Mazuru, Zimbabwe, women walk nearly four kilometers or more each day to carry water from a dam site to irrigate their farms.[66]

Employment opportunities

Research has shown that crops grown under irrigation, especially horticultural crops, can generate important employment opportunities for rural and urban youth. While 10 to 50 workers are needed to produce grains such as soybeans or sorghum

Motorized pump for irrigation, Burkina Faso

on 1,000 hectares, it takes 300 to 500 workers to produce citrus crops, and over 2,000 workers for tomatoes grown in greenhouses, on the same area of land.[67] Modern irrigation technologies may make agriculture more attractive, in particular to Africa's youth.[68] In Kenya, for instance, an irrigation development program through a PPP attracted 5,000 young participants. The government provided 90 percent of the financial capital as an interest-free loan, and a Kenyan company, Amiran Kenya, supplied the technical capacity and equipment, known as the Amiran Farmers Kit (AFK). This low-cost irrigation kit is based on drip irrigation technologies that use 30 to 60 percent less water than other irrigation techniques. A government fund of US$1.6 million allowed the acquisition of 420 kits in 2014, benefitting 200 youth groups and 15,000 farm families.[69]

When designing new irrigation systems, increased productivity and hence the return on investment are often decisive factors. However, it is crucial that other factors, such as women's empowerment and employment generation for youth and women in rural areas, are taken into account to ensure that irrigation systems are inclusive and benefit all stakeholders. Ultimately, this will contribute to higher incomes, better nutrition, and improved household resilience in the face of climate change and weather extremes.

Addressing the risks of irrigation

An efficient use of fertilizers, insecticides, herbicides and fungicides, coupled with appropriate irrigation technologies, can reduce water loss and the environmental impact of irrigation. In addition, appropriate policies and laws on access to land and water can help regulate resource use and prevent exclusion and conflicts over water abstraction for irrigation. However, inefficient irrigation and drainage systems can contribute to increased soil salinity and degradation, leading in turn to a decrease in soil fertility and the biodiversity of microorganisms, algae, plants and animals.[70] These risks are all well understood today and measures to effectively manage them should be systematically integrated in irrigation development goals.

Environment and health

When combined with poor land management practices, irrigation canincrease pressure on agro-ecosystems and the environment. These adverse impacts include water pollution where fertilizers are over-applied through drip irrigation systems and leach into local water bodies. When these water bodies serve as sources for potable water for local communities, poorly implemented irrigation systems can have adverse impacts on human health.[71] Moreover, irrigation has also been linked to higher rates of waterborne disease. In villages in central Ethiopia that had a high concentration of irrigated land, there were six times more incidents of malaria per month and the number of Anopheles mosquito breeding habitats was 3.6 times higher than in villages without irrigation systems. The most common breeding habitats are waterlogged field puddles, leakage pools from irrigation canals, and poorly functioning irrigation canals.[72] Regular maintenance of irrigation infrastructure is an effective and feasible option for minimizing this potential risk to human health.

Water competition

Estimates suggest that, without the appropriate policy and technology innovations, current water use will not be sustainable, and more than half of Africa's population will not have access to drinking water by 2030.[73] Inefficient water use and use of potable water for irrigation may exacerbate competition for water, particularly drinking water, as the use of treated wastewater in African agriculture remains rare. Across the continent, less than 2 percent of irrigated land uses treated wastewater.[74] Designing future irrigation practices in a way to use water more sustainably and prudently will help to avoid water crises in decades to come. This is possible if countries seize available opportunities to leapfrog and embrace the design and adoption of irrigation technologies and equipment based on alternative energy sources and advances in digital technologies, which could minimize the impact of irrigation on the environment, agricultural ecosystems, and human health.

Exclusion and conflicts

Conflicts among water users can occur when too much water is abstracted upstream, leaving little or no water available for downstream users for agriculture or household consumption.[75] When regulation of access to water resources and land was loosened in Sidi Bouzid, Tunisia, competition over water between family farmers and larger-scale producers increased sharply.[76] The challenge is to take these potential risks into account when designing irrigation schemes. Risk assessment should be a crucial part of any initial decisions regarding whether to implement new systems or to expand and upgrade existing irrigation systems.

6. Climate Change: A Driver for Irrigation

Agriculture and irrigation practices are strongly affected by climate change. Rising global temperatures, changing rainfall patterns, more extreme weather events causing more frequent and intense floods and droughts will increasingly disrupt the availability and use of water for rain-fed agriculture. Improvements in agricultural water management offer one of the most effective mechanisms to protect against the anticipated negative impacts of climate change on the quantity and quality of crop and livestock production, soil fertility, and the livelihoods of vulnerable rural communities. At the same time, better land management practices and improved fertilizer usage on irrigated lands can enhance carbon storage in soils thereby contributing to the mitigation of climate change. Yet, growing water scarcity and increased irrigation development will lead to greater use of groundwater resources and increases in energy consumption. In particular, the energy that is consumed for abstracting groundwater for irrigation can be significant. In India, electric and diesel groundwater pumping account for 4 to 6 percent of national greenhouse gas (GHG) emissions.[77] While some technologies, such as drip irrigation systems, can help to reduce water consumption, energy demand will still increase. Using renewable energy, for example solar-powered irrigation systems, can offer reliable, relatively low-cost, clean energy alternatives.[78]

Current and anticipated changes

Across Africa and other parts of the world, farmers are already battling the adverse impacts of climate change. Africa's climate is not only diverse, but also highly variable, which makes it difficult to separate the effects of natural variation from those produced by global warming. Nevertheless, there is growing evidence that climate change is having significant and predominantly deleterious effects, which differ across the continent, often in complex ways.

The African Risk Capacity (ARC), a specialized agency of the African Union, warns that without coping mechanisms in place droughts could significantly threaten growth of gross domestic product (GDP) in SSA. For instance, a once-in-10-year drought event could reduce the GDP of Malawi by 4 percent, with even larger impacts for 15- and 25-year droughts.[79]

While there is a high level of confidence in estimates of future temperature increases, the changes in rainfall are much more uncertain because of the influence of spatial, local topographical, and seasonal factors. The African climate is determined at the macro-level by three major drivers: tropical convection, the alternation of the monsoons, and the El Niño-Southern Oscillation of the Pacific Ocean. El Niño strongly influences year-to-year rainfall and temperature patterns in Africa. Over the last decade, there has been a significant increase in rainfall intensity in some parts of the continent, leading to more frequent flooding.

The 2015/16 El Niño led to the lowest rainfall levels in 35 years in Africa and caused intense drought in the Horn of Africa, with devastating impacts on the region's food security and countries' economies. In Ethiopia, Somalia and Eastern Sudan, 15 million people needed support to cope with the crisis. In southern Africa, particularly in Lesotho, Malawi, Swaziland and Zimbabwe, over 30 million people were affected, and more than 12 million people required immediate humanitarian assistance.[80] This came on the heels of the drought in 2012 when the United Nations World Food Programme (WFP) assisted 54.2 million people in Africa, spending US$2.7 billion – nearly two-thirds of WFP's global expenditure that year.[81]

Farmer lifting water for irrigation using rope-and-bucket method, Chad

Impacts on agriculture and farming communities

Climate change will have profound effects on food production, and the reliance of African farmers on rain-fed agriculture makes them particularly vulnerable to extreme weather events. In the absence of solid adaptation strategies and coping mechanisms, such as irrigation, many studies predict that temperature and weather changes will reduce yields, affect the quality and safety of crops and livestock and directly affect the livelihoods and food security of millions of Africa's smallholder farmers. While estimates vary greatly due to the uncertainty of future rainfall patterns, some studies suggest that by 2050 grain crop yields across Africa will shrink substantially. According to models developed by the International Food Policy Research Institute (IFPRI), by 2050, yields of rain-fed maize will decline by as much as 25 percent or more in some parts of Africa, relative to 2000 levels.[82] While cereal production is projected to double in SSA by mid-century, it will be about 5 percent less than it would have been in the absence of climate change. For some of Africa's other major staples, such as sorghum and millet, on which rural populations in the drylands depend, yield declines are estimated at more than 30 and 40 percent respectively.[83]

It is estimated that without additional investment in irrigation, the share of people at risk of hunger could increase by 5 percent by 2030 and 12 percent by 2050.

Furthermore, some studies project that maize, rice and wheat prices in 2050 will be 4, 7 and 15 percent higher respectively, while prices of other important crops, such as sweet potato, cassava and millet, will increase by 26, 20 and 4 percent respectively.[84] Higher food prices will lower the affordability of many agricultural products, including basic staples and livestock products. As a result, per capita calorie availability in SSA is projected to decline by 37 calories per day, affecting those who can least afford to reduce their caloric intake. Child malnutrition is also likely to worsen, with an increase from 30 to 39 million children affected between 2000 and 2030.[85]

Studies suggest that a set of targeted investments in productivity-enhancing research and development, water management, and infrastructure could more than offset the adverse impacts of climate change through 2030. With targeted investments, average crop yields in Africa are projected to grow more rapidly than those in other developing regions, with average increases of 47–56 percent, compared with 40 percent for developing countries as a whole and 35 percent globally.[86]

Although climate models have improved, and are benefitting from greater availability of data, uncertainties remain in their projections over years and decades, and at regional and local scales. Nevertheless, given the likely impacts outlined above, there is an urgent need to design and develop smart policies and regulations to promote sustainable irrigation among smallholder farming communities in Africa. Sustainable and cost-efficient systems, such as combined solar-powered drip irrigation systems, could help farmers adapt to shrinking water supplies, become more resilient to drought and variable rainfall patterns, and help to mitigate climate change.

Recognizing that the effects of climate change will increasingly affect rain-fed agriculture across the continent is a critical factor in favor of developing more irrigation in Africa. For instance, the costs of tripling the area under irrigation around the Zambezi basin would be about equal to the benefits. However, when the avoided damage from climate change and more frequent droughts is added as an additional benefit of increased irrigation, the overall benefits are double the costs.[87]

It is clear from the above that irrigation is an important coping mechanism to substantially improve farmers' resilience and livelihoods. It is estimated that without additional investment in irrigation, the share of people at risk of hunger could increase by 5 percent by 2030 and 12 percent by 2050.[88]


Irrigated rice fields, Nigeria

7. Opportunities for Innovation in Irrigation

Given the significant effects that climate change may have on the agriculture sector and on farming families in particular, irrigation has great potential not only to increase agricultural productivity but also to improve resilience and the nutrition of farming families, empower women, and generate much-needed employment opportunities.

In many countries across Africa, irrigated areas rely on basic or improvised techniques such as flood recession, spate irrigation, and use of wetlands, all of which are less productive and reliable than modern irrigation technologies.[89] However, there are signs of increasing uptake of on-farm pressurized irrigation technologies, such as sprinklers and micro-irrigation, that have potential to reduce water consumption and significantly improve the productivity and quality of horticultural crops. On average, 18 percent of areas equipped with modern irrigation technologies in Africa now use pressurized irrigation equipment, compared with just 2 percent in Asia and 12 percent in the rest of the world.[90]

As can be seen across the continent, there are innovations that can substantially increase countries' irrigation potential. Because irrigation is highly site-specific and not limited to a single method, a range of factors need to be considered in the selection of different irrigation innovations and water harvesting methods, including the size of farms, water availability, and other topographical features, such as field size, shape and soil type.[91] Market factors, such as crop prices, energy costs, and labor supply also need to be taken into consideration when developing irrigation technologies and systems. In addition, the costs of technologies, crop and farming characteristics, local climate, regulatory provisions such as groundwater pumping restrictions, drainage discharge limits, and water transfer provisions will define the effectiveness of the technology applied.[92]

In many cases, irrigation technologies are used in combination with rainwater harvesting – a technique used for collecting, storing and using rainwater for landscape irrigation – and water-spreading weirs. Rainwater harvesting is widespread in many African countries, implemented by individual farmers or at the community level. Unlike big dams, which collect and store water over large areas, small-scale rainwater harvesting loses less water to evaporation, as the rain is collected and stored locally through runoff from roofs or ground catchment, and does not deplete aquifers or impact other farmers' water supply. The type of storage plays an important role and is determined by material, size, rainfall amounts, water demands, location and costs.[93]

Water-spreading weirs harvest floodwater to distribute the runoff into valleys, allowing as much water as possible to infiltrate the soil and hence reach an aquifer. Water-spreading weirs can be developed using locally available materials, but as large-scale projects they require careful planning and construction.[94] In Niger, over 4,700 farms benefitted directly from water-spreading weirs and were able to increase their arable valley land from 0.6 ha to 2.2 ha on average, with an increase in millet yields of 85 percent and sorghum yields of 25–30 percent.[95]

Traditional irrigation methods

Small-scale irrigation

Agriculture in Africa is predominantly rain-fed, and those farmers who irrigate their farms primarily rely on traditional methods such as surface water diversion and rainwater harvesting, rope-and-bucket, pedal pumps, motor pumps, and rope-and-washer pumps. Examples from Kenya show that incomes can be increased by up to six-fold with use of small-scale irrigation techniques. Depending on market access, type of crop, and the number of growing seasons, the irrigation of horticultural products like snow peas, kale and onions can significantly increase farmers' incomes—under irrigation, farmers can earn US$1,400, US$450 and US$600 per hectare respectively, compared to a combined total of less than US$750 without irrigation.[96]

BOX 3: Rope-and-bucket irrigation

The most simple and cost-efficient means of irrigation remains the rope-and-bucket method, using surface water, rainwater or, most commonly, groundwater. Using any vessel, such as a bucket or tank, which is connected to a rope, the water is lifted manually and broadcast across a field with the use of a vessel. Although it is easy and equipment is inexpensive, the method is only suitable for small plots, as it remains arduous and time-consuming and does not use water efficiently.


Woman lifting water using rope-and-washer pump, Kenya

BOX 4: Rope-and-washer pumps

The rope-and-washer pump is a low-cost water pump that can be used in combination with any waterhole, such as a well, or a stream. The system enables farmers to pump water from up to 10 meters below ground. The materials needed to develop and maintain these systems are often available locally.[97] A project funded by the Slow Food Foundation for Biodiversity, and implemented by the Kihoto Self-help group in the Kenyan Rift Valley, used rope-and-washer pumps to help farming families save time normally spent on fetching and distributing water. Within the communities, where family farm plots average 0.4–2.0 ha, the use of the pumps contributed to higher crop yields and improved animal husbandry. It also contributed to a reduction of waterborne disease and malnutrition and, especially among girls, increased school attendance.[98]

BOX 5: Gravity-fed irrigation systems

Gravity-fed irrigation systems are widely used across Africa, often in combination with drip irrigation. Usually, farmers collect water from rivers or through rainwater harvesting, although sometimes water from small dams is used. As the system works entirely through gravity on sloped land or hillsides, no pumps or electricity are needed. Where land is flat, gravity can be created by placing the water tank above ground level. On the slopes of Mount Kenya and in the Karongi District in Rwanda, gravity-fed irrigation is used to grow crops and horticultural products.[99, 100] In South Africa, gravity-fed canal schemes were built in the 1970s and, by 2011, over one-third of land was irrigated using gravity-fed systems, with 17 percent using a gravity and pump combination.[101] Although gravity-fed irrigation schemes are an easy and inexpensive method for small-scale irrigation, they are not feasible for all plots as they depend on specific topographical and hydrological conditions.[102]

BOX 6: Treadle or pedal pumps

Treadle or pedal pumps are seen in rural areas of many African countries. While it is possible to build a pedal pump using spare bicycle parts and other tools, companies also sell various manual pump systems to smallholder farmers. A 2014 study by Cornell University in Zambia showed that 86 percent of farmers with pedal pumps were able to provide their families with two to three meals per day even during the lean months. These households were also 160 percent more likely to own livestock and 200 percent more likely to live in properly built homes using adequate construction materials, compared to the control group of farmers. A review of studies of different small-scale irrigation systems in Africa found that 70 percent of all studies on pedal pumps reported positive outcomes related to improved food security, reduced poverty levels, and increased crop revenues.[103]

BOX 7: Motorized pumps

Diesel- or gas-powered irrigation pumps are often used for irrigating plots and can help save time and labor for other income-generating activities. In the Fogera Region in Ethiopia, the use of motorized pumps has expanded rapidly in recent years, mainly as a result of a set of enabling factors that includes credit accessibility and distribution partners, hiring companies, and sharecropping. While a new motor pump in Ethiopia costs US$300–1,500[104], the pumps can be hired for just US$0.8/hour plus fuel. Although the motor pumps provide significant income-generating opportunities, maintenance, access to spare parts, and water shortages are major challenges. Also, the pollution from motorized pumps is a major concern. A sustainable approach will therefore require regulation and cooperation among stakeholders to avoid increased water depletion through higher rates of water pumping and to benefit as many households as possible.[105]

Community-led irrigation

In many cases irrigation systems are organized by communities. Where water supply and delivery systems are shared by farmers, individual farmers may combine community-led irrigation with other small-scale irrigation techniques or make direct use of flood irrigation on their own farms.

BOX 8: Traditional and improved river and surface diversion

Traditional river diversion usually uses locally available materials like rocks, branches and mud to divert the water. Examples from the South Pare Mountains in North East Tanzania show that traditional river diversions—furrows—are mainly small, hand-dug, unlined canals; these can stretch for several kilometers to reach farmers' plots. Water loss from furrows is high, ranging between 75 to 85 percent, and the furrows need to be regularly rebuilt when damaged by flood flows. In many cases, furrows are linked to micro-dams, where water is stored while fields are not irrigated.[106] Other examples from Tanzania show that improved traditional river diversion systems, characterized by constructed intakes and canals, resulted in over double the yields for paddy rice, when compared to unimproved traditional systems, and raised farmers' incomes substantially.[107,108]

BOX 9: Tidal irrigation

Tidal irrigation is used in agricultural areas along coastal plains with river water under tidal influence, and where rivers are large enough to guarantee a sufficient flow of fresh water into the sea to avoid salt water intrusion in the river mouth.[109] In The Gambia, tidal irrigation takes advantage of the ocean tides to direct water from the Gambia River onto fields. Since the river is tidal in its entirety, the irrigation system is available to many smallholder farmers along its entire length. Water-control gates are usually installed at the entry point of water and opened at high tide, which allows the river water to reach farms. The year-round access to the irrigation technology makes two cropping seasons possible for rice per year. The initial costs for tidal irrigation projects are high, estimated at approximately US$7.5 million for the project in The Gambia in 1983/84, and farmers must be trained to manage and maintain the system. However, the costs per hectare (US$40) and running costs then remain low since clearing of canals can be done locally.[110]

Innovative irrigation technologies

In addition to traditional irrigation methods, newer innovative and more environmentally sustainable technologies are increasingly used across Africa. A devastating drought in South Africa in 2017/18 demonstrated that irrigation projects must be implemented with frugal use of water resources, as well as best practices for soil management. Annual rainfall in Cape Town in 2017 was just 500 mm, compared to an annual average of 1,100 mm, destroying a provincial water supply system that is almost entirely reliant on the collection of surface water. In response to the water shortages, Cape Town residents reduced their daily consumption of water by nearly 60 percent, from 1.2 billion liters a day in 2015, to just over 500 million liters at the start of 2018. Between January and October 2018, restrictions imposed by the city included a reduction in agricultural water use by 60 percent, a push for use of water-management devices, and the use of new fittings and other devices to minimize water waste. Commercial and agricultural users who did not reduce their water usage sufficiently were subject to fines or to having water management devices installed on their properties.[111]

Although many new technologies are still out of reach for most smallholder farmers, there is potential to bring them to scale and make them more affordable and accessible. Africa now has the opportunity to leapfrog to more technologically-advanced and environmentally friendly irrigation systems. To maximize the benefits, new technologies and practices need to be adapted to suit local needs and contexts. Ideally, they should also be designed and manufactured using locally available materials, to make maintenance, repairs, and access to spare parts more feasible while generating new employment opportunities.

Microdosing water

Microdosing of inputs such as fertilizer, pesticides, or water is a highly efficient technique that minimizes the application of and overreliance on inputs. Microdosing involves the application of small quantities of inputs onto or close to the seed or plant. Drip irrigation is a method of water microdosing, applying a limited about of water directly where it is most needed, reducing waste and evaporation.[112]

BOX 10: Drip irrigation

Drip irrigation systems slowly emit water through small-diameter pipes directly to the roots of plants in order to lower evaporation and reduce water loss. Drip irrigation can improve soil moisture conditions, resulting in yield gains of up to 100 percent over conventional irrigation systems.[113] The yield increases are also reflected in better incomes for farmers. An example from Ghana showed income growth of over 100 percent resulting from use of drip irrigation on onion fields.[114] Since 1996, the Kenya Agricultural and Livestock Research Organization (KALRO), formerly the Kenya Agricultural Research Institute (KARI), has promoted gravity-fed drip irrigation systems to farmers who were previously watering their crops by hand. Depending on the crop, farmers reported additional income of between US$80 and US$200 with a single bucket kit per season.[115] "Smart" irrigation technology combinations can control water and fertilizer supply through mobile technologies or use solar energy to pump water.

Sprinklers

Sprinkler irrigation is a method of applying water in a controlled manner similar to rainfall. The sprinkler is normally attached to a pump using a water hose in order to distribute the water.

BOX 11: Center-pivot

Center-pivot irrigation is often referred to as a water-wheel or circle irrigation. The system consists of a long pipe (overhead sprinkler or nozzles) attached to a mechanically rotating pivot. Center-pivot sprinklers are primarily used by medium- and large-scale farmers, farming 20 to 100 hectares in African countries such as South Africa, Zambia, Zimbabwe, Nigeria, Mozambique and Kenya. Installing these systems on small farms is still too expensive. One option could be shared models, where farmers pool their resources; or the technology could be adapted to smaller plots of land, taking into account local conditions and capacities.[116]

BOX 12: Floppy Sprinkler

The Floppy Sprinkler was originally developed in South Africa and consists of a floppy tube that imitates rain drops. Of the two types of floppy sprinklers, one is more suitable for large-scale farming and requires an overhead cable system – compressed water is lifted and then released via special water tubes. The other system is based on the ground and suitable for small-scale irrigation. Both sprinklers are made of silicone and maintenance is minimal. The technology is used in many different African countries, including in Cameroon, Angola, Mozambique, Namibia, Swaziland (Eswatini), Zimbabwe and Egypt for a variety of crops. Evidence has shown yield increases of 15–30 percent and a reduction in water use of 17–44 percent. A study by the South African Institute for Agricultural Engineering confirmed that these systems were significantly more efficient than other large-scale irrigation systems, for example dragline irrigation. Although the study found the floppy system to have higher initial up-front costs, the long-term cost-efficiency was higher.[117,118]


Harvest of alfalfa on an irrigated field using the floppy sprinkler overhead system, Sudan

Irrigation using renewable energy

The use of renewable energy is increasing rapidly worldwide and is also becoming more common across Africa: renewable energy is scalable, it is available without extensive power grids, it is not based on fossil fuels, and it can be made available even in remote areas. Although the cost for photovoltaic technologies in African countries is still about 12 percent above the global average, global costs for solar technologies have decreased by almost 80 percent since 2010 and are likely to fall further over the next decade.[119,120]

BOX 13: Solar-powered pumps

Solar technology in combination with pumping systems for irrigation is a more environmentally friendly alternative to motorized pumps, with lower maintenance costs. Solar-powered drip irrigation systems require no batteries and the pump runs during the daytime. The pumps are self-regulating, meaning that on sunny and hot days, when evaporation is higher, the pumping speed and hence the volume of water will increase. In northern Benin, solar-powered drip irrigation was installed on plots of 0.5 ha and tested against similar plots reliant on hand-watering methods. On the solar-powered irrigated plots, the yields, incomes, and household consumption of vegetables were significantly higher compared to households using hand-watering methods. Overall, the standard of living for beneficiaries increased by 80 percent relative to non-beneficiaries. Although the solar-based techniques have higher up-front costs, a hypothetical comparison with motorized pumps has shown that the overall cost-effectiveness is higher when fuel prices are high and when solar technologies are used on large farms. But with high up-front costs, solar-powered technologies may still only be affordable for farmer cooperatives or larger-scale government-led irrigation systems.[121]

Digital systems and technologies

Mobile-phone-based systems can facilitate an efficient use of different irrigation technologies, for example when combined with solar drip irrigation schemes, providing timely and precise irrigation without the farmer having to be physically present. Not only can these technologies help facilitate the management and control of agricultural processes and allow for greater flexibility and efficiency, but they may also attract young people to agriculture.

BOX 14: Irrigation apps

Mobile apps are becoming increasingly prominent in the agricultural sector, including in irrigation. Some companies are designing irrigation systems in combination with a mobile app. The Nigerian National Space Research and Development Agency (NASDRA) recently unveiled its solar-powered automated irrigation system. The technology comes in combination with a soil sensor and a solar-powered water pump and uses signals from a navigation satellite. The system has been tested on different soil types and crop varieties. Soil conditions and moisture are measured constantly and reported back to the farmer on a mobile phone or laptop. Once the soil moisture falls below a certain threshold, the pump is automatically triggered.[122] Similar systems have been designed by scientists at Kenya's Meru University of Science and Technology.[123]

BOX 15: Soil sensor technologies

Soil moisture predictions are a good tool to assess the progress of growing season conditions and can provide early warning of natural hazards, including droughts and floods.[124] A new generation of soil sensor technologies is currently being developed for the African market. Some companies, such as Zenvus, have started selling electronic soil sensor technologies that are equipped with GPS, micro-SD and Wi-Fi for use on smartphones or laptops. These technologies help monitor data such as soil moisture and nutrients, pH and humidity levels, temperature, and sunlight, helping to increase knowledge of ongoing changes in the field and the environment; they also provide real-time guidance, recommendations and notifications on rainfall and droughts. One sensor can cover up to three hectares of land, depending on environmental factors. The sensors are currently available to purchase online, ranging between US$200–650.[125] Although the adoption of mobile technologies is growing rapidly in SSA, most smallholder farmers do not have access to laptops or smartphones[vi], and unless prices decrease substantially, most smallholders will be unable to afford these soil sensors. For that reason, a project in Tanzania assessed the potential to market a very simple version of the soil sensor technology, which consists of a sensor and an LED lamp that indicates a need for irrigation (or no need), with the ability to send information to the cloud and analyze in real time. Estimated costs range between US$50-100 (including the sensor, a data logger, and a SIM card). The project estimated that using the simple soil sensor can be profitable for Tanzanian farmers, especially for those planting tobacco, highland rice, or maize – crops which are most likely to benefit from use of a soil moisture sensor. While there might be a potential market for soil sensors, social habits and challenges must yet be addressed.[126]

vi In Tanzania only 13 percent and in Ghana, Senegal, Nigeria and Kenya only about one-third of adults own smartphones (Source: Pew Research Center, 2018. http://www.pewglobal.org/2018/10/09/internet-connectivity-seen-as-having-positive-impact-on-life-in-sub-saharan-africa/)

BOX 16: Hyperspectral imaging camera

With the technology of hyperspectral imaging, information on electromagnetic spectrums can be collected. Zenvus in Nigeria is making the first effort to distribute such cameras, which can analyze images and identify stressed crops, droughts, and outbreaks of pests and diseases. In combination with soil sensors, farmers can use this technology to evaluate the effectiveness of their irrigation and fertilizer application by correlating soil data with overall vegetative crop health. The camera is available in two different versions, one to be mounted on a stick and one optimized to work with drones to monitor larger farms. The camera costs US$190 and is currently only available in Nigeria.[127]

TABLE 1: Comparison of traditional small-scale irrigation methods

Method	Rope-and-bucket	Rope-and-washer	Hip pump	Treadle pump	Motorized pump	Solar pump
Type	Water-lifting	Water-lifting	Water-lifting	Water-lifting	Water-lifting	Water-lifting
Main user/ Average plot size	Smallholder farmers	Smallholder farmers / < 0.2 ha	Smallholder farmers / < 0.5 ha	Smallholder farmers / < 0.8 ha	Small- to medium-size farmers / 0.5 – 10 ha	Small- to medium-size farmers / 0.3 – 10 ha
Investment costs (US$/unit)	15	40	50	20-250	300-1,500	2,450-15,400
Maintenance costs (US$/year/ unit)	1	2	1	8-35	580[vii]	50-100
Advantages	■ Low cost ■ Locally available materials	■ Low cost ■ Less manual power needed ■ Might improve water supply ■ Locally available materials	■ Low cost ■ Can be combined with drip irrigation ■ Time saving ■ Portable ■ Easy to repair	■ Can be combined with drip irrigation ■ Portable ■ Time saving ■ Easy to repair	■ Reduces drudgery of lifting water ■ Time saving ■ Can be combined with drip irrigation or sprinkler ■ Can be used for small and medium sized plots	■ Environmentally friendly energy source ■ Time saving ■ Reduces drudgery of lifting water ■ Can be used for small and medium size plots ■ Can be combined with drip irrigation or sprinklers
Disadvantages	■ Requires substantial manual power ■ Only suitable for very small plots ■ No efficient water use ■ Time consuming	■ Only suitable for very small plots ■ No efficient water use ■ Time consuming	■ Only suitable for very small plots ■ No efficient water use	■ Only available through selected retailers in some countries ■ Costs might be higher in some countries	■ Only available through specific retailers ■ Rather high initial and maintenance costs – depending on fuel prices ■ Contributes to pollution ■ Spare parts might be difficult to access ■ Needs skills to repair	■ High initial costs ■ Only available through selected retailers ■ Spare parts might be difficult to access ■ Needs skills to repair

vii Assuming a usage of 200 d/year.

TABLE 2: Comparison of traditional, community-based irrigation methods[viii]

Method	River diversion	Tidal irrigation
Type	Water supply and irrigation	Water supply and irrigation
Main user & suitability	Small- to medium-size farmers	Small- to medium-size farmers
Advantages	▪ Provides (low-cost) water access ▪ Low maintenance costs ▪ Maintenance of canals can be done by farmers	▪ Provides (low-cost) water access ▪ Low maintenance costs ▪ Maintenance of canals can be done by farmers ▪ Does not require dams
Disadvantages	▪ Requires long-term planning with experts and technicians ▪ Very high initial costs ▪ Rather inefficient water use due to flooding ▪ Building of big water systems (including dams) might impact water supply elsewhere	▪ Can only take place in very specific geographic locations, particularly in tidal rivers ▪ Requires long-term planning with experts and technicians ▪ Very high initial costs

TABLE 3: Comparison of innovative irrigation technologies[ix]

Technology	Gravity-fed drip irrigation	Center-pivot	Floppy Sprinkler	Soil sensor	Hyperspectral camera
Type	Irrigation	Irrigation	Irrigation	Irrigation assistance	Irrigation assistance
Main user & suitability / Average plot size	Small-scale farming / 0.05 ha	Medium- to large-scale farming / 4.5–200 ha	Small-, medium-, large-scale farming / 0.2 – several '000 ha	Small-, medium-, large-scale farming / 1-3 ha covered by one sensor[x]	Small-, medium-, large-scale farming / every size possible – can run as a drone
Advantages	▪ Very low initial and maintenance costs ▪ Locally available materials ▪ Very efficient water use ▪ Can be combined with different water lifting systems	▪ Very efficient system ▪ Can be managed remotely	▪ Very efficient system ▪ Can be managed remotely	▪ Assists efficient water usage ▪ Can be combined with irrigation system ▪ Indicates drought-inflicted damages to crops ▪ Allows remote access to irrigation systems ▪ Helps to identify and assist in planting related issues concerning soil and nutrients	▪ Assists efficient water usage ▪ Indicates drought-inflicted damage to crops ▪ Helps to identify and assist in issues concerning plant growth and nutrients

viii, ix Investment and maintenance costs have been excluded in this analysis as estimations are highly site specific and depend on a number of factors, including the water costs, the pumping hours per day, the irrigation cycle, emitter type, emitter spacing, total area irrigated and other topographic factors.

x Depending on the steepness of the land.

Technology	Gravity-fed drip irrigation	Center-pivot	Floppy Sprinkler	Soil sensor	Hyperspectral camera
Disadvantages	■ Only suitable if there are gravity differences, e.g. through slopes ■ Takes long time for irrigation, depending on the pressure created by gravity ■ Pipes are prone to insect damage	■ Only suitable for medium-size plots and bigger ■ Very high investment costs ■ Requires efficient water supply ■ High loss of potential yield through round irrigation shape	■ Very high investment costs ■ Requires efficient water supply	■ Expensive for smallholder farmers ■ Requires mobile technology to control and access data in the cloud	■ Expensive for smallholder farmers ■ Requires mobile technology to control and access data in the cloud

Sprinkler irrigation on a vegetable plot, Kenya

8. Funding Models and Commercialization of Irrigation

One of the biggest obstacles to expanding irrigation schemes across Africa remains access to finance. This applies equally to small-scale and farmer-led as well as medium- and large-scale government-led irrigation systems. Most farmers depend on their own savings to invest in agricultural inputs, tools and machinery. The significant up-front costs of some modern irrigation tools and equipment put them well beyond the reach of many smallholders and may deter governments from making much-needed investments in irrigation. However, given that yields from irrigated crops are up to twice or more than yields for comparable rain-fed crops, water control investments can be profitable. Efforts to overcome financial and other constraints to irrigation development and expansion are a key element for agricultural transformation in Africa. Precisely for this reason, irrigation development is a key investment priority under CAADP.[128] To finance irrigation expansion at scale across Africa, a mix of investments and smart design of large- and small-scale irrigation schemes will be needed to benefit smallholder farmers and to leverage countries' full irrigation potential.[129]

Over the last 10 years, several countries in Asia have allocated 6 percent of governmental spending on agriculture, of which they invested over 60 percent in irrigation development, leading to a rapid growth in the areas under irrigation. In contrast, in 2017, African governments on average dedicated just 3.1 percent of national budgets to agriculture.

Depending on the size of irrigation schemes, current funding modalities differ substantially. Large-scale irrigation requires careful technical planning and decision-making at the highest political levels and can be very expensive. The bulk of funding for irrigation development comes from national government budgets, with most funds originating from multilateral development partners.[130] Over the last 10 years, several countries in Asia have allocated 6 percent of governmental spending on agriculture[131], of which they invested over 60 percent in irrigation development, leading to a rapid growth in the areas under irrigation.[132] In contrast, in 2017, African governments on average dedicated just 3.1 percent of national budgets to agriculture.[133] Under CAADP, governments agreed to increase agriculture sector expenditures to 10 percent of annual budgets. Despite considerable increases in expenditure levels, only 10 countries had met the target in 2017.[134] There is clearly room and an urgent need to scale up investments in priority areas such as water control for smallholder farmers. As examples from Asia show, irrigation investments raised the demand for inputs, like labor and technologies, which in turn increased the output of agricultural products.[135]

Studies suggest that if governments were to meet the 10 percent CAADP expenditure target for agriculture and allocate just 1–5 percent to irrigation development, considerable investments in irrigation infrastructure would in fact be feasible and profitable.

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Innovative financing models for small-scale, farmer-led irrigation systems

The development of small-scale irrigation is largely driven by individual farmers or farmers' groups and cooperatives.[137,138] Expansion of, and access to, formal financing services will be crucial as many small-scale farmers continue to lack the resources to finance the necessary equipment.[139] Although financial systems in Africa have improved over the past two decades, they still lag behind other developing economies. In 2017, only a third of adults in SSA had access to formal financial services[xi], compared to 54 percent in Latin America and 68 percent in South Asia.[140] Low-income farmers, and women farmers in particular, will need assistance to be able to pay for irrigation equipment.

Hiring services for irrigation equipment

Innovative modalities to lower the cost of access through "Uberization" and other hiring-service models offer real

xi Data based on having an account at a financial institution (World Bank, 2018).

opportunities and provide viable alternatives to costly subsidy programs and government-run procurement and distribution schemes. The hiring-service market, especially for engine-driven pumps, is still in its early stages in most African countries, and both medium-scale farmers and non-farmer entrepreneurs face uncertainty about whether sufficient demand exists. Moreover, there is a risk that due to improper maintenance or overuse, irrigation equipment will break down and engine lives be shortened. While mechanization more broadly has benefitted greatly from hiring schemes, for example through start-ups such as Hello Tractor, further development and trials are needed to make hiring schemes profitable for irrigation.[141]

Public–private partnerships (PPPs)

Irrigation also offers opportunities for new and innovative models of PPPs.[xii] While governments are key to creating investment-friendly environments, PPPs can improve the financial and innovative capacity of private and public players to address some of the challenges related to irrigation. Access to irrigation systems and equipment, in particular for smallholders, women and youth, initially requires a supportive fiscal regime in which sales taxes are low and barriers such as import duties on irrigation systems, spare parts, and raw materials for local manufacturing are minimized. Therefore, the private sector needs to be incentivized to enter PPPs for irrigation development through financial securities, smart subsidies, or tax waivers to promote engagement with smallholders. This can be complemented with investments in good infrastructure, including roads, accessible market facilities, rural electrification, and telecommunication systems. Governments can also play an important role in the provision of extension services, farmer training, and other technical support services that may further incentivize the sector to enter PPPs.

Innovative modalities to lower the cost of access through "Uberization" and other hiring-service models offer real opportunities and provide viable alternatives to costly subsidy programs and government-run procurement and distribution schemes.

In addition, solid public investments in irrigation could trigger further private sector investment in supportive infrastructure. One innovative approach in this context are Build-Operate-Transfer (BOT) models. A BOT is a type of PPP that focuses on outputs and involves the construction or significant refurbishment of projects. The ownership of the project stays with the government, while a private company is given the temporary right to operate the facility commercially, including also responsibility for investments. After the project period, the facility is transferred to the government.[142] In the irrigation sector, BOTs could help to mobilize new sources of capital to accelerate the development of water and irrigation projects and introduce innovation and technology transfer from the private sector. The advantage of BOTs lies in the shared risk between the private sector and government of delivering new infrastructure assets on time and on budget.[143]

Therefore, the private sector needs to be incentivized to enter PPPs for irrigation development through financial securities, smart subsidies, or tax waivers to promote engagement with smallholders.

Multiple-use water systems (MUS)

Large-scale irrigation developments can be very expensive to design and implement. In this context, MUS can provide low-cost water for domestic use, agriculture, and rural enterprise.[144] By allowing water to serve different purposes and by sharing the same infrastructure, MUS can increase water productivity while at the same time reducing water stress.[145,146] To establish effective MUS, multistakeholder "Learning Alliances" have been proposed as a new form of collective development to foster more inclusive decision making and to strengthen stakeholders' capacity and commitment to act.

The benefit of MUS and Learning Alliances from an investment side lies in the different interest groups involved and the diversification and pooling of possible funding sources. The results of a cost-benefit analysis of single-use versus multiple-use water services suggest that higher investments in the short term to address people's multiple needs maximize impact in the long term.[147,148,149] In the Tillabery Region of Niger, 60 percent of households that benefitted from a MUS project increased food consumption from 1.3 to 3 meals per day, and 93 percent of the same households reported an increase in income of US$117 per agricultural season.[150]

Global funding opportunities

There are a number of global funding mechanisms that countries can tap into for grants and low-interest loans to finance the development of targeted irrigation programs or to upgrade existing irrigation infrastructure. Access to these funds also helps governments to mitigate the initial high up-front costs often associated with the acquisition of modern irrigation tools and equipment and the development of irrigation infrastructure.

xii It is important to recognize that "private sector" can refer to farmers themselves as well as the companies, agro-dealers, or other stakeholder providing farmers with tools and equipment.

The Green Climate Fund

The Green Climate Fund (GCF) is a multilateral climate fund, set up in 2010 by all 194 countries of the United Nations Framework Convention on Climate Change (UNFCCC) to support developing countries in responding to the impacts of climate change. The GCF invests in the design and implementation of mitigation and adaptation strategies or low-emission, climate-resilient development—including irrigation infrastructure—and currently co-finances irrigation projects in 14 African countries worth over US$400 million. In Morocco, the GCF, together with the Moroccan government and the *Agence Française de Développement* (AFD), is investing approximately US$90 million in a five-year project for irrigation development and adaptation of irrigated agriculture to climate change. Due to increased temperatures and water scarcity, the predominantly large-scale farms in the region rely on oasis-based water along the Guir wadi, which has been depleted by several years of drought and irregular rainfall. To preserve underground water supplies, the project will build an irrigation system connected to a nearby dam, thereby ensuring sustainable flows of water to farms while preserving water resources for other downstream users. It is estimated that the project will benefit 15,500 farmers.[151]

In the irrigation sector, BOTs could help to mobilize new sources of capital to accelerate the development of water and irrigation projects and introduce innovation and technology transfer from the private sector.

In Tanzania, the GCF, the Tanzanian government, the German Development Bank KfW, and local user groups have invested US$167 million in safeguarding water supplies and improve farming conditions in the Simiyu Region. The region is heavily dependent on agriculture, but farming conditions are threatened by the unreliability of the two rainy seasons and a failure to adapt agricultural practices to climate change. The project aims to strengthen the government's community-based adaptation planning and to improve water supply infrastructure, sanitation services, and agricultural practices, in particular through climate-smart agricultural approaches, including small-scale irrigation systems such as drip irrigation and sprinklers. It is estimated that the project will benefit three million people in the region.[152]

The GCF has a multi-layered approach to mobilizing climate finance, working directly with governments and the private sector. National Designated Authorities (NDAs) – often ministries of environment – act as a country's interface with the GCF, developing project ideas and submitting funding proposals for the GCF Board for approval.[153]

In the Tillabery Region of Niger, 60 percent of households that benefitted from a MUS project increased food consumption from 1.3 to 3 meals per day, and 93 percent of the same households reported an increase in income of US$117 per agricultural season.

The Global Agriculture and Food Security Program

Another international fund that governments can tap into to finance irrigation expansion and development is the Global Agriculture and Food Security Program (GAFSP). In Malawi, Niger and Togo, the GAFSP has provided funding of US$39 million, US$21 million, and US$19 million, respectively, for developing water collection and irrigation system projects. The projects aim to strengthen smallholder farmers' resilience in the face of climate change and changing weather patterns by reducing farmers' dependence on rainfall.[154] The GAFSP offer a range of public and private investment tools, including grants, concessional loans, blended finance, technical assistance, and advisory services and its projects are led by governments, the private sector, and civil society organizations. Funds are channelled as grants to countries through their governments via the Public Sector Window; financing packages to private sector enterprises and agribusinesses through the Private Sector Window; and grants to producer organizations with smallholder farmer membership through the Missing Middle Initiative (MMI).[155]

9. Policy Frameworks: Continental and Global

There is now growing attention amongst policymakers to the need for and potential of irrigation to contribute to continental and global agricultural transformation agendas, including meeting the targets and goals set out under the African Union's Agenda 2063 and the 2025 African Water Vision, and the Sustainable Development Goals (SDGs).

Continental policies

Irrigation and water management for African agriculture is closely tied into continental and global policy frameworks and processes. At the continental level, under the African Union (AU) Agenda 2063 first 10-year plan, a target under Goal #7—*Environmentally sustainable climate resilient economies and communities*—seeks to increase levels of water productivity from rain-fed agriculture and irrigation by 60 percent from 2013 levels, and to harvest at least 10 percent of rainwater for human, agricultural and industrial use. Goal #5—*Modern agriculture for increased productivity and production*—promotes policies that contribute to value addition in agriculture through investments in agro-processing, irrigation, and road infrastructure to meet several targets, including the doubling of agricultural productivity.[157]

Drip irrigation system, Malawi

The importance of water and irrigation is further stressed in the Malabo Declaration's Goal #3—*Commitment to ending hunger in Africa by 2025*—committing heads of state and governments to efficient and effective water management systems, notably through irrigation to accelerate agricultural growth and end hunger in Africa by 2025.[157] The AU's Biennial Review (BR) Report, which monitors and reviews the progress made by member states in implementing the Malabo Declaration, captures efforts on irrigation in a combined indicator. Goal #3.1—*Access to agriculture inputs and technologies*—covers investments in and development of irrigation schemes. In 2017, only eight countries were on track to meeting the goal: Ethiopia, Ghana, Mauritania, Mauritius, Morocco, Namibia, Rwanda and Zambia. The BR explicitly notes the need for investments in irrigation in five countries, namely Niger, Sierra Leone, South Africa, Zambia and Zimbabwe. Given the potential role of irrigation in strengthening agricultural growth and improving the livelihoods of farming communities in rural areas, a dedicated indicator on irrigation development within the BR that captures countries' investments in and development of small- and large-sale irrigation could be beneficial.[158]

An analysis by IFPRI in 2011 found that most of the 24 countries in SSA that signed CAADP compacts with investment plans mentioned the need for irrigation development to meet the envisioned food security goals, and most stated the need for both small- and large-scale irrigation development. However, only six countries listed specific plans for area expansion, generally for a timeframe to 2015, including Burkina Faso (55,000 ha), Liberia (19,250 ha), Malawi (228,000 ha), Mali (45,500 ha), Niger (75,000 ha), and Rwanda (13,000 ha). Although including irrigation expansion goals in the national policies should be encouraged, the ambitions of some of countries appear to have been both too large and too rapid. Malawi's and Liberia's expansion plans suggest increases of 400 percent and 1,000 percent over existing areas, respectively.[159]

The 2025 African Water Vision, a framework developed in 2000 by the African Union, the African Development Bank (AfDB), and the United Nations Economic Commission for Africa (UNECA) calls for "*an Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation, and the environment*." The framework stresses the need to increase water productivity of rain-fed agriculture and irrigation by 60 percent and the area under irrigation by 100 percent by 2025.[160] Based on this vision and the aim of promoting development and poverty eradication through the effective management of the continent's water resources and provision of water supply services, the African Ministers' Council on Water (AMCOW) was formed in 2002 in

Abuja, Nigeria. The AMCOW offers guidance on the achievement of the African Water Vision at regional, subregional and national levels, working in partnership with development organizations, civil society, and other relevant stakeholders. Under theme #1—*Water infrastructure for economic growth*—the plan stresses the optimal use, rehabilitation and effective management of dams, hydropower schemes, irrigation schemes, and water supply and sewage infrastructure.[161]

Global policies

At the global level, efficient use of water for agriculture features heavily within development policy processes and frameworks. Within SDG #6—*Clean Water and Sanitation*—the need for improving water quality, integrated water resource management, and the protection and restoration of water-related ecosystems is stressed. Further, the need to support developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies is highlighted in the targets for 2030.[162]

The African Green Revolution Forum, held in Kigali in September 2018, focused on the role of possible investments and development opportunities in small-scale and farmer-led irrigation in Africa.[163] A joint statement affirmed the support for inclusive and sustainable farmer-led irrigation in Africa and its role for achieving food security and poverty reduction.[164]

To meet the various goals established under continental and global policy frameworks, particularly the Malabo Declaration and the SDGs, African countries need to elevate water for agriculture and irrigation to top policy priorities within their national agriculture investment strategies.


Farmer watering her seedlings, Malawi

10. Methodology and Country Profiles

Several countries across Africa have a high level of irrigation infrastructure, have made good progress in improving their level of irrigation uptake, or both. Their experience in terms of institutional innovations, policy design, and implementation on the ground is reviewed in detail in this report to draw lessons for other African countries. The remaining part of this report summarizes the findings of a systematic analysis of what countries at the forefront of progress on irrigation have done right to facilitate policy innovation that brings positive change to scale in Africa's agriculture sector.

To select countries for this analysis, data was analyzed on the total area equipped for irrigation to identify a cluster of countries (excluding island states) with significant land under irrigation. A threshold of 100,000 hectares of land under irrigation was defined and countries with a total area equipped for irrigation above that threshold formed the cluster of countries from which the study countries were selected. Countries that are in conflict or currently irrigate all arable land were excluded from the analysis as outliers.

In the second stage, countries that achieved high levels of irrigation or have made significant progress on irrigation uptake were selected. As indicators, the report analyzed data by FAO on (1) the percentage of the total area equipped for irrigation between 2012 and 2014 to measure a country's level of irrigation, and (2) the percentage increase in the share of arable land under irrigation between 2002–2004 and 2012–2014 to measure progress in irrigation uptake. These indicators were chosen as it was assumed that a higher percentage of the total area equipped for irrigation would reflect a higher level of irrigation, while a higher percentage increase in the share of arable land under irrigation would reflect more substantial progress in irrigation uptake.

The country selection also took into account regional representation across the continent, including North Africa and SSA. Therefore, countries within the defined cluster were ranked based on each indicator and the top country from North Africa and the top two countries from SSA under each indicator were selected for the case study analysis. Morocco, South Africa and Mali were identified for their high level of irrigation; Ethiopia, Kenya and Niger were identified for their pace of irrigation expansion. Table 4 shows the percentages of area equipped for irrigation and the increase of the share of arable land under irrigation for the selected countries, while table 5 provides a summary of the institutional innovations, policy and programmatic interventions and implementation modalities of each country analysis.

Large-scale sprinkler irrigation, Libya

TABLE 4: Top-ranking countries on level of irrigation in 2012–2014 and pace of irrigation expansion between 2002–2004 and 2012–2014

Level of irrigation (%)		Pace of expansion of irrigated areas (%)	
Morocco	18.9	**Ethiopia**	51.5
South Africa	13.4	**Kenya**	36.8
Mali	5.8	**Niger**	20.0

Source: Authors' compilation based on data from FAO.

TABLE 5: Institutional innovations, programmatic interventions, and implementation modalities of the six case-study countries

Country	Institutional innovations	Policy / Programmatic interventions	Implementation modalities
Ethiopia	■ Irrigation development led by Ministry of Water, Irrigation and Electricity in tandem with: • Water Works Design and Supervision Enterprise (WWDSE) on design and construction • Water Works Construction Enterprise (WWCE) on dam construction for irrigation • Water Resources Development Fund (WRDF) on finance, specifically long-term loans • Ministry of Agriculture and Natural Resource Development (MoARD) on community-managed small-scale irrigation schemes (up to 250 ha) • Ministry of Environment, Forest and Climate Change (MoEFCC) on assessing environmental impact; and • Ministry of Finance and Economic Cooperation (MoFEC) on allocating capital budget for the construction ■ Establishment of Agricultural Transformation Agency, being involved in water resource detection	■ Implementation of the first Water Resources Management Policy (WRMP) in 1999 ■ Development of the Ethiopian Water Sector Strategy (EWSS) and the Water Sector Development Programme (WSDP) in 2001 ■ Capturing irrigation in the Policy and Investment Framework (PIF) in Ethiopia's 2010–2020 National Agriculture Investment Plan ■ Development of the Climate Resilient Green Economy (CRGE) initiative in 2011 ■ Introduction of technical and vocational training programs in 2003	■ Comprehensive portfolio of interventions with clear and well-articulated responsibilities among participating organizations ■ Combination of infrastructure development, financial intermediation and skill building ■ Prioritization of small- and medium-scale irrigation systems

Country	Institutional innovations	Policy / Programmatic interventions	Implementation modalities
Kenya	▪ Establishment of National Irrigation Board in 1966 ▪ Assignment of responsibility for water management to the Ministry of Agriculture, Livestock, Fisheries and Irrigation ▪ Devolution of planning and implementation of irrigation programs to local counties ▪ Allocation of water and delivery of water permits by the Water Resources Authority ▪ Coordination and promotion of investment in integrated natural resource use, including irrigation, by six Regional Development Authorities ▪ Leadership on research on irrigation by the Kenya Agricultural Research Institute and the Tegemeo Institute at Egerton University ▪ Adoption of the Irrigation Bill, in 2017 to set up a national irrigation development authority	▪ Adoption of long-term development plan, Vision 2030, in 2008 ▪ Initiation of several flagship projects e.g. Ahero, West Kano, Kerio Valley, Mwea, and Ewaso Nyiro North, by the National Irrigation Board including the Galana Kulalu Food Security Project, launched by the President ▪ A holistic approach to project development includes additional infrastructure and value chain development such as training, storage, processing and transport ▪ Different private companies providing smart small-scale irrigation solutions, like solar pumps and treadle pumps	▪ Implementation mainly led by the government and development partners, but also supported by private sector involvement ▪ Prioritization of small-, medium- and large-scale irrigation systems ▪ A focus on smart irrigation technologies drawing expertise from local educational institutions and the private sector ▪ With finance from alternative sources, such as Green Climate Fund, a drive to increase solar powered irrigation
Mali	▪ Creation of the *Office du Niger* (ON) service in 1932, a large-scale irrigation scheme in what is now the Ségou Region ▪ Creation of a division in charge of hydro-agricultural development in the National Directorate of Rural Engineering (DNGR) within the Ministry of Agriculture ▪ Establishment of the Regional Chambers of Agriculture of Mali, public institutions with legal status and financial autonomy, in 1993 to represent those working in agriculture, including irrigated agriculture, to public authorities and participates in the design and implementation of rural development policies and programs ▪ Creation of the Agency for Land Management and Supply of Irrigation Water (ATI) in 2015	▪ Programs for expanding and maintaining the large-scale irrigation scheme of the *Office du Niger* since 1960 ▪ Implementation of a program to expand large-scale irrigation development under the *Office du Niger*, including the Alatona program in 2009 ▪ Irrigation infrastructure development under the Program for Increasing Agricultural Productivity in Mali (PAPAM) in 2011 ▪ Irrigation infrastructure development under the National Program of Irrigation of Proximity (PNIP), in 2012	▪ Implementation mainly led by the government with increasing involvement of private sector ▪ Prioritization of both small-scale and large-scale irrigation systems ▪ Inclusion of beneficiaries in the implementation of policies and programs for more ownership ▪ Targeting of women and youth under government irrigation programs

Country	Institutional innovations	Policy / Programmatic interventions	Implementation modalities
Morocco	■ Creation of a Directorate of Irrigation and Development of the Agricultural Area within the Ministry of Agriculture, in charge of design, implementation, M&E of irrigation policies and programs ■ Establishment of Regional Offices of Agricultural Development (ORMVA) in 1966 ■ Creation of Association(s) of irrigation professionals through law in 1990 ■ Creation of 52 agricultural vocational training centers for skill development and training qualified technicians to service and repair agricultural equipment and tools, including irrigation equipment	■ Introduction of irrigation equipment subsidy programs in 1985, including an exemption from VAT for irrigation equipment and subsidy of 40 percent for all components of irrigation investment at farm level ■ Irrigation expansion under the hydro-agricultural development program ■ Execution of a 2008-2020 National Program for Irrigation Water Saving (PNEEI) ■ Development of a Program of Irrigation Expansion (PEI) in 2008 to upgrade 1.5 billion m^3 of water through hydro-agricultural developments, covering an area of 160,000 ha by 2020, as part of the *Plan Maroc Vert* ■ Innovative PPP programs for greater private sector involvement in irrigation	■ Major emphasis on finance for facilitating access to modern irrigation technologies ■ Strong involvement of the private sector in implementation through PPPs ■ Prioritization of both small scale and large-scale irrigation systems ■ Inclusion of beneficiaries in the implementation of policies and programs for more ownership ■ Promotion of environmentally friendly technologies and practices
Niger	■ Creation of the General Directorate of Rural Engineering within the Ministry of Agriculture in charge of irrigation development ■ Establishment of the National Office of Hydro Agricultural Management for promoting irrigated agriculture in Niger in 1978 ■ Creation of the network of *Regional Chambers of Agriculture* in 2006 ■ Creation of the *Office in charge of implementing the initiatives Nigeriens Nourished Nigeriens* (I3N) executing irrigation programs in 2011	■ Development of irrigation policies and programs through national sectoral policies, including the Accelerated Development and Poverty Reduction Strategy in 2002 and the Rural Development Strategy in 2003 ■ Development of the National Strategy for the Development of Irrigation and Collection of Runoff Water (SNDI/CER) in 2005 to improve the contribution of irrigated agriculture to agricultural GDP ■ Launch of irrigation programs under the initiative I3N, for increasing production in 2011 ■ Development of the Small Irrigation Strategy for harmonization of interventions and funding approaches in small-scale irrigation in 2015 ■ Private Irrigation Promotion Project implemented by the private sector between 2003 and 2008	■ Government-led programs with an increasing involvement of the private sector ■ Prioritization of small-scale irrigation systems implemented simultaneously with other national sectoral policies

Country	Institutional innovations	Policy / Programmatic interventions	Implementation modalities
South Africa	■ The National Water Act 1998 stipulated fundamental reforms on the use and management of water resources ■ The Directorate of Water Use and Irrigation Development (DWID) is responsible for the efficient development and revitalization of irrigation schemes and water use ■ Establishment of the Agricultural Research Council and the Water Research Commission (1971) ■ Participation in the International Commission on Irrigation and Drainage (ICID)	■ Development of an Irrigation Strategy under DAFF in 2015 • Revitalization of smallholder irrigation schemes, estimated to cost US$ 1 billion ■ Implementation of Water Restrictions through policies, since 2016 ■ Creation of the South African Irrigation Institute (SABI) with focus on the efficient use of irrigation water and optimization of all other associated resources ■ Implementation of the 2nd National Water Resource Strategy from 2013 underlying the need for groundwater development and management, water harvesting and infrastructure management	■ Prioritization of large-scale irrigation systems, but also projects on small- and medium-sized schemes ■ Joint projects with development partners, NGOs and research institutes ■ Private company involvement in training and irrigation management ■ Development of new technologies mainly driven through the private sector ■ Operationalizing of community-driven multiple use water services project in collaboration with the IWMI

Farmer using rope-and-bucket method for irrigation, Burkina Faso

CASE STUDY

Ethiopia

Between 2002 and 2014, the area under irrigation in Ethiopia increased by almost 52 percent. In 2015, the estimated total area equipped for irrigation was 858,340 hectares (ha). In addition, around 1.1 million ha were estimated to be cultivated through farmer-led irrigation.[165] The 2018 Biennial Review Report by the African Union revealed that Ethiopia is on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 6.03 out of 10, which vastly exceeds the 2017 minimum score of 5.53.[166] Nevertheless, the share of arable land equipped for irrigation currently accounts for only about 5 percent,[167] even though the economic potential for large- and small-scale irrigation development is very high. **The internal rate of return (IRR)[xiii] for large-scale irrigation is over 7 percent, with an estimated expansion area of 0.75 million ha. The IRR for small-scale irrigation is even higher, at 12 percent, with an estimated area of 0.16 million ha.[168]**

INSTITUTIONAL INNOVATIONS

At federal level the Ministry of Water, Irrigation and Electricity (MoWIE) and its subsidiary organizations – including Water Works Design and Supervision Enterprise (WWDSE), Water Works Construction Enterprise (WWCE), and Water Resources Development Fund (WRDF) – the Ministry of Agriculture and Natural Resource Development (MoARD), the Ministry of Environment, Forest and Climate Change (MoEFCC), and the Ministry of Finance and Economic Cooperation (MoFEC) are all responsible for development of irrigation sector infrastructure in Ethiopia. The MoWIE leads the development and implementation of guidelines, strategies, polices, programs, and sectoral laws and regulations and is the main actor to handle medium- and large-scale irrigation schemes. It is also responsible for regional and inter-regional water resource development and management, as well as for functions that involve international procurement.

The WWDSE conducts studies related to irrigation, basin development master plans, and other water projects. Moreover, it carries out surveys, designs, and specifications, delivers consultancy services on resource development, and builds national capacity in the field of water resource study, design, and construction supervision. The WWCE is in charge of the construction of dams pertaining to water resource development for irrigation and other related development purposes. The WRDF is part of the MoWIE, providing long-term loans and acting as a semi-autonomous body on behalf of the Ministry to expand sustainable irrigation development. Loans are issued for a period of 20 to 25 years at 3–5 percent fixed interest rates. Among others, the MoARD is responsible for developing community-managed small-scale irrigation schemes (up to 250 ha); while the MoEFCC is in charge of investigating the environmental impact of irrigation projects; and the MoFEC is responsible for allocating capital budget for the construction of such projects. Regional and local-level (district and subdistrict) irrigation sectors follow the same structure, even if the placement of the sector in terms of organizational structure differs across regions. Some regions such as Oromia recently reorganized a separate irrigation authority, while in other regions like SNNP and Beneshangul Gumuz, the responsibilities are with the Bureau of Agriculture. In addition, River Basin Authorities are responsible for the management and implementation of water-related activities in their respective basins. Irrigation Water Users Associations and Irrigation Cooperatives are local-level institutions engaged in mobilizing and coordinating communities' sustainable and efficient use of irrigation water. The beneficiary communities are also responsible for operating and managing irrigation schemes.[169]

In 2010, the Agricultural Transformation Agency (ATA) was established, chaired by the Prime Minister. In 2013, the ATA began mapping over 32,400 square kilometers (km^2) to identify water resources, especially shallow groundwater, with potential for irrigation development. The final results of shallow groundwater mapping in 89 districts (woredas) indicate the presence of nearly 3 billion m^3 of water at a depth of less than 30 meters. This could allow approximately 100,000 ha of land to be brought under irrigation, benefitting 376,000 households.[170]

At the regulatory level, the Ethiopian Water Resource Management Proclamation No. 197/2000, Council of Ministers Water Resource Regulation No. 115/2005, River Basin Councils and Authorities Proclamation No. 534/2007, Rural Land Administration and Land Use Proclamation No. 456/2005 and Irrigation Water Users Association (IWUA) Proclamation 2014 are the legal instruments that govern the operation and management of irrigation in Ethiopia.[171,172]

Policies and strategies

Agriculture and irrigation have been featured on the Ethiopian policy agenda since 1991, when the government implemented its strategy of Agricultural Development-Led Industrialisation (ADLI), which sees agriculture as the engine of growth. In 1999, the Government of Ethiopia issued the first Water Resources Management Policy (WRMP) of its kind. The WRMP set guidelines for water resources planning, development,

xiii The displayed internal rate of return (IRR) (You et al., 2011) provides the estimated financial return for possible irrigation investments over a period of 50 years. The IRR is a measure of profitability of potential investments in irrigation. The higher the IRR, the higher the profit.

CASE STUDY

Ethiopia

Farmer watering her plants, Ethiopia

and management. In particular, the policy sought to enhance the production of food crops and raw materials needed for agro-industries through irrigation on an efficient and sustainable basis. To translate the WRMP into action, the Ministry of Water Resources (MoWR) issued the Ethiopian Water Sector Strategy (EWSS) in 2001.[173] Within the strategy, the Water Sector Development Programme (WSDP) set out five different sub-components: Water Supply and Sewerage, Irrigation and Drainage, Hydropower Development, General Water Resources, and Institutions/Capacity Building. The principal objective of the Irrigation Development Programme is environmentally and financially sustainable expansion of agricultural land under irrigation, and improved water use efficiency toward achieving food self-sufficiency at the national level, and satisfying the raw material demand of local industries. To this end, the policy foresees to build micro dams on rivers/streams, consider cost-effective pumping stations using pressurized irrigation technologies, make higher budgetary allocations to irrigation, promote the use of shallow wells using hand and foot pumps; and promote the participation of the private sector in the management of water resources.[174]

In 2003, the Rural Development Policy and Strategies presented specific policies and strategies to guide agricultural and rural development, aimed at productive and sustainable utilization of agricultural land through irrigation, multicropping, and diversified production.[175] The recently completed Plan for Accelerated and Sustained Development to End Poverty (PASDEP) 2005/06–2009/10 and the Five Year Growth and Transformation Plan (GTP I) underpinned the objectives for the agriculture sector. Besides others, PASDEP promoted irrigation development while GTP I further aimed to improve the management of natural resources with a focus on improving sustainable water utilization and the expansion of irrigation.[176,177] Irrigation is also captured in the Policy and Investment Framework (PIF) in Ethiopia's 2010–2020 National Agriculture Investment Plan (NAIP). The PIF calls for major investments in irrigation development, including both smallholder and larger-scale commercial schemes to exploit Ethiopia's abundant, yet underutilized, water resources. In particular, the plan seeks to increase the area under irrigation by 8 percent annually, and to improve water conservation and water use efficiency. Overall, the government aims

Ethiopia

to allocate over half of the total funding of US$15 billion until 2020 to irrigation development.[178] In addition to the goals set in the NAIP, the Growth and Transformation Plan (GTP II) 2015–2020 aims to increase irrigation-based agriculture to 4.1 million ha for small-scale and to 954,000 ha for medium- and large-scale schemes, including the use of alternative energy sources like solar and wind power.[179] Recognizing the close links between environmental and development concerns, the government is working to integrate climate considerations into its broader development planning processes. The Climate Resilient Green Economy (CRGE) initiative, under the leadership of the Prime Minister's Office, the EPA, and the Ethiopian Development Research Institute, was launched in late 2011. The initiative developed a strategy to build a green economy and laid the foundation for integrated planning for climate-resilient development. The Resilience Strategy for Agriculture acknowledges irrigation as a critical response to climate change for smallholder and industrial agriculture.[180]

PROGRAMMATIC INTERVENTIONS

In collaboration with development partners, the government set up different irrigation projects across the country. Between 2008 and 2015, the Participatory Small-Scale Irrigation Development Programme (PASIDP) aimed to develop a sustainable, farmer-owned and -managed system of small-scale irrigated agriculture. The US$58 million program was largely funded by the International Fund for Agricultural Development (IFAD) and coordinated by the Ministry of Agriculture and water users associations.[181,182] PASIDP sought to: encourage a highly participatory approach to small-scale irrigation development; improve catchment area planning; support construction of small-scale irrigation schemes covering about 12,000 ha; improve farming practices, particularly in soil and water conservation and seed production; and promote home gardens for women. Between 2008 and 2015, interventions under PASIDP developed 116 small-scale irrigation schemes that covered over 12,000 ha of arable land. The project interventions are estimated to have reached more than 311,000 people in 62,200 households in the four regions covered by the project. Beneficiary households were able to double their average crop yields and revenues and had food consumption expenditures that were twice as high.[183]

In the Tigray region, another joint project between the Ethiopian Bureau of Agriculture, local extension officers, and the NGO Farm Africa was established in 2012 to support women and young people to increase their incomes and improve their nutrition through, among other approaches, small-scale irrigation. Under this project, 27 motorized pumps, 200 treadle pumps, and 200 pressurized and drip irrigation pumps were installed in 200 households, together with a 500-meter canal. The local community received intensive support and training on community management, use, and maintenance of irrigation equipment and irrigation scheduling, and technical support on agricultural production. In addition, 600 fruit and vegetable seedlings were distributed to 300 farmers. Overall, the project reached nearly 6,400 women and landless people, of which 700 farming families benefitted directly from the irrigation project.[184,185]

In 2003, a collaboration between the MoWR and the Ministry of Education initiated the Water Works Technical and Vocational Training Programme, with 480 trainees in six training centers in four regional states. During the three-year program, students are trained on irrigation, water supply, and electromechanics. The curricula include the design, construction supervision and operation, and maintenance of irrigation and water supply tools and equipment.[186] In addition to vocational training, some universities provide specialized courses and general training on aspects of irrigation and water resource management.[187]

Furthermore, the government has focused investment in agricultural water management technologies. Different irrigation water control structures have been implemented, such as temporary or permanent river or stream diversions, spate irrigation, micro-dams, rainwater harvesting and ponds, and pumping systems (from groundwater, rivers, or lakes). Surface (gravity-fed) canal systems are currently the most common irrigation technology in the country.[188] Data from the Ethiopian Revenue and Custom Authority state that around 800,000 motor pumps were imported between August 2004 and December 2010.[189] The government imports these pumps free of duty and tax and sells them through cooperatives.[190] Ethiopia's remarkable growth in irrigation expansion has largely been driven by the government's commitment to comprehensive institutional innovations and targeted policy and programmatic interventions, as well as strong regulatory frameworks that govern irrigation and the use of water in agriculture. ■

CASE STUDY

Kenya

In 2010, Kenya had an estimated total area equipped for irrigation of 150,570 hectares (ha).[191] Although the 2018 Biennial Review Report by the African Union revealed that Kenya is not on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 5.43 out of 10, which falls just below the 2017 minimum score of 5.53, the score reflects good progress.[192] According to data on three-year averages, Kenya increased the area under irrigation by about 37 percent between 2002/2004 and 2012/2014. Currently, the share of arable land equipped for irrigation accounts for just 2.6 percent.[193] **The economic potential for both large- and small-scale irrigation is very high, with an internal rate of return of approximately 7 percent and 40 percent, respectively, and the potential to bring 0.3 million ha and 0.05 million ha under irrigation.[194]**

INSTITUTIONAL INNOVATIONS

The majority of Kenya's irrigation schemes prior to independence were based on traditional systems, although there were some state-owned schemes too. By 1963, Kenya had developed a total of 2,500 ha for irrigation. Between 1963 and 1980, the focus was on expanding existing schemes and developing new, smaller schemes with support from development partners. As such, the National Irrigation Board (NIB) was formed in 1966 to manage public irrigation and private community-based schemes.[195]

Between 1978 and 1983 the emphasis continued to be on small-scale, farmer-managed irrigation, but out of the 6,700 ha initially projected, only 2,500 ha were equipped by 1989. Since the 1990s, export of horticultural crops has been the main driver for irrigation development.[196] Over the years, responsibility for irrigation has been within the Ministry of Water, which has itself undergone several mergers and de-mergers with other ministries.[197] Currently, the responsibility for water management lies with the Ministry of Agriculture, Livestock, Fisheries and Irrigation, replacing the former Ministry of Water and Irrigation. Under this Ministry, the Irrigation and Drainage Directorate (IDD) is responsible for the overall coordination of irrigation activities, specifically for the development of smallholder irrigation. Prior to the 2010 Constitution, the IDD was responsible for policy and planning, while the NIB was responsible for implementation on the ground. However, the 2010 Constitution devolved both planning and implementation to local counties, at least for the projects they finance.[198]

At the national level the Water Resources Authority (WRA), formerly the Water Resources Management Authority (WRMA), is responsible for the allocation of water and delivery of water permits for various needs, including agriculture. The WRA delivers water permits only after ecological and basic human needs, international treaties and interbasin water transfers, and reserve and domestic water demands have been met.[199]

At subnational level, the six Regional Development Authorities (RDAs), based on the main river basins of the country, plan, coordinate, and promote investment for integrated natural resource use, including irrigation projects.

A farmer irrigating their field, South Africa

CASE STUDY

Kenya

Duplication of functions thus arises between the Ministry of Agriculture, Livestock, Fisheries and Irrigation and the IDD, NIB, and RDAs.[200] Further, the Kenya Agricultural and Livestock Research Organization (KALRO), formerly the Kenya Agricultural Research Institute (KARI) and the Tegemeo Institute at Egerton University lead on irrigation research.[201]

In 2017, the government issued an Irrigation Bill, intended to set up a national irrigation development authority, to be run by a private company. The authority will be responsible for developing and improving irrigation infrastructure, providing irrigation services to private, medium-scale, and smallholder schemes, and for technical advisory services during the development of irrigation schemes.[202]

This is supported by President Uhuru Kenyatta's Big Four Initiative, announced in late 2017. As one of four main priorities, it includes one pillar on Food Security and Nutrition with the need to form an Agriculture and Irrigation Sector Working Group (AISWAG) to provide coordination for irrigation projects enhancing large-scale, commercial production.[203]

POLICY AND PROGRAMMATIC INTERVENTIONS

In 2008, Vision 2030 was launched by the government and is the long-term development blueprint for the country.[204] Several other policies and plans have been linked to Vision 2030, such as the Agricultural Sector Development Strategy 2009–2020 (ASDS). Within the ASDS the water and irrigation subsector aims to address the following intervention strategies:

- Finalization and implementation of the national irrigation policy and legal framework, including an increase in the government's financial allocation to irrigation of at least 2 percent of gross domestic product annually;
- Intensification and expansion of irrigation through a multisectoral approach and establishment of public-private partnerships with the aim to develop 32,000 ha of existing irrigated land per year and 704,000 ha of new irrigation areas by 2030;
- Improvement of rainwater harvesting and storage for agriculture, with an increase from 184 million cubic meters (m^3) to 25 billion m^3;
- Rehabilitation and protection of water catchments; and
- Implementation of the irrigation flagship projects, including the schemes in Bura, Hola, Ahero, West Kano, Bunyala, Perkerra, Kerio Valley, Mwea, Taita Taveta, Ewaso Nyiro North, and Ngurumani.[205]

In 2014, one of the government's flagship irrigation development projects, the "Galana Kulalu Food Security Project" run by the NIB, was initiated with the aim to reduce the price of maize. The contract for the project was awarded to Green Arava Ltd, with funding by the Government of Kenya. The project seeks to develop infrastructure for viable and economic utilization of natural resources, including water storage, water conveyance and distribution, irrigation, livestock production, and aquaculture.

The first phase of implementation comprises a 4,000-ha model farm that will be entirely self-sufficient. Phase two is followed by expansion to over 160,000 ha of farms that should replicate the outcomes of the model farm.[206] Fertilization and filtration will be available for all irrigation systems to optimize crop yields. At the operational center of the model farm, maize mills will be constructed, including storage silos and a packing house for vegetables with cooling rooms for storage. An electrical workshop, locksmith, and garage will be installed, and trainings will be made available to farm employees.[207]

Besides the irrigation component NIB has scheduled other activities, including construction of roads and community irrigation projects. In 2018 the NIB handed over about 8,000 ha of total area to private firms and the Agricultural Development Corporation (ADC) to plant and mill more maize.[208]

Smart irrigation strategies

In 2016, Kenya's Meru University of Science and Technology developed a "sensor-based automatic irrigation system" app that monitors the need for water in fields and controls irrigation equipment. The app makes use of sensors placed in a field to determine the soil's moisture. If it is too dry, a control unit uses solar panels to open the valve of a water tank and closes it again when the soil is damp enough. The upfront costs are rather high – US$480 per 0.1 ha for a combined app and irrigation system, including solar panels and two drip irrigation lines. The system can be expanded to an additional 0.1 ha for US$48.[209]

The US company SunCulture, based in Nairobi, has been selling solar irrigation kits to Kenyan smallholder farmers since 2013. The SunCulture AgroSolar irrigation system combines the energy efficiency of solar power with the effectiveness of drip irrigation. Solar panels provide the pump's electricity without the need for batteries or inverters. Water is pumped into a raised water storage tank during the day. During the evening, the irrigation takes place and a valve on the water tank is opened; using gravity, water flows down through a filtration system onto the crop root zones via the irrigation tape. The kit costs US$2,500, including the solar pumping system, drip irrigation equipment for 0.4 ha, and training on how to operate

Kenya

the system. According to experience, farmers can increase their yields by 300 percent or more and save over US$10,000 per year compared to using petrol or furrow systems.[210]

KickStart, an international company headquartered in Kenya and operating in 17 African countries, markets two different types of pumps – a treadle pump and a hip pump. The hip pump is the smaller version, weighing 4.5 kilograms (kg), whereas the treadle pump weighs 16 kg. Both pumping systems have the capacity to pump water from a depth of 7 meters, a maximum pumping height of 14 meters, and an overall push distance of 200 meters on flat ground. The hip pump irrigates up to 0.5 ha of land per day, while the treadle pump can irrigate up to 0.8 ha per day. The pumps and spare parts are sold through agrodealers. Costs for the larger treadle pump range between US$150–250, while the hip pump is sold for around US$50. For most farmers, this is still beyond reach. KickStart is currently in the process of developing financing options and microcredits. By September 2018, about 327,000 pumps had been sold.[211]

Furthermore, a project co-financed by the Green Climate Fund, KawiSafi Ventures, Acumen Fund, and other investors aims to create an investment fund to drive off-grid solar power in Kenya and East Africa. Investments totalling US$110 million are scheduled to develop 10 to 15 alternative energy small- and medium-sized enterprises. Solar power can be useful for various agriculture-related activities. Examples include solar-powered irrigation pumps and power for small businesses such as rice processors. The project estimates that savings for households can range from approximately US$75 to US$200 per year, depending on the daily cost of kerosene, the amount of kerosene displaced, and the cost of the solar system in the specific geographic market. Further, more powerful solar home systems have the ability to power micro and small business to increase income for consumers and can be used for agricultural inventions. Solar-powered irrigation pumps and refrigeration can increase farmers' yields and ultimately income.[212] One of the few companies selling solar home systems is the British company Sollatek, which has been operating in Kenya since 1985, selling its products through a regionwide network of distributors. Besides a range of domestic solar systems, like lamps and solar panels, Sollatek sells solar water pumps as well as solar refrigerators and freezers.[213] Over the last ten years, Kenya has significantly increased the area under irrigation, largely due to strong policy innovations and programmatic interventions as well as an active role of the private sector in the dissemination of smart irrigation technologies. However, the potential to expand the share of arable land under irrigation remains high.


Farmers using solar pumps to irrigate their plots, Kenya

CASE STUDY

Mali

Mali has a long tradition of irrigation due to strong institutional and programmatic innovations to both improve and expand irrigation levels. The active involvement of the private sector and the important role of small-scale, farmer-led schemes have contributed to irrigation uptake in the country. Compared to other countries in West Africa, Mali's irrigation capacities have advanced substantially, with nearly 6 percent of arable land currently equipped for irrigation.[214] **Mali also has considerable potential to expand land under irrigation, estimated at 0.19 million hectares (ha) for large-scale irrigation, with an internal rate of return (IRR) of 10 percent, while the potential for small-scale irrigation expansion is 0.3 million ha, with a much higher expected IRR (60 percent).[215]** Irrigated agriculture contributes significantly to the Malian agricultural gross domestic product. This achievement is largely due to institutional and programmatic commitments for increasing irrigation uptake. Despite this, the 2018 Biennial Review Report by the African Union revealed that Mali is not on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 4.56 out of 10, which falls below the 2017 minimum score of 5.53.[216]

INSTITUTIONAL INNOVATIONS

In 1993, the Government of Mali created nine regional Chambers of Agriculture, public institutions with legal status and financial autonomy and coordinated at the national level by the Permanent Assembly of Malian Agricultural Chambers (APCAM). APCAM represents those stakeholders working in agriculture, including irrigated agriculture, to public authorities and participates in the design and implementation of rural development policies and programs. APCAM participates in most agricultural policy discussions at the national and regional levels, with the issues discussed ranging from land tenure reform to irrigation expansion. APCAM also provides farmers and their professional organizations with the necessary support and skills to ensure their own development. It is composed of nine Autonomous and Decentralized Regional Chambers of Agriculture and a Permanent Assembly.[217] In 2005, a division to lead hydro-agricultural development was created as part of the National Directorate of Rural Engineering (DNGR) within the Ministry of Agriculture. The division is responsible for developing a national strategy on access to water for agricultural use, as well as creating plans, programs, and projects for its implementation, especially with regard to irrigation and other agricultural infrastructure and technologies.[218] Through regional directorates and subregional services the DNGR monitors and ensures the effectiveness of its programs on the ground.[219] Moreover, in 2015 the government established the Agency for Land Management and Supply of Irrigation Water (ATI), an autonomous entity that works closely with government services. ATI mobilizes public and private funding for the purchase and application of irrigation equipment, supported with maintenance services. ATI recovers part of the investment costs from producers, who pay for the requested services for use in future investments.[220]

POLICY AND PROGRAMMATIC INTERVENTIONS

In Mali, irrigation policies have long been anchored within national sectoral policies. As part of the 1992 Rural Development Plan (SDDR), a strategy for expanding irrigation systems and a rural infrastructure was partly implemented. In 1997, following adoption of the Accelerated Growth Strategy, programs for boosting the level of crop production under irrigation were implemented. In addition, under the 1998 Poverty Reduction Strategy, a framework for management of irrigated land was established and development of small-scale irrigation and hydro-agriculture promoted. In the same context, under the National Environmental Protection Policy of 1998, the focus of irrigation was on promotion of sustainable agricultural production systems and environmentally sustainable farming methods.[221] In 1999, the government adopted the National Strategy for Irrigation Development (SNDI), the main framework for implementation of irrigation programs and actions. The SNDI considered irrigation as one of the most effective means of ensuring food security and nutrition, reducing imports, increasing rural incomes, and limiting emigration from rural areas.[222] Furthermore, in 2017, the Government of Mali passed a law that requires a minimum of 15 percent of irrigated lands to be allocated to women and youth under government irrigation land development programs.[223]

Investment in irrigation in Mali dates prior to independence, with the creation of the Niger Office (ON) in 1932, a large-scale irrigation scheme in what is now the Ségou Region. Management of the scheme – the largest in West Africa – was taken over by the Government of Mali in 1960 and it now operates as a semi-autonomous government agency. Despite the potential for expansion of irrigable land, only 120,000 ha are currently cultivated by smallholders, mainly for rice and sugarcane production. To further expand irrigated area, the Government of Mali mandated ON to provide plots of land already equipped for irrigation (also financed by the government) to smallholder farmers who hold a land use permit. Investors who hold a land lease are assisted by ON to develop land for irrigation. Many investors have acquired a land lease, as the government regards private investment as an opportunity to develop and modernize its irrigated agriculture. In

CASE STUDY

Mali

2010, more than 770,000 ha were attributed to investors.[224] Furthermore, ON is in charge of providing extension services, including information/knowledge on operating and maintaining irrigation systems to farmers for a fee.[225]

Between 2009 and 2012, the ON scheme received additional government and international support to expand the land under irrigation by 4,940 ha in the Alatona zone. The project aimed at facilitating access to technologies for irrigation, access to loans and investments on land, and income-generating activities for women while improving farm yields, crop revenue and household incomes. Close to 1,000 households were allocated 5 ha of developed land each, as well as training on rights and obligations; they also received extension services to improve farming and business skills and to create farmers' associations. Not only did farmers receive funds for an initial deposit into a microfinance institution, they also learned how to secure further loans. At the same time, local financial institutions were trained on how to track loan repayments. Seeds and other inputs were provided to farmers to begin cultivating the land. Agricultural production reached an estimated 15 metric tons per farmer on 5 ha, a 10-fold increase over non-beneficiaries, who averaged 5 tons on 5 ha.[226]

Under the Program for Increasing Agricultural Productivity in Mali (PAPAM), started in 2011, irrigation infrastructure was developed as a means to cope with the adverse impacts of climate change. This was complemented with the provision of additional environmentally friendly technologies such as biogas digesters and solar energy systems through a subprogram of PAPAM in the southern regions of Kayes and Sikasso.[227] The overall program developed 2,805 ha and 104 market gardening schemes for small-scale irrigation, benefitting 6,375 farmers, 10 of which are equipped with solar pumps and 94 with manual water extraction.[228]

Since 2012, the government has been implementing the National Program of Irrigation of Proximity (PNIP) in Sikasso, Koulikoro, Pays Dogon, and the Delta Intérieur du Niger to improve overall food security in these regions. The program seeks to develop irrigation infrastructure, including micro dams, for supplemental water supply during periods of insufficient rainfall or drought. The small irrigation dams store rainwater in retention ponds that can be used to irrigate farm lands and extend the growing season. The additional access to water may also be used for fish production, livestock watering, and vegetable gardening to diversify livelihoods and improve the nutrition status of those communities. It is estimated that by 2021 the PNIP will increase land under irrigation by 126,000 ha and benefit up to 3 million people.[229]

Large-scale farming using a center -pivot irrigation system, Mali

A study in northern Mali showed that investment in small-scale irrigation not only improves household consumption and production, and hence nutrition, but also leads to an increase in assets and incomes. More importantly, driven by the increased production and household consumption, irrigation investment induces households to save more and share more within their villages, which is a type of investment in informal social insurance. Irrigation investments therefore offer "spillover gains," both at household and community level, outside of the requisite productivity gains.[230] The return on investment of irrigation systems in Mali varies; for example, rice yields usually lie between 4–6 tons with full water control, while free flooding does not yield more than 1 ton, and controlled flooding stands between 1–2 tons. Mali has a long tradition of irrigation due to strong institutional and programmatic innovations to both improve and expand irrigation levels. The active involvement of the private sector contributed to irrigation uptake. In addition, small-scale, farmer-led irrigation is gaining importance in the irrigation policy process. Although the government increased investments in the expansion of land under irrigation, to date only a small share of the country's land potential has been tapped.■

CASE STUDY

Morocco

Morocco has shown strong ambitions in increasing its irrigation uptake and has positioned itself for large-scale adoption of water-saving irrigation technologies. The government has also tapped into the country's high potential for further irrigation expansion. With institutions dedicated to irrigation and strong PPPs, Morocco has proven itself to be a leader in irrigation development on the continent.

It is estimated that nearly 20 percent of Morocco's arable land is currently equipped for irrigation.[231] **The potential to increase the amount of irrigated land is high, estimated at 0.35 million hectares (ha) for large-scale irrigation schemes, with an internal rate of return (IRR) of 18 percent, versus 0.31 million ha for small-scale irrigation schemes, with an IRR of 11 percent.[232]** Irrigated agriculture comprises one-half of Morocco's agricultural gross domestic product (GDP), indicating its higher productivity compared to rain-fed agriculture. The 2018 Biennial Review Report by the African Union revealed that Morocco is on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 7.46 out of 10, which vastly exceeds the 2017 minimum score of 5.53.[233] This is largely due to institutional and programmatic commitments by the government to improve irrigation for a more productive agriculture sector.

INSTITUTIONAL INNOVATIONS

At institutional level the Directorate of Irrigation and Development of the Agricultural Area within the Ministry of Agriculture is in charge of the design, implementation, monitoring, and evaluation of irrigation policies and programs. The Directorate also leads on the promotion and regulation of PPPs focused on irrigation.[234] Morocco started to transform its institutions in 1966 with the creation of the Regional Offices of Agricultural Development (ORMVA), situated within the Ministry of Agriculture. A public institution with legal status and enjoying financial autonomy, ORMVA is responsible for technical studies, project execution and management of hydro-agricultural equipment, management of water resources for agricultural use, and dissemination of new farming technologies. Departments responsible for managing irrigation systems have been equipped with computerized tools and clear procedures and guidelines for the planning, programming, operation, and maintenance of irrigation systems. This enhances engineers' technical capacity to conduct computer-assisted maintenance, and to invoice for water used for irrigation. The government actively involves farmers in the planning of irrigation systems and developed an effective accountability system to manage resources and equipment that farmers use. In addition, a law for the creation of associations of irrigation professionals was passed in 1990.[235] Represented on the management board of ORMVA, the associations participate in the development of annual irrigation programs and in rehabilitation and maintenance of equipment and ensure the distribution of water for irrigation to their members. At the other end of the value chain, the National Office for Health Security of Food Products (ONSSA) is in charge of regulating the conformity of products, including quality control of water used for irrigation, to prevent the consumption of food contaminated with foodborne pathogens.[236]

POLICY AND PROGRAMMATIC INTERVENTIONS

Irrigation policy and programs are at the heart of Morocco's agriculture sector development strategy. To stimulate irrigation uptake, several incentives were put in place by the government. For instance, irrigation equipment is exempt from VAT (value-added tax), thereby making it more affordable.[237] In addition, subsidies of approximately 17 percent were offered for irrigation infrastructure from 1985 to expand irrigation across the country. From 1996, the focus of this financial incentive scheme was refined to encourage farmers to adopt water-conserving irrigation techniques. In 2002, subsidy rates for irrigation systems, including localized drip irrigation, were raised to 40 percent, depending on water availability. More importantly, the subsidies were expanded to all components of irrigation investment at farm level, ranging from mobilization of water resources and construction of storage basins to distribution of water to the plot. Thanks to these efforts, the use of modern water-saving irrigation technologies increased markedly in Morocco. In 2006, the subsidy rate was raised to 60 percent of the investment cost for drip irrigation, and all farmers producing under irrigated agriculture were eligible to request government support. As a result, at the end of 2008, the total area equipped with modern water-saving irrigation technologies by the private sector amounted to 196,500 ha, including 165,000 ha of drip irrigation, up from 108,400 ha in 2000. Currently, the government subsidizes investment in infrastructure and technologies for drip irrigation through the Agricultural Development Fund. The subsidy rate is 80 percent for individual farmers and 100 percent for groups of farmers and smallholders cultivating on less than 5 ha.[238]

As part of the *Plan Maroc Vert* (Agricultural Development Strategy of the Moroccan government), important irrigation programs were implemented. In 2008, the Program of Irrigation Expansion (PEI) was initiated to upgrade 1.5 billion cubic meters (m^3) of water through hydro-agricultural developments, covering an area of 160,000 ha by 2020.[239]

CASE STUDY

Morocco

In addition, in its pursuit of the objective of increasing water use efficiency in irrigation for sustainability, the Government of Morocco implemented the National Program for Irrigation Water Saving (PNEEI) over the period 2008–2020. PNEEI aims to improve and modernize traditional and collective irrigation systems for expanding the use of drip irrigation. To support this program, farmers can access financial assistance from the Agricultural Development Fund to help them purchase the equipment. In addition, farmers benefit from advice and guidance on how to increase the return on water used by producing high-value crops and joining aggregation systems. Due to these government efforts, the amount of land equipped with drip irrigation witnessed a significant increase between 2008 and 2014 to 450,000 ha, with the aim of reaching 550,000 ha by 2020 under the *Plan Maroc Vert*.[240]

Morocco also emphasized PPPs for irrigation development under the *Plan Maroc Vert*. In 2008, the government launched the Innovative Public-Private Partnerships Program, which seeks to encourage greater private sector involvement in the irrigation sector. For instance, the program offers long-term leases on land for private investors to develop new agricultural projects.[241] PPPs in irrigation reduce the financial burden of subsidies for investment on the public sector; improve sustainability and quality of irrigation and drainage services available for farmers, at an affordable cost; and promote more efficient use of water resources through appropriate incentives such as volumetric billing. The program encourages irrigation schemes in zones with high agricultural potential through the desalination of seawater.[242] In 2015, the Ministry of Agriculture contracted a private firm to build, operate, and co-finance the desalination and irrigation infrastructure over 13,600 ha in the plain of Chtouka in the region of Souss Massa Draa over a period of 30 years.[243]

The expansion of land under irrigation and the adoption of modern technologies greatly contributed to the growth and increased resilience of Morocco's agriculture sector. Since 2008, agricultural output has increased, and the sector and smallholder farmers have become less vulnerable to climatic shocks. For instance, the 2015–2016 agricultural season was marked by a drop in rainfall of over 50 percent compared to the usual average. However, agricultural GDP fell by only 7 percent, a tangible indicator that the irrigation program has increased farmers' resilience and protection against climatic variations. Prior to the expansion of irrigation, the fall in GDP might have reached up to 40 percent.[244]

Farmers installing drip irrigation, Malawi

CASE STUDY

Niger

The Government of Niger has shown strong commitment through institutional and programmatic innovations relevant to irrigation expansion. Importantly, the government has emphasized private small-scale irrigation development and private sector involvement. Between 2003 and 2013, Niger witnessed a rapid increase in the uptake of irrigation: the share of arable land under irrigation increased by 20 percent.[245] Yet the 2018 Biennial Review Report by the African Union revealed that Niger is not on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 0.29 out of 10, which falls well below the 2017 minimum score of 5.53.[246] **The potential to increase the amount of irrigated land was estimated at 0.07 million hectares (ha) for large-scale irrigation systems, with an internal rate of return (IRR) of 9 percent, versus 0.13 million ha for small-scale irrigation systems, with an IRR of 40 percent.**[247] Up to 20 percent of Niger's agricultural gross domestic product (GDP) is generated through irrigated agriculture. Such achievements are partly due the government's institutional and programmatic innovations to improve existing irrigation infrastructure and expand it across the country.

INSITUTIONAL INNOVATIONS

In close cooperation with other government agencies focused on irrigation, the General Directorate of Rural Engineering within the Ministry of Agriculture is responsible for developing and implementing a national policy on agricultural land development, surface and groundwater mobilization, rural infrastructure construction, and irrigation development. In 1978, Niger created the National Office of Hydro Agricultural Management (ONAHA) – a national agency to promote irrigated agriculture in Niger through the construction and management of irrigation schemes. However, in 1986, ONAHA was transformed into a public company so that cooperatives, the government, and local authorities must pay for services provided. As a result, ONAHA has financial autonomy and draws its funding from its commercial activities.[248] In 2006, recognizing the importance of the private sector in transforming agriculture, the government set up the Network of Regional Chambers of Agriculture (RECA). RECA constitutes a platform for advocacy and dialogue between stakeholders to strengthen agricultural organizations and producers, including those of irrigated agriculture.[249] Furthermore, in 2012, Niger created an office in charge of implementing the Nigeriens Nourishing Nigeriens (I3N) initiative aimed at strengthening national capacities for food production, food supply, and resilience in the face of food crises and climatic disasters. The I3N initiative includes irrigation programs to mobilize funding through collaboration among public, private, technical, and financial partners.[250]

POLICY AND PROGRAMMATIC INTERVENTIONS

In Niger most irrigation policies and programs have been developed through national sectoral policies. Five policies and strategies are particularly noteworthy. In 2002, Niger implemented the Accelerated Development and Poverty Reduction Strategy, aimed at halving poverty levels. The strategy considered irrigation, in particular small-scale irrigation, as one of the main priority areas to accelerate economic development and reduce poverty.[251]

In addition, in 2003, the government launched the Rural Development Strategy to boost economic growth in rural areas and improve food security. As part of this strategy, an irrigation development program to increase agricultural production under irrigation was developed. The program encourages private investment in small-scale irrigation through construction of community infrastructure needed to mobilize surface and groundwater resources, and the establishment of appropriate financing mechanisms.[252]

In 2005, the government developed the National Strategy for the Development of Irrigation and Collection of Runoff Waters (SNDI/CER), aimed at improving the share of irrigated agriculture in agricultural GDP. The government developed a framework to attract investment and private sector involvement in irrigation activities, as well as to encourage integrated and sustainable management of water and land resources. The framework also defines the roles and capacity-building activities of public and private actors involved in irrigation development and the collection of runoff water.[253]

In 2012, under the I3N initiative, a program for increasing agricultural production under irrigation sought to raise the contribution of irrigated crops to GDP from 20 percent in 2011 to 30 percent by 2015 by expanding the land under irrigation.[254] Finally, in 2015, Niger developed the Strategy of Small Irrigation, which seeks to harmonize interventions and funding approaches in small-scale irrigation to develop a decentralized mechanism for development of sustainable small-scale irrigation.[255]

Between 2008 and 2012, a small-scale irrigation project was implemented by the Ministry of Agriculture and its partners to improve food security in the region of Tillabéri. The project promoted the expansion of irrigation capacity in 49 small perimeters and provided quality seeds and fertilizers, in addition to training and other technical support, to beneficiaries. The organizational capacity of 64 groups of farmers with about 4,000 members, of whom more than 80 percent were women, was strengthened. Beneficiaries improved their water management systems and used irrigation technologies more adapted

CASE STUDY

Niger

to their context. Due to this intervention, more than 4,000 families were able to significantly increase their income, from US$170 per harvest to US$255, whereas before the intervention, families produced only for their own consumption.[256]

Between 2003 and 2008, a small irrigation project, the Private Irrigation Promotion Project, was implemented by the Nigerien Agency for the Promotion of Private Irrigation (ANPIP). Its objective was to promote farmer-led, small-scale irrigation and increase the production and profitability of high value-added irrigated crops for small producers by using simple, low-cost technologies. The direct beneficiaries were small-scale farmers with less than 10 ha of land. Farmers received access to advice, equipment, and inputs through input shops. Equipment was subsidized between 50–90 percent, with the highest rates applied to small pumps, manual pumps, and drip irrigation systems. With the subsidy, farmers acquired 10,870 motor pumps and 7,809 pedal pumps. Local entrepreneurship also rose, spawning drillers, pump manufacturers, and repair workers. The project included a capacity-building program for national private sector operators such as input suppliers, transporters, agrifood industries, wholesalers, retailers, and some decentralized government services. Horticultural yields improved considerably: onion yields increased from 26 to 41 tons per ha between 2001 and 2006, and pepper yields increased from 11 to 19 tons per ha during the same period. Revenue per hectare for those farmers growing onions and peppers increased by nearly 80 percent.[257]

Recently, the government has been partnering with the private sector to promote the development of innovative irrigation technologies and facilitate their adoption at scale. In 2011, the "Tele-Irrigation" kit was developed and brought to market by a local company. The kit consists of a solar station and pump, a water distribution network, and a mobile phone. It allows farmers to remotely control their irrigation systems using a mobile phone. Tele-Irrigation also makes it possible to collect and disseminate real-time and remote meteorological and hydrological data, including temperature, soil moisture content, rainfall, solar radiation, and wind speed. As a result, farmers save time, use water more efficiently, and can increase their irrigated land size, which in turn may increase their production and income. The technology contributes to a reduction in greenhouse gases by using solar energy. Furthermore, to compensate for lack of fodder during the dry season, Tele-Irrigation kits are being adopted to produce fodder in breeding centers.[258] Niger's growth in irrigation uptake in the decade to 2013 was largely driven by an increase in small-scale irrigation uptake, and private sector involvement. The government's commitment to expanding irrigation has been demonstrated through comprehensive institutional innovations and targeted policy and programmatic interventions. Despite this, Niger still has a large potential to increase the amount of land under irrigation.


Small-scale farmer irrigating her plots, Niger

CASE STUDY

South Africa

While hardly any smallholder land is irrigated and only moderate progress in irrigation development has been made, South Africa has huge potential in irrigation development. The country's total irrigated area was approximately 1.3 million hectares (ha) in 2014/15, which constitutes 10 percent of cultivated land.[259] The country is home to around a quarter million irrigators, including about 32,000 smallholder farmers. The latter accounted for about 3 percent of all area equipped for irrigation in 2010.[260, 261] The 2018 Biennial Review Report by the African Union revealed that South Africa is currently not on track to meet Malabo Commitment area #3.1, "Access to agriculture inputs and technologies," given its score of 3.02 out of 10, which falls well below the 2017 minimum score of 5.53.[262] **However, according to research by the International Food Policy Research Institute, the economic potential for both large- and small-scale irrigation is considerable, with an internal rate of return (IRR) of approximately 8 percent and 14 percent, respectively, and the potential to bring 0.4 million ha for large-scale and 0.2 million ha for small-scale under irrigation.[263]**

INSTITUTIONAL INNOVATIONS

South Africa has demonstrated its dedication to irrigation at both domestic and international level. Soon after independence, South Africa joined the International Commission on Irrigation and Drainage (ICID) through its representative body, the South African National Committee on Irrigation and Drainage (SANCID). ICID was established in 1950 as a scientific, technical, professional, voluntary, not-for-profit, non-governmental international organization. Drawing members from governmental, quasi-governmental, and private business organizations as well as academic assoiciations, ICID promotes the research and development of new technologies in the fields of irrigation, drainage, and flood control.[264]

Domestically, the National Water Act (NWA) of 1998 stipulated some fundamental reforms on the use and management of water resources. Central to the NWA of 1998 was the principle that water is a scarce natural resource that belongs to all South Africans and must be used beneficially and in the public interest (generating social benefits, economic efficiency, and environmental sustainability). The NWA sets out a legal framework for the government to protect, use, develop, conserve, manage, and control the country's water resources. It also incorporates the establishment of catchment management agencies, the transformation of existing irrigation boards into water user associations, and the possible establishment of an agency to manage the national water resource infrastructure. Although the approach showed ambition, its implementation has been rather limited.[265]

Since 2010, the Department of Agriculture, Forestry and Fisheries (DAFF), located within the Ministry of Agriculture, Forestry and Fisheries, has been responsible for guiding irrigated agriculture in South Africa. While the Ministry holds the overall responsibility for its Departments, Departments themselves are divided into Directorates. Within the DAFF, the Directorate of Water Use and Irrigation Development (DWID) in its Forestry and Natural Resources Management branch is responsible for the efficient development and revitalization of irrigation schemes and water use of the country.[266]

Under the DAFF, the DWID developed the Irrigation Strategy for South Africa in 2015, which provides direction for institutional reform and guidelines on public investment in irrigation initiatives. The Irrigation Strategy sets a target of a more than 50 percent increase in irrigated land in South Africa over the next 10 to 20 years by revitalizing smallholder irrigation schemes across the country, a goal estimated to cost US$1 billion.[267] The Strategy also calls for collaboration with the Provincial Departments of Agriculture and the Department of Water and Sanitation (DWS). Taking into consideration the natural resource base, the strategy focuses on the following objectives:

- Institutional arrangements
- Irrigation research, training, extension, and advisory services
- Revitalization
- New development
- Improved management and efficiency of water use

The DWS, which acts under the responsibility of the Ministry of Water and Sanitation, was established in 2014, following its division from the Department of Water Affairs and Forestry. The DWS is responsible for formulation and implementation of South Africa's water resources policy, and for water services provided by the local government. The 2nd National Water Resource Strategy, implemented from 2013, also touches on irrigation and underlines the need for groundwater development and management, water harvesting, importation of water-intensive goods, and infrastructure management, as well as the advantages of multiple use planning.[268]

The DWS's assessments are highly relevant for local policies. The assessments were applied in 2016, when the city of Cape Town implemented Level 2 Water Restrictions, limiting the amount of water usage for personal, commercial, industrial, and agricultural use. The restrictions were gradually further increased, reaching their peak in January 2018 at Level 6b Water Restrictions. As of October 2018, Level 5 Water Restrictions are in effect,

South Africa

restricting personal water use to 70 liters per person per day and reducing water use for agricultural purposes by 50 percent.[269]

The Water Research Commission (WRC) is South Africa's premier water knowledge hub, established under the Water Research Act in 1971. The funds for the WRC are generated by a levy on water use. Today, the Commission's main activities include policy advice and decision-making, developing innovative water-related products and services, developing sustainable solutions to establish highly informed water decision-making through science and technology at all levels and deepening water research and development in South Africa, across Africa and in other developing regions. The research results and new technology-based products and processes are subsequently disseminated to end-users. The WRC also supports projects that use satellite imagery and requests research to estimate the areas and water use associated with irrigated agriculture in South Africa.[270,271,272]

Finally, various institutes of the Agricultural Research Council (ARC) are involved in irrigation-related research, such as calibration of soil-based irrigation and identification of waterlogging and salt accumulation. The Council also designs irrigation systems and trains farmers on sustainable water management techniques to grow vegetables and to improve farmer productivity and food security in local communities, as well as to commercialize the production of crops.[273]

POLICY AND PROGRAMMATIC INTERVENTIONS

The WRC supports initiatives for multiple use water systems (MUS) that provide low-cost water services for domestic use, agriculture (irrigation, rain-fed), and to rural enterprises. In this respect, a four-year "Operationalizing community-driven multiple use water services" project is being implemented in Limpopo in collaboration with the International Water Management Institute (IWMI) and local nongovernmental organization (NGO) Tsogang, with support from the WRC and the African Development Bank (AfDB). The project seeks to: demonstrate participatory planning for sustainable multipurpose infrastructure in selected rural villages; enhance the knowledge base of MUS; and bring to scale the MUS approach at district, provincial, and national level.

Outside of government-led interventions, South Africa's civil society is very active in promoting appropriate irrigation technology for water conservation and management. The nonprofit Association for Water and Rural Development (AWARD) was founded in 1999 to build active civil society participation in water and biodiversity stewardship, management, and governance. Jointly with the United States Agency for International Development (USAID), AWARD runs the RESILIM-Olifants Programme, which focuses on resilience building in the transboundary Olifants River Basin, shared between South Africa and Mozambique. The Olifants river water supply system provides water for domestic and industrial water use purposes, irrigation, mining, and power generation, serving more than 3 million people. The project also seeks to institutionalize water conservation and water demand management as a climate change adaptation strategy in two local municipalities through formal training courses and feedback sessions and through the provision of guidelines.[274]

The South African Irrigation Institute (SABI) is another nonprofit organization dealing with irrigation. It focuses on the promotion of improved designs, equipment, methods, and management for the efficient use of irrigation water and optimization of all other associated resources. Among other activities, SABI runs the IrrigationWise Academy, offering a range of training programs to boost optimum irrigation practices and water conservation for parastatal organizations, large farms, and commodity groups. Its emphasis is on strengthening technical and engineering skills in both the agricultural and landscape sectors.[275]

Alongside government and the nonprofit organizations, the private sector plays a major role as custodians of water in South Africa. With respect to irrigation it leads on the development of new technologies on irrigation and agronomy. For instance, Irritech Agencies International, a specialist irrigation company operating across Africa, was established in 1992 with offices in Pietermaritzburg, South Africa and Lusaka, Zambia. The company provides irrigation solutions ranging from irrigation design and steel fabrication, attending to logistics, administration, and the sale of spare parts, to provision of travelling technicians, service, and repair in the field. Its teams are equipped and resourced to design, install, service, and repair drip, sprinkler, pod, micro, pivot, and bulk water systems anywhere in Africa.[276] Providing different types of irrigation systems, Irritech works with other companies like NETAFIM and Valley. NETAFIM is an international company specializing in smart drip and micro-irrigation products.[277] Valley is a US company that entered the South African market in 1999 mainly to provide pivot irrigation systems and smart technologies, including remote management modules for the control of irrigation systems.[278] South Africa's strong institutional frameworks demonstrate the country's commitment to increasing irrigation uptake. Although the 2017/18 drought significantly impacted the country, the government's response offers lessons for other countries looking to build and strengthen their own institutions and policies on irrigation and water management.■

11. Conclusion

Food production in Africa continues to rely almost exclusively on rain-fed agriculture, leaving farmers and rural communities vulnerable to more erratic rainfall patterns and climatic extremes. Currently, a mere 6 percent of cultivated land is irrigated in Africa. Yet, the potential for irrigation expansion is vast, particularly in SSA. For countries to deliver on the food security and nutrition targets under the African Union's Agenda 2063 and the Malabo Declaration, collective and individual action is needed at all government levels, from the private sector, and among farming communities to expand irrigation across the continent—from small-scale schemes to farmer-led innovations and large-scale irrigation systems.

Irrigation development can make good business sense, given that yields from irrigated crops are double or more of comparable rain-fed yields on the continent and that the benefits of expanding areas under irrigation are estimated to be double the costs under climate change. In the most vulnerable parts of Africa, irrigated agriculture also means that farmers can extend the growing season(s), increase productivity and incomes, and improve their livelihoods. But irrigation development must be planned carefully to avoid adverse impacts on the environment and human health.

One strategy to realize the continent's irrigation potential is to replicate and scale up successful interventions that have worked on the ground in African countries. Doing that in a critical mass of countries across the continent would help meet the targets and goals under the African Union's Agenda 2063 and the Malabo Declaration.

Several common features distinguish those African countries that have made significant progress in increasing their irrigation potential. The case studies have shown that success has been most effective where governments have made irrigation a top policy and investment priority – by creating conducive fiscal environments, providing supportive infrastructure, and/or deploying smart regulations. The countries analyzed have also shown a growing role of the private sector in the design, development and dissemination of innovative, smart technologies as well as business models in operating and maintaining facilities. The experience of the six case study countries analyzed in this report can help other African governments develop country-specific strategies to increase resilience and improve livelihoods in Africa's rural communities and beyond.

The Malabo Montpellier Panel has identified a set of policies and practices summarized below that, if brought to scale, could significantly improve the resilience and livelihoods of rural communities and spur overall agricultural growth and transformation in Africa.

Farmer watering red peppers in a greenhouse, Malawi

Recommendations

1 Irrigation needs to be elevated to a top policy and long-term investment priority.

2 Smart regulation for water use needs to be coupled with incentives to promote the dissemination of technologies for the use of treated waste water.

3 To minimize the potential risks of irrigation to human health and the environment, regulation governing the regular maintenance of irrigation infrastructure and the use of fertilizers in irrigation systems is needed, complemented by significant ongoing investments in the maintenance and repair of irrigation and drainage systems.

4 Increased investments need to be made by the private sector to build and improve distribution networks for irrigation equipment.

5 The private sector has a crucial role to play in the design, development and dissemination of innovative, smart technologies for irrigation.

6 To take irrigation to scale through effective public–private partnerships, financial securities, smart subsidies, or tax waivers need to be put in place as incentives for the private sector to engage with smallholders.

7 Irrigation requires collective action in most circumstances. Incentives for collective action need to be provided, as well as policies for conflict resolution mechanisms at local level.

8 Increased investment in institutional and physical infrastructure to expand access to skills development and upgrading is critical.

9 The acquisition of new irrigation systems and equipment by smallholder farmers requires a supportive fiscal regime where barriers to accessing finance for equipment and services are removed and access to micro-credits and leasing arrangements for irrigation equipment is facilitated.

Notes

1 NEPAD.2013. Agriculture in Africa. Transformation and Outlook. Johannesburg, South Africa. http://www.un.org/en/africa/osaa/pdf/pubs/2013africanagricultures.pdf

2 Authors calculations based on FAO. Accessed 15 November, 2018. FAOSTAT. http://www.fao.org/faostat/en/#data/EL

3 FAO. Accessed 15 November, 2018. AQUASTAT. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/nr/water/aquastat/main/index.stm

4 J. A. Burney, and R. L. Naylor. 2012. Smallholder irrigation as a poverty alleviation tool in Sub-Saharan Africa. World Development, 40(1): 110-123. https://doi.org/10.1016/j.worlddev.2011.05.007

5 N. Mango, C. Makate, L. Tamene, P. Mponela, and G. Ndengu. 2018. Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. Land, 7(2), 49. https://doi.org/10.3390/land7020049

6 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. https://www.donorplatform.org/news-caadp/au-summit-1st-biennial-review-on-the-status-of-agriculture-in-africa-triggers-unique-momentum-249.html

7 A. Bouzaher and S. Devarajan. 2009. Climate Change: Africa's Development Opportunity. Energy-Climate Change Technology (ETC) Conference Bergen, 23-24 September 2009. World Bank. http://blogs.worldbank.org/files/africacan/Climate%20Change_Africa%20Development%20Opp.pdf

8 NEPAD. 2013. Agriculture in Africa. Transformation and Outlook. Johannesburg, South Africa. http://www.un.org/en/africa/osaa/pdf/pubs/2013africanagricultures.pdf

9 J. A. Burney, R. L. Naylor, and S. L. Postel. 2013. The case for distributed irrigation as a development priority in Sub-Saharan Africa. Proceedings of the National Academy of Sciences, 110(31): 12513–12517. http://doi.org/10.1073/pnas.1203597110

10 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

11 FAO. Accessed 4 December, 2018. AQUASTAT. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

12 bid.

13 C. Ringler. 2017. Investments in irrigation for global food security. IFPRI Policy Note. International Food Policy Research Institute. https://doi.org/10.2499/9780896292543

14 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

15 FAO. 2014. FAO Statistical Yearbook 2014. Africa Food and Agriculture. Accra, Ghana. http://www.fao.org/3/a-i3620e.pdf

16 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

17 Authors calculations based on FAO. Accessed 15 November, 2018. FAOSTAT. http://www.fao.org/faostat/en/#data/EL

18 Ibid.

19 B. Lankford, I. Makin, N. Matthews, P. G. McCornick, A. Noble, and T. Shah. 2016. A Compact to Revitalise Large-Scale Irrigation Systems Using a Leadership-Partnership-Ownership 'Theory of Change'. Water Alternatives, 9(1): 1-32. http://www.water-alternatives.org/index.php/alldoc/articles/302-a9-1-1/file

20 Water Research Commission and Department of Agriculture, Forestry and Fisheries, South Africa. 2018. An Earth Observation Approach towards Mapping Irrigated Areas and Quantifying Water Use by Irrigated Crops in South Africa. http://www0.sun.ac.za/cga/wp-content/uploads/2018/09/WRC-report-TT-745-17-Press-release.pdf

21 J. Grimm and M. Richter. 2006. Financing Small-Scale Irrigation in Sub-Saharan Africa Part 1: Desk Study. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.694.6012&rep=rep1&type=pdf

22 B. Lankford, I. Makin, N. Matthews, P. G. McCornick, A. Noble, and T. Shah. 2016. A Compact to Revitalise Large-Scale Irrigation Systems Using a Leadership-Partnership-Ownership 'Theory of Change'. Water Alternatives, 9(1): 1-32. http://www.water-alternatives.org/index.php/alldoc/articles/302-a9-1-1/file

23 SAFI. Accessed 14 November, 2018. How can irrigation contribute to agricultural growth in Africa? http://www.safi-research.org/

24 M. Svendsen, M. Ewing, S. Msangi, 2009. Measuring irrigation performance in Africa. IFPRI Discussion Paper 894. International Food Policy Research Institute. http://www.ifpri.org/publication/measuring-irrigation-performance-africa

25 L. Domènech. 2015. Improving irrigation access to combat food insecurity and undernutrition: A review. Global Food Security, 6: 24-33. https://doi.org/10.1016/j.gfs.2015.09.001

26 Ibid.

27 FAO and IFC. 2014. Senegal: Irrigation market brief. Food and Agriculture Organization of the United Nations. Rome, Italy. http://www.fao.org/3/a-i5365e.pdf

28 FAO. 2014. FAO Statistical Yearbook 2014. Africa Food and Agriculture. Accra, Ghana. http://www.fao.org/3/a-i3620e.pdf

29 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

30 H. Xie, L. You, B. Wielgosz, and C. Ringler. 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. Agricultural Water Management, 131: 183-193. https://doi.org/10.1016/j.agwat.2013.08.011

31 P. Pavelic, K. G. Villholth, Y. Shu, L.- M. Rebelo, and V. Smakhtin. 2013. Smallholder groundwater irrigation in Sub-Saharan Africa: country-level estimates of development potential. Water International. 38(4): 392-407. https://doi.org/10.1080/02508060.2013.819601

32 B. Garthwaite. 2018. Irrigation and agricultural water management in Africa. Briefing Note prepared for Malabo Montpellier Panel, 4 September, 2018. Team Lead – EBA Water Law Team (World Bank).

33 Montpellier Panel. 2013. Sustainable intensification: a new paradigm for African Agriculture. Montpellier Panel Report. https://www.mamopanel.org/resources/reports-and-briefings/sustainable-intensification-new-paradigm-african-a/

34 World Bank. 2008. Agriculture for Development. World Development Report. World Bank. Washington, DC. https://siteresources.worldbank.org/INTWDR2008/Resources/WDR_00_book.pdf

35 Ibid.

36 Ibid.

37 R. C. Calow, A. M. MacDonald, A. L. Nicol, and N. S. Robins. 2010. Ground water security and drought in Africa: linking availability, access, and demand. Ground Water, 48(2): 246-256. https://doi.org/10.1111/j.1745-6584.2009.00558.x

38 C. Falcoz, and E. Seurot. 2009. Survey on Social Economic and Agronomic Impact of the Installation of the Swiss Concrete Pedal Pump in Tanzania. ENSAIA, Engineering school of agronomy. Nancy, France. http://www.sswm.info/sites/default/files/reference_attachments/FALCOZ~2.PDF

39 I. K. Kulecho and E. K. Weatherhead. 2005. Reasons for smallholder farmers discontinuing with low-cost micro-irrigation: a case study from Kenya. Irrigation Drainage System, 19(2): 179-188. https://doi.org/10.1007/s10795-005-4419-6

40 Agency for Agricultural Development. 2015. Investor's Guide in the Agricultural Sector in Morocco. Ministry of Agriculture, Fisheries, Rural Development, Water and Forests of Morocco. Rabat, Morocco. http://www.agriculture.gov.ma/en/pages/focus/investor%E2%80%99s-guide-agricultural-sector-morocco

41 J. Wanyama, H. Ssegane, I. Kisekka, A. J. Komakech, N. Banadda, et al. 2017. Irrigation Development in Uganda: Constraints, Lessons Learned, and Future Perspectives. Journal of Irrigation and Drainage Engineering, 143(5): 04017003-10. https://doi.org/10.1061/%28ASCE%29IR.1943-4774.0001159

42 One. Posted 23 August, 2017. YES! Malian women make progress in fight for land rights. https://www.one.org/international/blog/malian-women-fight-for-land-rights/

43 Actes de la République du Mali Présidence de la république. 2017. LOI N°2017- 001/ Du 11 AVRIL 2017 Portant Sur Le Foncier Agricole. Journal officiel de la République du Mali. http://extwprlegs1.fao.org/docs/pdf/mli165599.pdf

44 J. Grimm and M. Richter. 2018. Financial Services for Developing Small-Scale Irrigation in Sub-Saharan Africa. Agriculture and Rural Development Notes. Issue 41 September 2008. Word Bank. http://documents.worldbank.org/curated/en/470351468203353319/pdf/455680BRI0Box334063B01PUBLIC10ARD0Note41.pdf

45 A. Salami, B. A. Kamara, and Z. Brixiona. 2010. Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities. Working Papers Series No. 105. African Development Bank Group. Tunis, Tunisia. https://www.commdev.org/wp-content/uploads/2015/06/Smallholder-Agriculture-East-Africa-Trends-Constraints-Opportunities.pdf

46 FAO and IFC. 2014. Senegal: Irrigation market brief. Food and Agriculture Organization of the United Nations. Rome, Italy. http://www.fao.org/3/a-i5365e.pdf

47 G. Gebregziabher, M. A. Giordano, S. J. Langan, and R.E. Namara. 2014. Economic analysis of factors influencing adoption of motor pumps in Ethiopia. Journal of Development and Agricultural Economics, 6(12): 490-500. https://academicjournals.org/journal/JDAE/article-abstract/90D5FBB48609

48 B. M. Mati. 2008. Capacity development for smallholder irrigation in Kenya. Irrigation and Drainage, 57: 332-340. https://doi.org/10.1002/ird.437

49 A. E. Bekele. 2014. Five key constraints to small scale irrigation development in Ethiopia: socioeconomic view. Global Advanced Research Journal of Management and Business Studies, 3(10): 441-444. http://garj.org/garjmbs/10/2014/3/10/five-key-constraints-to-small-scale-irrigation-development-in-ethiopia-socio-economic-view

50 G. Toenniessen, A. Adesina, and J. DeVries. 2008. Building an alliance for a green revolution in Africa. Annals of the New York Academy of Sciences, 1136: 233-242. https://doi.org/10.1196/annals.1425.028

51 A. T. Emmanuel. 2012. Building an effective advocacy movement for sustainable and equitable agricultural development in Africa modernisation of smallholder agriculture and policy making in Uganda. Trust Africa. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/african%20water%20vision%202025%20to%20be%20sent%20to%20wwf5.pdf

52 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

53 HLPE. 2015. Water for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome, Italy. http://www.fao.org/3/a-av045e.pdf%20box%206

54 R. Zougmoré, A. Mando, J. Ringersma, and L. Stroosnijder. 2006. Effect of Combined Water and Nutrient Management on Runoff and Sorghum Yield in Semi-Arid Burkina Faso. Soil Use and Management, 19: 257-64. https://doi.org/10.1111/j.1475-2743.2003.tb00312.x

55 J. S. Pachpute. 2010. A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa. Agricultural Water Management, 97(9): 1251-1258. https://doi.org/10.1016/j.agwat.2009.11.009

56 H. Xie, L. You, B. Wielgosz, and C. Ringler. 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. Agricultural Water Management, 131: 183-193. https://doi.org/10.1016/j.agwat.2013.08.011

57 J. A. Burney, and R. L. Naylor. 2012. Smallholder irrigation as a poverty alleviation tool in Sub-Saharan Africa. World Development, 40(1): 110-123. https://doi.org/10.1016/j.worlddev.2011.05.007

58 P. Tillie, K. Louhichi, and S. Gomez-Y-Paloma. 2018. Chapter 4. Does small irrigation boost smallholder agricultural production – evidence from a small irrigation programme in Niger. In F. Wouterse and O. Badiane (eds.). Fostering transformation and growth in Niger's agricultural sector. https://doi.org/10.3920/978-90-8686-873-5_4

59 C. Ringler, M. W. Rosegrant, N. Perez, and H. Xie. The Future of Irrigation: Farmer-Led. In preparation for publication by the World Bank as a background paper for the WFIF conference. International Food Policy Research Institute, unpublished.

60 R. Nkhata, C. Jumbe, and M. Mwabumba. 2014. Does irrigation have an impact on food security and poverty: Evidence from Bwanje Valley Irrigation Scheme in Malawi. MaSSP Working Paper 4. International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128180

61 C. de Fraiture and M. Giordano. 2014. Small Private Irrigation: A Thriving but Overlooked Sector. Agricultural Water Management, 131: 167-174. https://doi.org/10.1016/j.agwat.2013.07.005

62 J. Njuki, E. Waithanji, B. Sakwa, J. Kariuki, E. Mukewa, et al. 2014. Can market-based approaches to technology development and dissemination benefit women smallholder farmers? A qualitative assessment of gender dynamics in the ownership, purchase, and use of irrigation pumps in Kenya and Tanzania. IFPRI Discussion Paper 1357. International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128211

63 G. Gebregziabher, R. E. Namara, and S. Holden. 2014. Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. Agricultural Water Management, 96(12): 1837-1843. https://doi.org/10.1016/j.agwat.2009.08.004

64 F. Grassi, J. Landberg, and S. Huyer. 2015. Running out of time: The reduction of women's work burden in agricultural production. Food and Agriculture Organization of the United Nations. Rome, Italy. http://www.fao.org/3/a-i4741e.pdf

65 International Renewable Energy Agency. 2016. Solar pumping for irrigation: Improving livelihoods and sustainability. The International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Solar_Pumping_for_Irrigation_2016.pdf

66 J. Magrath. 2015. Transforming Lives in Zimbabwe. Rural Sustainable Energy Development Project. OXFAM Case Study. https://oxfamilibrary.openrepository.com/bitstream/handle/10546/567000/cs-zimbabwe-solar-power-170815-en.pdf;jsessionid=F0285389DD5FDC62A8F8BAD0AEF8EF2C?sequence=1

67 World Bank and IFAD. 2017. Rural Youth Employment. Paper commissioned by the German Federal Ministry for Economic Cooperation and Development as an Input Document for the G20 - Development Working Group. https://www.bmz.de/de/zentrales_downloadarchiv/g20/Rural_Youth_Employment_-_WB-IFAD-Synthesis_Study_DWG.pdf

68 L. Fox, L. W. Senbet, and W. Simbanegavi. 2016. Youth Employment in Sub-Saharan Africa: Challenges, Constraints and Opportunities. Journal of African Economies, 25(1): i3–i15. https://doi.org/10.1093/jae/ejv027

69 L. Rutten and S. L. Fanou. 2015. Chapter 4. Innovative and Inclusive Finance for Youth in Agriculture. In Alliance for a Green Revolution in Africa (eds.). Africa Agriculture Status Report: Youth in Agriculture in Sub-Saharan Africa. Nairobi, Kenya. https://agra.org/AGRAOld/wp-content/uploads/2016/04/africa-agriculture-status-report-2015.pdf

70 FAO and IWMI. 2017. Water pollution from agriculture: A global review. Rome, Italy. http://www.fao.org/3/a-i7754e.pdf

71 Ibid.

72 S. Kibret, G. G. Wilson, H. Tekie, and B. Petros. 2014. Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control. Malaria Journal, 13: 360. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4182787/

73 H. Besada and K. Werner. 2015. An assessment of the effects of Africa's water crisis on food security and management, International Journal of Water Resources Development, 31(1): 120-133. https://doi.org/10.1080/07900627.2014.905124

74 F. Lebdi. 2016. Irrigation for Agricultural Transformation. Background Paper for African Transformation Report 2016: Transforming Africa's Agriculture. Accra, Ghana. http://acetforafrica.org/acet/wp-content/uploads/publications/2016/09/IrrigationforAgricultural_PAPER.pdf

75 A. C. V. Getirana and V. F. Malta. 2010. Investigating Strategies of an Irrigation Conflict. Water Resources Management, 24(12): 2893–2916. https://link.springer.com/content/pdf/10.1007%2Fs11269-010-9586-z.pdf

76 M. Jouili, I. Kahouli, and M. Elloumi. 2013. Appropriation des ressources hydrauliques et processus d'exclusion dans la région de sidi Bouzid (Tunisie centrale). Études rurales, 192: 117-134. https://journals.openedition.org/etudesrurales/9929

77 T. Shah. 2009. Climate change and groundwater: India's opportunities for mitigation and adaptation. Environmental Research Letters, 4(3): 1-13. http://doi.org/10.1088/1748-9326/4/3/035005

78 FAO. 2007. Chapter 5: Water management for Climate-Smart Agriculture. In FAO (eds.). Climate Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b6-water/chapter-b6-5/en/

79 African Risk Capacity. 2016. The cost of drought in Africa. African Union. Johannesburg, South Africa. http://www.africanriskcapacity.org/wp-content/uploads/2016/11/arc_cost_of_drought_en.pdf

80 WFP and FAO. 2016. 2016-2017 ENSO Overview. Accessed 22 October, 2018. United Nations World Food Programme. https://reliefweb.int/sites/reliefweb.int/files/resources/wfp_fao_el_nino_overview_by_fsc_5.pdf

81 African Risk Capacity. 2016. The cost of drought. African Union. Johannesburg, South Africa. http://www.africanriskcapacity.org/wp-content/uploads/2016/11/arc_cost_of_drought_en.pdf

82 K. Wiebe, T. B. Sulser, D. Mason-D'Croz, and M. W. Rosegrant. 2016. Chapter 2: The Effects of Climate Change on Agriculture and Food Security in Africa. In ReSAKSS. Annual Trends and Outlook Report. International Food Policy Research Institute. http://www.resakss.org/sites/default/files/Ch2%20ReSAKSS_AW_ATOR_2016_Final.pdf

83 E. Blanc. 2012. The Impact of Climate Change on Crop Yields in Sub-Saharan Africa. American Journal of Climate Change, 1(1): 1-13. http://doi.org/10.4236/ajcc.2012.11001

84 C. Ringler, T. Zhu, X. Cai, J. Koo, and D. Wang. 2010. Climate Change Impacts on Food Security in Sub-Saharan Africa. IFPRI Discussion Paper 01042. International Food Policy Research Institute. http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/6983/filename/6984.pdf

85 Ibid.

86 K. Wiebe, T. B. Sulser, D. Mason-D'Croz, and M. W. Rosegrant. 2016. Chapter 2: The Effects of Climate Change on Agriculture and Food Security in Africa. In ReSAKSS. Annual Trends and Outlook Report. International Food Policy Research Institute. http://www.resakss.org/sites/default/files/Ch2%20ReSAKSS_AW_ATOR_2016_Final.pdf

87 A. Bouzaher and S. Devarajan. 2009. Climate Change: Africa's Development Opportunity. Energy-Climate Change Technology (ETC) Conference Bergen, 23-24 September 2009. World Bank. http://blogs.worldbank.org/files/africacan/Climate%20Change_Africa%20Development%20Opp.pdf

88 C. Ringler, M. W. Rosegrant, N. Perez, and H. Xie. The Future of Irrigation: Farmer-Led. In preparation for publication by the World Bank as a background paper for the WFIF conference. International Food Policy Research Institute, unpublished.

89 M. Svendsen, M. Ewing, S. Msangi, 2009. Measuring irrigation performance in Africa. IFPRI Discussion Paper 894. International Food Policy Research Institute. http://www.ifpri.org/publication/measuring-irrigation-performance-africa

90 Ibid.

91 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

92 B. James, H. Manyire, E. Tambi, and S. Bangali. 2015. Barriers to Scaling up/out Climate Smart Agriculture and Strategies to Enhance Adoption in Africa. Forum for Agricultural Research in Africa. Accra, Ghana. http://faraafrica.org/wp-content/uploads/2015/10/Barriers-to-scaling-up-out-CSA-in-Africa.pdf

93 UNEP. 2001. Chapter 9: Examples of Rainwater Harvesting and Utilisation around the World. In UNEP (eds.). An Environmentally Sound Approach for Sustainable Urban Water Management: An Introductory Guide for Decision-Makers. http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/9.asp

94 FAO EIP Water. Accessed August 6, 2018. Floodwater Harvesting - Case Study 4: Water-Spreading Weirs for the Development of Degraded Dry River Valleys. Food and Agriculture Organization of the United Nations. http://www.eip-water.eu/projects/fao-floodwater-harvesting-case-study-4-water-spreading-weirs-deve-lopment-degraded-dry

95 Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). 2012. Water-Spreading Weirs for the Development of Degraded Dry River Valleys. http://www.giz.de/fachexpertise/downloads/giz2013-en-water-spreading-weirs.pdf

96 R. Purcell. 1997. Potential for Small-Scale Irrigation in Sub-Saharan Africa: The Kenyan Example in Irrigation Technology Transfer in Support of Food Security. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/w7314e/w7314e07.htm

97 UNEP. 1998. Chapter: 2.1.6 Rope-Washer Pump. In UNEP (eds.). Sourcebook of Alternative Technologies for Freshwater Augumentation in Africa. http://www.unep.or.jp/ietc/publications/techpublications/techpub-8a/rope.asp

98 NECOFA, Kenya. Posted 25 August, 2010. A Water and Sanitation Programme using Rope and Washer at Kihoto Shg. Network for Ecofarming in Africa, Kenya Chapter. http://Necofakenya.Wordpress.Com/2010/08/25/A-Water-And-Sanitation-Programme-Using-Rope-And-Washer-At-Kihoto-Shg/

99 The Government of Rwanda and ICRAF. 2010. Rwanda Irrigation Master Plan. http://www.worldagroforestry.org/downloads/Publications/PDFS/B16738.pdf

100 R. Purcell. 1997. Potential for Small-Scale Irrigation in Sub-Saharan Africa: The Kenyan Example in Irrigation Technology Transfer in Support of Food

Security. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/w7314e/w7314e07.htm

101 W. van Averbeke, J. Denison, and P. N. S. Mnkeni. 2011. Smallholder Irrigation Schemes in South Africa: A Review of Knowledge Generated by the Water Research Commission. Water SA, 37(5): 797-808. http://dx.doi.org/10.4314/wsa.v37i5.17

102 J. Kamwamba - Mtethiwa, K. Weatherhead, and J. Knox. 2016. Assessing Performance of Small-Scale Pumped Irrigation Systems in sub-Saharan Africa: Evidence from a Systematic Review. Irrigation and Drainage, 65(3): 308-18. https://doi.org/10.1002/ird.1950

103 Ibid.

104 Ibid.

105 M. Dessalegn and D. J. Merrey. 2015. Motor Pump Revolution in Ethiopia: Promises at a Crossroads. Water alternatives, 8(2): 237-257. http://www.water-alternatives.org/index.php/alldoc/articles/vol8/v8issue2/289-a8-2-12/file

106 M. L. Mul, J. S. Kemerink, N. F. Vyagusa, M. G. Mshana, P. van der Zaag, and H. Makurira. 2011. Water Allocation Practices among Smallholder Farmers in the South Pare Mountains, Tanzania: The Issue of Scale. Agricultural Water Management, 98(11): 1752-1760. http://doi.org/10.1016/j.agwat.2010.02.014

107 AgWater Solutions. Accessed 8 August, 2018. River Diversions. Agricultural Water Management Solutions. International Water Management Institute. http://awm-solutions.iwmi.org/river-diversions.aspx

108 B. Keraita, M. Giordano, and H. Mahoo. 2012. AgWater Solutions Project Case Study. International Water Management Institute. http://awm-solutions.iwmi.org/Data/Sites/3/Documents/PDF/publication-outputs/learning-and-discussion-briefs/tz-traditional-irrigation.pdf

109 ICID. Accessed on 18 September, 2018. Resources - Irrigation - Tidal Irrigation. International Commission on Irrigation and Drainage. http://www.icid.org/res_irri_tidal.html

110 UNEP. 1998. Chapter: 4.3 Tidal Irrigation, The Gambia. In UNEP (eds.). Sourcebook of Alternative Technologies for Freshwater Augumentation in Africa. http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0fnl2.2--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-10&cl=CL1.4&d=HASHa7909460293ada0236fd7d.5.3&gt=1

111 City of Cape Town. Accessed 14 November, 2018. Commercial water restrictions explained. http://www.capetown.gov.za/work%20and%20business/commercial-utility-services/commercial-water-and-sanitation-services/Commercial-water-restrictions-explained

112 Agriculture for Impact. Accessed September 18, 2018. Microdosing. http://ag4impact.org/sid/ecological-intensification/precision-agriculture/microdosing/

113 J. Burney, L. Woltering, M. Burke, R. Naylor, and D. Pasternak. 2010. Solar-Powered Drip Irrigation Enhances Food Security in the Sudano-Sahel. Proceedings of the National Academy of Sciences, 107(5): 1848-1853. http://doi.org/10.1073/pnas.0909678107

114 iDE. Accessed August 8, 2018. Watering Can vs. Drip Irrigation in Ghana. http://www.ideglobal.org/key-project/experimenting-with-resource-smart-technology-in-ghana

115 S. N. Ngigi, J. N. Thome, D. W. Waweru, and H.G. Blank. 2011. Low-Cost Irrigation for Poverty Reduction. International Water Management Institute. http://publications.iwmi.org/pdf/H028340.pdf

116 S. Peterson. Posted February 12, 2014. Helping Smallholder Farmers in Sub-Saharan Africa Escape Poverty. World Agriculture Network. http://worldagnetwork.com/helping-smallholder-farmers-in-sub-saharan-africa-escape-poverty/

117 Floppy Sprinkler. Accessed 19 September, 2018. Floppy Sprinkler. Rain on Demand. http://www.floppysprinkler.com/

118 G. B. Simpson and F. B. Reinders. 1999. Evaluation of the Performance of Two Types of Sprinkler Irrigation Emitters Installed on Permanent and Dragline Systems. South African Water Research Commission Report No. KV 119/99. http://www.wrc.org.za/Pages/DisplayItem.aspx?ItemID=7972&FromURL=%2FPages%2FAllKH.aspx%3F

119 L. E. Jones and G. Olsson. 2017. Solar Photovoltaic and Wind Energy Providing Water. Global Challenges, 1(5). http://doi.org/10.1002/gch2.201600022

120 International Renewable Energy Agency. Accessed 19 September, 2018. Data and Statistics. International Renewable Energy Agency. http://www.irena.org/

121 J. A. Burney, R. L. Naylor, and S. L. Postel. 2013. The case for distributed irrigation as a development priority in Sub-Saharan Africa. Proceedings of the National Academy of Sciences, 110(31): 12513–12517. http://doi.org/10.1073/pnas.1203597110

122 The Guardian. Posted 11 June, 2018. NASRDA says Automated Irrigation System will make farmers cultivate more. http://guardian.ng/technology/nasrda-says-automated-irrigation-system-will-make-farmers-cultivate-more/

123 VOA Africa. Posted 24 January, 2017. Kenyan Irrigation App Aims to Cut Water Waste, Crop Losses. http://www.voanews.com/a/kenya-irrigation-app-aims-to-cut-water-waste-crop-losses/3689955.html

124 A. McNally, S. Shukla, K. Arsenault, S. Wang, C. Peters-Lidard, and J. I. Verdin. 2016. Evaluating ESA CCI Soil Moisture in East Africa. International Journal of Applied Earth Observation and Geoinformation, 48: 96-109. https://doi.org/10.1016/j.jag.2016.01.001

125 ZENVUS. Accessed July 25, 2018. Intelligent Solutions for Farms and Gardens. http://www.zenvus.com/

126 R. Sim, S. Plummer, and M. Fellahi. 2015. Assessment of Potential Markets for Soil Moisture Sensor in Tanzania. UC Davis D-Lab. http://piet.ucdavis.edu/wp-content/uploads/2015/05/D-Lab-Soil-Moisture-Sensor-Final-Report.pdf

127 ZENVUS. Accessed July 25, 2018. Intelligent Solutions for Farms and Gardens. http://www.zenvus.com/

128 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

129 Ibid.

130 Ibid.

131 FAO. Accessed 19 November, 2018. Statistics. Government expenditure on agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/economic/ess/investment/expenditure/en/

132 C. Ringler, M. W. Rosegrant, N. Perez, and H. Xie. The Future of Irrigation: Farmer-Led. In preparation for publication by the World Bank as a background paper for the WFIF conference. International Food Policy Research Institute, unpublished.

133 ReSAKSS. Accessed 14 September, 2018. ReSAKSS. International Food Policy Research Institute. http://www.resakss.org/

134 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/workingdocuments/33640-wd-full_br_report_eng.pdf

135 I. Hussain and M. A. Hanjra. 2004. Irrigation and poverty alleviation: review of the empirical evidence. Irrigation and Drainage, 53(1): 1-15. http://onlinelibrary.wiley.com/doi/abs/10.1002/ird.114

136 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

137 I. Hussain and M. A. Hanjra. 2004. Irrigation and poverty alleviation: review of the empirical evidence. Irrigation and Drainage, 53(1): 1-15. http://onlinelibrary.wiley.com/doi/abs/10.1002/ird.114

138 J. Grimm and M. Richter. 2006. Financing Small-Scale Irrigation in Sub-Saharan Africa Part 1: Desk Study. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.694.6012&rep=rep1&type=pdf

139 M. Ayyagari, P. Juarros, M. S. M. Peria, and S. Singh. 2016. Access to Finance and Job Growth: Firm-Level Evidence across Developing Countries. Policy Research Working Papers. World Bank. http://doi.org/10.1596/1813-9450-7604

140 World Bank. Accessed 21 September, 2018. Global Financial Inclusion. Data Bank. http://databank.worldbank.org/data/home

141 J. Grimm and M. Richter. 2006. Financing Small-Scale Irrigation in Sub-Saharan Africa Part 1: Desk Study. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.694.6012&rep=rep1&type=pdf

142 World Bank. Accessed 25 October, 2018. Concessions, Build-Operate-Transfer (BOT) and Design-Build-Operate (DBO) Projects. World Bank. http://ppp.worldbank.org/public-private-partnership/agreements/concessions-bots-dbos

143 World Bank. 2014. Water PPPs in Africa. World Bank. http://www.ifc.org/wps/wcm/connect/838c700045139b7099359dc66d9c728b/WBG_AfricaWaterPPPs.pdf?MOD=AJPERES

144 D. Renault, R. Wahaj, and S. Smits. 2013. Multiple Uses of Water Services in Large Irrigation Systems: Auditing and Planning Modernization the MASSMUS Approach. FAO Irrigation and Drainage Paper 67. Food and Agriculture Organization of the United Nations. Rome, Italy. http://www.fao.org/docrep/018/i3414e/i3414e.pdf

145 FAO. Accessed 17 September, 2018. Land and Water. Multiple Use of Water. Food and Agriculture Organization of the United Nations. http://www.fao.org/land-water/water/watergovernance/multiple-use-of-water/en/

146 D. Renault, R. Wahaj, and S. Smits. 2013. Multiple Uses of Water Services in Large Irrigation Systems: Auditing and Planning Modernization the MASSMUS Approach. FAO Irrigation and Drainage Paper 67. Food and Agriculture Organization of the United Nations. Rome, Italy. http://www.fao.org/docrep/018/i3414e/i3414e.pdf

147 F. W. T. Penning de Vries, H. Sally, and A. Inocencio. 2005. Opportunities for Private Sector Participation in Agricultural Water Development and Management. Working Paper 100. International Water Management Institute. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR100.pdf

148 SAIRLA. Accessed 21 September, 2018. Home - SAIRLA. http://sairla.nri.org/

149 Winrock International. 2012. Multiple-Use Water Services. http://www.winrock.org/wp-content/uploads/2016/03/MUS-and-Winrock-Briefing-v3-may-2013.pdf

150 N. B. Legesse. 2013. Community Based Integrated Water Resources Management Programme in Banibango and Soumatte, presented at the MUS (Multiple Use Services) Group meeting, London, 5 September, 2013. Oxfam, UK. http://www.musgroup.net/sites/default/files/e753515ce-b858ea374113929fcb65132.pdf

151 Green Climate Fund. Accessed 14 August, 2018. About the Fund. http://www.greenclimate.fund/who-we-are/about-the-fund

152 Ibid.

153 Ibid.

154 Actionaid. Accessed 13 November, 2018. Global Agriculture and Food Security Program. http://www.actionaidusa.org/work/gafsp/

155 GAFSP. Accessed 13 November, 2018. Empowering Smallholder Farmers. The Global Agriculture and Food Security Program. http://www.gafsp-fund.org/approach

156 African Union. 2015. Agenda 2063. The Africa We Want. First Ten Year Implementation Plan 2014-2023. African Union, Addis Ababa, Ethiopia. http://au.int/sites/default/files/documents/33126-doc-ten_year_implementation_book.pdf

157 African Union. 2014. Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods. http://ecowas-agriculture.org/sites/default/files/Malabo_Declaration_on_Accelerated_Agricultural_Growth_and_Transformation_for_Shared_Prosperity_and_Improved_Livelihoods_adopted_June_2014-2.pdf

158 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/working-documents/33640-wd-full_br_report_eng.pdf

159 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

160 African Union and African Development Bank. 2004. The Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development. http://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/african%20water%20vision%202025%20to%20be%20sent%20to%20wwf5.pdf

161 African Minister's Council on Water. 2010. AMCOW Workplan, January 2011 – December 2013. http://www.amcow-online.org/images/about/AMCOW%20Workplan.pdf

162 United Nations. 2015. Sustainable Development Goals: 17 Goals to Transform Our World. United Nations Sustainable Development. http://www.un.org/sustainabledevelopment/

163 African Green Revolution Forum. 2018. About AGRF. http://agrf.org/

164 African Green Revolution Forum. 2018. The Kigali Communiqué Decisions and Commitments from the African Green Revolution Forum 2018. Kigali, Rwanda. http://agrf.org/wp-content/uploads/2018/09/AGRA_AGRF-Kigali-Communique_v7_White_HR.pdf

165 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

166 African Union. 2018 .The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/working-documents/33640-wd-full_br_report_eng.pdf

167 FAO. Accessed 27 September, 2018. FAOSTAT - Percentage of Arable Land Equipped for Irrigation (3 Year Average). http://www.fao.org/faostat/en/#home

168 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

169 R. D. Bekele. Irrigation Systems in Ethiopia: Technological and Institutional Analysis. Doctoral Dissertation. Rheinische Friedrich-Wilhelms-Universität Bonn, forthcoming.

170 Ethiopian Agricultural Transformation Agency. Accessed 18 October, 2018. Shallow Ground Water Mapping. http://www.ata.gov.et/programs/highlighted-deliverables/input-voucher-sales-system-ivs/

171 F. Negash. 2011. Managing water for inclusive and sustainable growth in Ethiopia: key challenges and priorities. https://ec.europa.eu/europeaid/sites/devco/files/erd-consca-dev-researchpapers-negash-20110101_en.pdf

172 P. Lempériere, F. Hagos, N. Lefore, A. Haileslassie, and S. Langan. 2014. Establishing and Strengthening Irrigation Water Users Associations (IWUAs) in Ethiopia. Colombo, Sri Lanka: International Water Management Institute (IWMI). https://hdl.handle.net/10568/68734

173 Ministry of Water Resources Ethiopia. 2001. Ethiopian Water Sector Strategy. http://chilot.me/wp-content/uploads/2011/08/water-strategy.pdf

174 Ibid.

175 Federal Democratic Republic of Ethiopia and Ministry of Agriculture and Rural Development. 2010. Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010-2020.

176 Ibid.

177 Ministry of Finance and Economic Development Ethiopia. 2006. Ethiopia - Building on Progress - A Plan for Accelerated and Sustained Development to End Poverty (PASDEP). http://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/Plan_for_Accelerated_and_Sustained_%28PASDEP%29_final_July_2007_Volume_I_3.pdf

178 Federal Democratic Republic of Ethiopia and Ministry of Agriculture and Rural Development. 2010. Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010-2020.

179 M. Otoo, N. Lefore, P. Schmitter, J. Barron, and G. Gebregziabher. 2018. Business Model Scenarios and Suitability: Smallholder Solar Pump-Based Irrigation in Ethiopia. IWMI Research Report 172. International Water Management Institute. http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/pub172/rr172.pdf

180 Federal Democratic Republic of Ethiopia. 2015. Ethiopia's Climate Resilient Green Economy Climate. Climate Resilience Strategy: Water and Energy. http://gggi.org/site/assets/uploads/2017/11/2015-08-Sectoral-Climate-Resilience-Strategies-for-Ethiopia-2-Water-and-Energy-Climate-Resilience-Strategy.pdf

181 A. Garbero and T. Songsermsawas. 2018. Ethiopia's Participatory Small-Scale Irrigation Development Programme (PASIDP) in Effective Rural Development. IFAD's Evidence-Based Approach to Managing for Results, ed. International Fund for Agricultural Development. Rome, Italy. http://www.ifad.org/documents/38714170/40704829/DEF_web.pdf/ab2c358b-963f-4048-8486-762cbf73c43a

182 Ministry of Agriculture Ethiopia and IFAD. 2013. Participatory Small Holder Irrigation Development Project (PASIDP). Mid-Term Review Report. http://operations.ifad.org/documents/654016/c3c0ad33-d073-4940-ba3b-69fb44e93845

183 A. Garbero and T. Songsermsawas. 2018. Ethiopia's Participatory Small-Scale Irrigation Development Programme (PASIDP) in Effective Rural Development. IFAD's Evidence-Based Approach to Managing for Results, ed. International Fund for Agricultural Development. Rome, Italy. http://www.ifad.org/documents/38714170/40704829/DEF_web.pdf/ab2c358b-963f-4048-8486-762cbf73c43a

184 Farm Africa. 2017. Chapter 6: Small-Scale Irrigation. In Farm Africa (eds.). Food Security in Tigray. http://www.farmafrica.org/downloads/resources/farm-africafood-security-in-tigraysmall-scale-irrigation-(6-of-6).pdf

185 Farm Africa. Accessed 12 October, 2018. Food Security in Tigray. http://www.farmafrica.org/ethiopia/food-security-in-tigray

186 Ministry of Water Resources Ethiopia. 2004. National Water Development Report Ethiopia. http://unesdoc.unesco.org/images/0014/001459/145926e.pdf

187 Ibid.

188 R. D. Bekele. Irrigation Systems in Ethiopia: Technological and Institutional Analysis. Doctoral Dissertation. Rheinische Friedrich-Wilhelms-Universität Bonn, forthcoming.

189 G. Gebregziabher, M. A. Giordano, S. J. Langan, and R.E. Namara. 2014. Economic analysis of factors influencing adoption of motor pumps in Ethiopia. Journal of Development and Agricultural Economics, 6(12): 490-500. https://academicjournals.org/journal/JDAE/article-abstract/90D5FBB48609

190 A. E. V. Evans, M. Giordano, T. Clayton. 2012. Investing in agricultural water management to benefit smallholder farmers in Ethiopia. IWMI Working Paper 152. International Water Management Institute. http://doi.org/10.5337/2012.215

191 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

192 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/working-documents/33640-wd-full_br_report_eng.pdf

193 FAO. Accessed 27 September, 2018. FAOSTAT - Percentage of Arable Land Equipped for Irrigation (3 Year Average). Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#home

194 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

195 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

196 Ibid.

197 Ministry of Water and Sanitation, Kenya. Accessed 19 October, 2018. About the Ministry. Ministry of Water and Sanitation. http://www.water.go.ke/about-the-ministry/

198 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

199 Water Resource Authority, Kenya. Accessed 19 October, 2018. Home. Water Resources Authority. http://www.wra.go.ke/home/

200 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

201 Ibid.

202 The Republic of Kenya. 2017. The Irrigation Bill. http://www.parliament.go.ke/sites/default/files/2017-05/The_Irrigation_Bill_2017.pdf

203 The President of the Republic of Kenya. Accessed 16 November, 2018. The Big Four – Food Security and Nutrition. http://www.president.go.ke/food-security-and-nutrition/

204 Republic of Kenya. Accessed 24 October, 2018. Kenya Vision 2030. http://vision2030.go.ke/

205 Republic of Kenya. 2009. Agricultural Sector Development Strategy (ASDS). http://www.kecosce.org/downloads/AGRICULTURE_SECTOR_DEVELOMENT_STRATEGY_2009_2025.pdf

206 National Irrigation Board Kenya. Accessed 22 October, 2018. Galana Kulalu Irrigation Development Project. http://nib.or.ke/projects/flagship-projects/galana

207 Green Arava LTD. Accessed 22 October, 2018. Galana Kulalu - Kenya. http://greenarava.com/agri-projects/?v=39

208 Daily Nation. Posted 19 January, 2018. Private Investors to Run Galana Kulalu Irrigation Project. http://www.nation.co.ke/news/Private-investors-to-run-Galana-Kulalu-Irrigation-project/1056-4269226-10cg0pez/index.html

209 VOA Africa. Posted 24 January, 2017. Kenyan Irrigation App Aims to Cut Water Waste, Crop Losses. http://www.voanews.com/a/kenya-irrigation-app-aims-to-cut-water-waste-crop-losses/3689955.html

210 SunCulture. Accessed 25 July, 2018. SunCulture – Transforming Agriculture Through the Power of the Sun. http://sunculture.com/

211 KickStart. Accessed 23 October, 2018. KickStart. The Tools to End Poverty. http://kickstart.org/

212 Green Climate Fund. 2015. FP005 KawiSafi Ventures Fund in East Africa - Project. http://www.greenclimate.fund/-/kawisawi-ventures-fund-in-east-africa

213 Sollatek. Accessed 25 October, 2018. Sollatek - the Power to Protect. http://sollatek.co.ke/

214 FAO. Accessed 23 September, 2018. FAOSTAT. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/EL

215 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

216 African Union. 2018 .The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/working-documents/33640-wd-full_br_report_eng.pdf

217 UPA Développement international. Accessed 14 November, 2018. Assemblée Permanente des Chambres d'Agriculture du Mali. https://www.upadi-agri.org/assemblee-permanente-des-chambres-dagriculture-du-mali-apcam/

218 Direction Nationale du Génie Rural. 2014. Rapport annuel 2014. Ministère de l'Agriculture du Mali. http://mali.countrystat.org/fileadmin/user_upload/countrystat_fenix/congo/docs/DNGR%20rapport%20annuel%202014.pdf

219 Ibid.

220 Agence d'Aménagement des Terres et de fourniture de l'eau d'Irrigation (ATI). Accessed 14 November, 2018. A propos de l' Agence. http://atimali.ml/presentation

221 Ministère du Développement Rural et de l'Eau. 1999. Stratégie nationale de développement de l'irrigation. Document de stratégie sous–sectorielle sur le développement de l'irrigation au Mali. http://www.passip.org/passip_intranet/pdf-intranet/Politique/9-64%20Strategie_Nationale_D%C3%A9veloppement_Irrigation_1999.pdf

222 Direction Nationale du Génie Rural. 2016. Expériences en matière d'irrigation du Mali. République du Mali. http://www.dngr.gouv.ml/pdf/Bonnes-Pratiques-en-Irrigation-au-Mali.pdf

223 One. Posted 23 August, 2017. YES! Malian women make progress in fight for land rights. https://www.one.org/international/blog/malian-women-fight-for-land-rights/

224 A. Adamczewski, J. Y. Jamin, P. Burnod, E. H. Boutout Ly, and J.P. Tonneau. 2013. Terre, eau et capitaux: investissements ou accaparements fonciers à l'Office du Niger? Cahiers Agricultures, 22 (1): 22-32. http://publications.cirad.fr/une_notice.php?dk=567662

225 World Bank. 2017. Commercial Irrigated Agriculture Development Project. Report No: PIDISDSC17562. World Bank. Washington, DC. http://documents.worldbank.org/curated/en/265781506532233318/pdf/ITM00184-P159765-09-27-2017-1506532229268.pdf

226 Millennium Challenge Corporation. Measuring Results of the Alatona Irrigation Project in Mali. Accessed 14 November, 2018. https://www.mcc.gov/resources/doc/summary-measuring-results-of-the-alatona-irrigation-project-in-mali

227 Agence de l'Environnement et du Développement Durable. Accessed 14 November, 2018. ASAP PAPAM. http://aedd.gouv.ml/asap-papam/

228 Mali7. Posted 23 January, 2018. Agriculture: Le Projet PAPAM arrive à son terme. https://mali7.net/2018/01/23/agriculture-le-projet-papam-arrive-a-son-terme/

229 USAID. 2016. Mali small-scale irrigation project. Fact Sheet. Bamako, Mali. https://www.usaid.gov/sites/default/files/documents/1860/USAID_AEG_-_KfW_Irrigation_Fact_Sheet_-_FTF_-_Nov_16_FINAL.pdf

230 A. Dillon. 2011. The Effect of Irrigation on Poverty Reduction, Asset Accumulation, and Informal Insurance: Evidence from Northern Mali. World Development, 39: 2165-2175. https://www.sciencedirect.com/science/article/abs/pii/S0305750X11000763

231 FAO. Accessed 20 September, 2018. FAOSTAT. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/EL

232 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

233 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. https://www.donorplatform.org/news-caadp/au-summit-1st-biennial-review-on-the-status-of-agriculture-in-africa-triggers-unique-momentum-249.html

234 Ministère de l'Agriculture, de la Pêche Maritime, du développement Rural et des Eaux et Forêts. Accessed 14 November, 2018. Direction de l'irrigation et de l'aménagement de l'espace agricole. http://www.agriculture.gov.ma/organigramme/direction-irrigation-et-amenagement-espace-agricole

235 E. M. Arrifi. 2009. L'économie et la valorisation de l'eau en irrigation au Maroc: un défi pour la durabilité de l'agriculture irriguée. Symposium international « Agriculture durable en région Méditerranéenne (AGDUMED) » Rabat, Maroc, 14-16 Mai, 2009. http://www.agrimaroc.net/agdumed2009/Arrifi_Economie_valorisation_eau_%20irrigation_Maroc.pdf

236 Office National de Sécurité Sanitaire des Produits Alimentaires. Accessed 26 November, 2018. Contrôle des intrants agricoles. http://www.onssa.gov.ma/fr/intrants-agricoles/controle-des-intrants-agricoles

237 Agency for Agricultural Development. 2015. Investor's Guide in the Agricultural Sector in Morocco. Ministry of Agriculture, Fisheries, Rural Development, Water and Forests of Morocco. Rabat, Morocco. http://www.agriculture.gov.ma/en/pages/focus/investor%E2%80%99s-guide-agricultural-sector-morocco

238 Fonds de Développement Agricole. 2018. Les Aides Financières de l'État pour la promotion des investissements agricoles. http://www.agriculture.gov.ma/sites/default/files/fda/FDA_2018_VF.pdf

239 Ministère de l'Agriculture et de la Pêche Maritime. 2016. Projet de loi de finance au titre de l'exercice budgétaire 2016. Projet Ministériel de Performance Du Département de l'Agriculture. http://lof.finances.gov.ma/sites/default/files/budget/files/pmp_dep_agriculture_2016_fr.pdf

240 Challenge. Posted 29 April, 2016. Mécanisation agricole: Le PMV tracte la mécanisation Agricole. http://www.challenge.ma/mecanisation-agricole-le-pmv-tracte-la-mecanisation-agricole-67747/

241 Ministère de l'Agriculture et de la Pêche Maritime. 2016. Projet de loi de finance au titre de l'exercice budgétaire 2016. Projet Ministériel de Performance Du Département de l'Agriculture. http://lof.finances.gov.ma/sites/default/files/budget/files/pmp_dep_agriculture_2016_fr.pdf

242 Ibid.

243 Agency for Agricultural Development. 2015. Investor's Guide in the Agricultural Sector in Morocco. Ministry of Agriculture, Fisheries, Rural Development, Water and Forests of Morocco. Rabat, Morocco. http://www.agriculture.gov.ma/en/pages/focus/investor%E2%80%99s-guide-agricultural-sector-morocco

244 M. Sidiki. 2017. La Rareté de l'Eau: Défis et Opportunités: Cas du Secteur Agricole au Maroc. Séminaire de haut-niveau « rareté de l'eau : défis et opportunités » Rome, Italy, 17 Novembre, 2017. https://www.ciheam.org/uploads/attachments/623/WaterScarcity_ACEA_FAO_CIHEAM_17112017_Intervention_Mohammed_Sadiki_VP_CIHEAM.pdf

245 FAO. Accessed 23 September, 2018. FAOSTAT. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/EL

246 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. https://www.donorplatform.org/news-caadp/au-summit-1st-biennial-review-on-the-status-of-agriculture-in-africa-triggers-unique-momentum-249.html

247 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

248 A.C. Bazile, B. Vennat, and E. Dressayre. 2015. Rôles et place des sociétés d'aménagement dans le développement de l'irrigation en Afrique de l'ouest: Diagnostic institutionnel spécifique de l'office national des aménagements hydro-agricoles (ONAHA). Rapport d'études. COSTEA. https://www.comite-costea.fr/content/download/4773/36353/version/1/file/Axe_1_2_Rapport_Diagnostic-specifique_ONAHA.pdf

249 Ministère de l'Agriculture. 2015. Stratégie de la Petite Irrigation au Niger. République du Niger. http://www.reca-niger.org/IMG/pdf/SPIN_FINALE_Niger.pdf

250 Ibid.

251 République du Niger. 2007. Stratégie de Développement Accéléré et de Réduction de la Pauvreté 2008 – 2012. https://en.unesco.org/creativity/sites/creativity/files/Conv2005_EU_Docs_Niger_SDARP.pdf

252 République du Niger. 2003. Stratégie de Développement Rural. Le secteur rural, principal moteur de la croissance Economique. Niamey Niger. https://www.pseau.org/outils/ouvrages/mhe_strategie_de_developpement_rural_2003.pdf

253 Ministère de l'Agriculture. 2015. Stratégie de la Petite Irrigation au Niger. République du Niger. http://www.reca-niger.org/IMG/pdf/SPIN_FINALE_Niger.pdf

254 République du Niger. 2012. Initiative 3N pour la sécurité alimentaire et nutritionnelle et le développement Agricole durable. Les Nigériens Nourrissent les Nigériens. Plan d'Investissement 2012-2015. Volume I. Niamey, Niger. http://extwprlegs1.fao.org/docs/pdf/ner145888.pdf

255 Ministère de l'Agriculture. 2015. Stratégie de la Petite Irrigation au Niger. République du Niger. http://www.reca-niger.org/IMG/pdf/SPIN_FINALE_Niger.pdf

256 Reliefweb. Posted 16 April, 2013. La petite irrigation pour lutter contre l'insécurité alimentaire. https://reliefweb.int/report/niger/la-petite-irrigation-pour-lutter-contre-l%E2%80%99ins%C3%A9curit%C3%A9-alimentaire

257 Ministère de l'Agriculture. 2015. Stratégie de la Petite Irrigation au Niger. République du Niger. http://www.reca-niger.org/IMG/pdf/SPIN_FINALE_Niger.pdf

258 PPAAP/WAAPA-Niger. Accessed 14 November 14, 2018. Télé irrigation: Un procédé révolutionnaire pour contrôler l'irrigation par le téléphone cellulaire. http://ppaao-niger.org/index.php?option=com_content&view=article&id=206:tele-irrigation-un-procede-revolutionnaire-pour-controler-l-irrigation-par-le-telephone-cellulaire&catid=91&Itemid=483

259 Water Research Commission and Department of Agriculture, Forestry and Fisheries, South Africa. 2018. An Earth Observation Approach towards Mapping Irrigated Areas and Quantifying Water Use by Irrigated Crops in South Africa. http://www0.sun.ac.za/cga/wp-content/uploads/2018/09/WRC-report-TT-745-17-Press-release.pdf

260 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

261 W. van Averbeke, J. Denison, and P. N. S. Mnkeni. 2011. Smallholder Irrigation Schemes in South Africa: A Review of Knowledge Generated by the Water Research Commission. Water SA 37(5): 797-808. http://dx.doi.org/10.4314/wsa.v37i5.17

262 African Union. 2018. The 2017 Progress Report to the Assembly. Highlights on Intra-African Trade for Agriculture Commodities and Services: Risks and Opportunities. http://au.int/sites/default/files/newsevents/workingdocuments/33640-wd-full_br_report_eng.pdf

263 L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, et al. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy, 36(6): 770-782. http://doi.org/10.1016/j.foodpol.2011.09.001

264 South African National Committee on Irrigation and Drainage. Accessed 17 October, 2018. SANCID. http://www.sancid.org.za/#

265 B. Schreiner. 2013. Viewpoint – Why Has the South African National Water Act Been so Difficult to Implement? Water Alternatives, 6(2): 239-245. http://www.water-alternatives.org/index.php/all-abs/211-a6-2-8/file

266 FAO. Accessed 27 September, 2018. AQUASTAT - Area Equipped for Irrigation. Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/main/index.stm

267 Department of Agriculture, Forestry and Fisheries, South Africa. 2015. Irrigation Strategy for South Africa. http://www.daff.gov.za/doaDev/sideMenu/ForestryWeb/dwaf/cmsdocs/Elsa/Docs/Forests/Woodl/Final%20Irrigation%20Strategy%20March%202015%20with%20cover%20(3).pdf

268 Department of Water and Sanitation, South Africa. 2013. 2nd National Water Resources Strategy. http://www.dwa.gov.za/documents/Other/Strategic%20Plan/NWRS2-Final-email-version.pdf

269 City of Cape Town. 2018. Level 5 Water Restrictions. (October 2018) Frequently Asked Questions. City of Cape Town, 16 October, 2018.

270 Water Research Commission South Africa. Accessed 16 October, 2018. WRC Vision, Mission and Values. http://www.wrc.org.za/about-us/vision/

271 S. Matthews. 2017. Project Modelling Irrigation Water Use through Satellite Technology Progresses. The Water Wheel, 16(4): 20–23. http://hdl.handle.net/10520/EJC-9672323af

272 Water Research Commission. 2018. Annual Report 2017/18. http://www.wrc.org.za/about-us/annual-reports/

273 Agricultural Research Council, South Africa. 2016. Annual Report 2015/16. http://www.arc.agric.za/Documents/Annual%20Reports/ARC%20Annual%20Report%202016-2016.pdf.pdf

274 AWARD. Accessed 18 October, 2018. RESILIM-O. Association for Water and Rural Development. http://award.org.za/index.php/projects/usaid-resilm-o/

275 South African Irrigation Institute. Accessed 17 October, 2018. SABI. http://www.sabi.co.za/council.html

276 Irritech. Accessed 17 October, 2018. Home. http://www.irritechsa.co.za/

277 NETAFIM. Accessed 17 October, 2018. Netafim - Smart Drip and Micro Irrigation Solutions. https://www.netafim.co.za/

278 Valley. Accessed 17 October, 2018. Home. http://ww2.valleyirrigation.com/valley-irrigation/za

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