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Getaw Tadesse, Mahamadou Tankari, Ismael Fofana, Racine Ly, Boureima Sawadogo, and Sabne Koanda

Feasibility, Scalability and Ex-ante Impacts of Small-scale Irrigation Technologies in Burkina Faso

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Disclaimer

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Contents

ACRONYMS

AGRA	Alliance for a Green Revolution in Africa
AU	The African Union
CGE	Computable General Equilibrium
DIPAC	*Développement de l'Irrigation Privée et des Activités Connexes* / Private Irrigation and Related Activities Development Program
DREAM	Dynamic Research Evaluation for Management
ECOWAS	Economic Community of West African States
FCFA	Franc of the Financial Community of Africa
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
Ha	Hectares
ICRISAT	International Crops Research Institute for Semi-arid Tropics
IFPRI	International Food Policy Research Institute
IRR	Internal Rate of Return
MAAH	*Ministère de l'Agriculture et des Aménagements Hydrauliques* / Ministry of Agriculture and Hydraulic Facilities
MAHRH	*Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques* / Ministry of Agriculture, Hydraulics, and Fisheries Resources
O&M	Operations and Maintenance/Management
PNDES	*Plan National de Développement Économique et Social* / National Economic and Social Development Plan
PNSR	*Programme National du Secteur Rural* / National Rural Sector Program
PPIV	*Programme de Développement de la Petite Irrigation Villageoise* / Small Village Irrigation Development Program
PS-PASP	*Politique Sectorielle de Production Agro-Sylvo-Pastorale* / Sectoral Policy for Agro-sylvo-pastoral production
PSSA	*Programme Spécial de Sécurité Alimentaire* / Special Food Security Program
PVC	Polyvinyl chloride
SAM	Social Accounting Matrix
SAP	Structural Adjustment Program
SNDDAI	*Stratégie Nationale de Développement Durable de l'Agriculture Irriguée* / National Strategy for Sustainable Development of Irrigated Agriculture
SSA	Africa south of the Sahara
SSI	Small-scale Irrigation
SWAT	Soil and Water Assessment Tool

Abstract

This study explores emerging small-scale irrigation (SSI) technologies and their possible impacts on growth and poverty reduction in Burkina Faso. A modeling approach integrating biophysical and economic models was used to estimate the feasibility and adaptability of four selected technologies: treadle pumps, motor pumps, small reservoirs, and communal river diversions (or water diversions). A Computable General Equilibrium model (CGE) adapted to the country context was developed to simulate the impacts of these technologies on economic growth and poverty reduction. In addition, the study used geospatial analysis to identify the best locations for SSI expansion. In Burkina Faso, the treadle pump, motor pump, small reservoirs and communal river diversions are expandable over 849,000 hectares (ha), 1,066,000 ha, 572,000 ha, and 63,2000 ha, respectively. A large proportion of the rural population (12.8 million) could use small reservoirs, while treadle pumps rank second in this regard. Expanding these technologies could boost the national economy by about 1,574 billion FCFA and generate an agricultural value-add of 875 billion FCFA. It would also reduce the number of the poor by about 321,000 people (97-98 percent of whom live in rural areas), indicating a significant spin-off effect following investments in small-scale irrigation. Potential feasible areas for irrigation are in the Western, South-Western, Central-East and Central regions of Burkina Faso, corresponding to the main irrigable plains of the country. The study proposes a roadmap for the development of SSI, in line with these results and with existing frameworks at continental and regional levels.

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1. INTRODUCTION

The need to create resilient food systems through the development of key value chains for climate resilient agricultural products, while strengthening the links between science, policy and strengthening of food and nutrition security for vulnerable communities, has never been more urgent. Global attention is once again focused on food security following the UN Summit on Food Systems in September 2021, which laid the groundwork for transforming global food systems to achieve the Sustainable Development Goals (SDGs) by 2030 in particular Goal one and Goal two. The rising number of young people coupled with the growing demand for food and jobs is a continental and global concern.

The importance of irrigation in improving agricultural productivity and food security, promoting climate-resilient agriculture, as well as creating jobs in rural Africa in general and the Sahel in particular, is no longer in doubt. Previous efforts to promote improved seeds and fertilizers have contributed significantly to the growth of agricultural production through increased land productivity (Tefera et al. 2021). However, agricultural labor productivity has remained stagnant (Tefera et al. 2021). As farmers who depend on rain-fed agriculture are only active for three to six months annually, focusing on irrigation is key to improving agricultural labor productivity. Irrigation enables farmers to grow crops throughout the year and depending on the crop, to harvest more than once a year. This induces an increase in labor productivity, which is more crucial than land productivity in raising incomes and reducing poverty.

There is growing political will and commitment to support the development of small-scale irrigation (SSI) in the region as governments develop specific strategies for its promotion and expansion. Burkina Faso adopted a national strategy for the sustainable development of irrigated agriculture in 2004 with the aim of supporting the development of small-scale irrigation. In addition, regional and international development partners, alongside local and national governments, are increasingly inclined to invest in SSI. The realization that smallholder farmers can play a key role in development of irrigation in Africa south of the Sahara, has placed water use by these farmers at the top of the political agenda (DWFI, 2018). This perspective was a crucial focal point at a policy forum organized in 2018 by the World Bank and the Daugherty Water for Food Institute (DWFI, 2018). In September of the same year, the World Bank, in collaboration with the African Development Bank and the Alliance for a Green Revolution in Africa (AGRA), launched the "farmer-led irrigation initiative" (World Bank, 2018). The African Union (AU) also developed its continental framework for small-scale irrigation development in 2020 (AU, 2020).

Irrigation potential in Burkina Faso varies by source and region. Previous project and program evaluations estimated an overall potential of approximately 233.5 ha (MAHRH 2004). Almost all this potential (93.4 percent) is in the Western, Boucle du Mouhoun, Southwest, Central East and Central regions, which correspond to the main irrigable plains of the country. Despite these opportunities and the enormous potential of SSI systems in Burkina Faso, the level of irrigated arable land remains low. In Burkina Faso, 77,055 ha of the potential 233,500 ha was under irrigation, representing 33 percent of irrigable land in 2019 (Kambou, 2019). Moreover, although total irrigated land doubled in 15 years (between 2004 and 2019), representing an average annual growth rate of 7 percent, given the initial low level of irrigated areas and the need for rapid growth of the agricultural sector, this rate of irrigation expansion is relatively slow. Crucially, the average annual growth rate decreased from ten percent in 2004-2013 to four percent in 2013-2019. In line with this untapped potential, a project dubbed Pro-Sahel (Innovation and Technology in Small-Scale Irrigation Systems for Small-Scale Producers in the Sahel) was developed with a view to identifying scalable technologies, innovations, and investment pathways to extend irrigation to small-scale producers in Niger and Burkina Faso. Focusing on the case of Burkina Faso, this report presents evidence that is intended to guide decision-making for SSI development in Burkina Faso.

The report structure follows. After the introduction, Section 2 describes the state of small-scale irrigation in Burkina Faso and provides an overview of irrigation technologies and developments within the country. Section 3 describes the methodology used to: i) Analyze the feasibility of SSI, ii) Predict the scalability of the selected technologies, i.e., treadle pump, motor pump, small reservoir, and communal river diversion, in terms of area and population coverage, and iii) Assess the ex-ante impacts of irrigation technologies. Section 4 presents the results of the analyses and covers issues related to water availability, priority crops for small-scale irrigation, feasibility of small-scale irrigation, scalability of selected technologies and their ex-ante economic and welfare impacts. The final section provides the report's conclusion.

2. THE STATE OF SMALL-SCALE IRRIGATION DEVELOPMENT IN BURKINA FASO

2.1 Review of Small-scale Irrigation Policy

Irrigation was introduced into Burkina Faso during the colonial period. The first irrigated crops were grown in 1920 by the Catholic missions of Bam and Pabré (Zougrana, 1998). At the time, irrigation was practiced on small areas and used to produce exotic vegetables for consumption by European missionaries. The first earth dams were built in the 1960s, mainly to produce vegetable crops during the dry season. Watering practices then involved buckets and calabashes. The aim of this irrigated agriculture was to produce vegetables for sale in urban centers and for export. Between 1960 and 1970, the country developed dozens of I perimeters and built several dams (MAHRH, 2004).

In the 1990s, following several serious droughts, public authorities became involved in developing strategies for agricultural production and water management (Aouba, 1993, Albergel et al., 1985). Since this period, the development of irrigation through the management of water resources, as well as the development and adaptation of irrigated perimeters and lowlands, have been considered to be a means of climate risk adaptation for increased agricultural production in Burkina Faso. The irrigation schemes initially developed were mainly used by colonial farmers to grow rice, with agricultural technicians supervising the development and organization of producers.

Farmers have also taken the initiative to develop small farms on private plots where they practice small-scale irrigation. Informal irrigation practices have become widespread in the years since 2000. In the mid-1990s, the Government of Burkina Faso committed to supporting private irrigation development initiatives through the pilot project (DIPAC - *Programme de Développement de l'Irrigation Privée et des Activités Connexes*) which was also supported by the World Bank. The project's objectives were to facilitate producers' access to irrigation technologies, water pumping and transport equipment, as well as to draw water from alluvial aquifers.

Since 1990, Burkina Faso's government has engaged in various economic reform processes as part of the Structural Adjustment Programs (SAPs). The state withdrew from agricultural production and left this to the private sector, which encouraged the emergence of private or community irrigation. At the start of the 21st century, emphasis shifted to small-scale irrigation due to the recurrent shortcomings observed in the development and exploitation of large- and medium-scale irrigation schemes. For instance, in 2001, the Government launched three small-scale irrigation programs including the DIPAC project, the Special Food Security Program (PSSA - *Programme Spécial de Sécurité Alimentaire*) and the Small-scale Village Irrigation Development Program (PPIV - *Programme de Développement de la Petite Irrigation Villageoise*). These projects and programs are also included in the Poverty Reduction Strategy Paper (DSRP - *Document de Stratégie pour la Réduction de la Pauvreté*). Various types of irrigation equipment (e.g., treadle pumps, motor pumps, piping, small composting equipment, maize seeds) were made available to farmers at subsidized prices. Since 2002, Burkina Faso's government has intensified its interventions targeting the development of irrigation.

This eventually led to the development of a National Strategy for Sustainable Development of Irrigated Agriculture (SNDDAI - *Stratégie Nationale de Développement Durable de l'Agriculture Irriguée*), that was adopted in 2004 and implemented between 2004 and 2015. The SNDDAI was later replaced by the National Rural Sector Program (PNSR - *Programme National du Secteur Rural*), which focused on accelerated growth and sustainable development in rural areas over the 2011-2015 period. The approach taken for irrigation development was: i) Promotion of simple, suitable, and inexpensive hydro-agricultural developments, with a specific focus on small-scale irrigation projects and lowland areas; ii) Intensification of rice cultivation to cover the country's needs; iii) Development of off-season crop diversification. These guidelines advanced the privatization of irrigated agriculture through development of dozens of small-scale irrigation projects and programs.

The PNSR was updated for the 2016-2025 period as part of the implementation of the National Economic and Social Development Plan (PNDES - *Plan National de Développement Economique et Social*). The PNSR has been implemented in various sectoral policies such as the National Food Security and Nutrition Policy for 2025 and the Sectoral Agro-sylvo-pastoral Production Policy for 2018-2027. Part of these policies' objectives are to attract more technical and financial partners as well as to create a framework for strategic direction and harmonization of irrigation projects and programs. In recent years, the Government of Burkina Faso has committed itself to promoting growth poles and has continued to encourage private investors to invest in irrigated agricultural production. These are the growth poles of Bagré and Sourou with various public land parcels identified for the development of irrigation.

Integration of small-scale irrigation into food security plans and strategies has progressed in recent years. Implementation of the PNSR is carried out through the Sectoral Agro-sylvo-pastoral Production Policy (PS-PASP - *Politique Sectorielle de Production Agro-Sylvo-Pastorale*) for the 2018-2027 period. The PS-PASP is in line with the 2016 ECOWAS Agricultural Policy Guidelines and the (2013) Dakar Declaration on the Sahel Irrigation Initiative. It also builds on the African Union (AU) Framework for Irrigation Development and Agricultural Water Management in Africa. The policy projects development of 59,146 ha of irrigated perimeters to increase the total area of irrigated perimeters from 12,854 ha in 2015 to 72,000 ha in 2026 (MAAH, 2015).

2.2 Introduction of Small-scale Irrigation Technologies

Several irrigation technologies and options have been tested and used in Burkina Faso, including small surface water tanks, water extraction pumps and water distribution drainage technologies. This sub-section presents a brief review of the different technologies in terms of their advantages and disadvantages, to support the selection of scalable technologies.

Small reservoirs

Due to recurrent droughts in the 1970s and 1980s, Burkina Faso built several hydraulic structures, including small water reservoirs. It is difficult to account for all the small water reservoirs in Burkina Faso, but their number is estimated to be 1,700 (Venot and Cecchi, 2011). Irrigation around small water reservoirs in Burkina Faso is not a new phenomenon. In the 1990s, vegetable crops were grown around such reservoirs. However, the emergence of irrigation activities around small reservoirs has increased in recent decades, a development that is linked to the import of motor pumps from China. Government subsidies and development projects have also encouraged the recent increase in private irrigation activities upstream of small reservoirs. The development of small reservoirs has led to an increase in informal irrigation with farmers using small pumps to grow vegetables.

Government and donors have encouraged the construction of small reservoirs and use of irrigation technologies, which has led to an increase in low-cost, small-scale irrigation activities over the past two decades. Various trials and demonstrations, as well as training programs, have made it easier for small-scale farmers to adopt and maintain new technologies.

Water pumps

Three pumping systems are generally used in Burkina Faso's small-scale irrigation systems: i) human-powered pumps, ii) motor pumps and iii) solar pumps. For human-powered pumps, a distinction is made between treadle pumps and manual pumps. The unit cost of a MoneyMaker suction pump is 60,000 FCFA on average. This type of pump is generally used for small-scale commercial farming and generates high net incomes (Gadelle, 2002).

Over the past 15 years, the use of 2.5 to 5 horsepower motor pumps for small-scale irrigation has increased significantly. The motor pumps commonly used in small-scale irrigation are surface suction pumps which are generally used to pump surface water (dams, ponds, streams, etc.), manually drilled wells and shallow wells (to a maximum depth of 7m). Because farmers have often encountered problems with motor pumps due to the large size of their motors, the DIPAC project in Burkina Faso has developed a range of high-performance motor pumps adapted to local conditions, capable of irrigating 0.5 to 2 ha of crops.

Solar pumps have emerged over the past twenty years. They are now considered a proven technology due to their performance and the materials used in their manufacture (Aliti, 2012).

Drainage/water distribution technologies

Agricultural producers in Burkina Faso have experimented with various irrigation and drainage techniques to improve yields, including gravity-fed, sprinkler, and drip irrigation methods. Gravity-fed irrigation is a technique that involves watering crops by releasing water to flow over the soil surface, with the aid of gravity. According to Aliti (2012), the construction cost of a gravitational network is three to four times lower than that of a pressurized network, but the former produces an efficiency of less than 30 percent and requires a large workforce, while the latter reaches an efficiency of 80 percent to 90 percent. There are three types of gravity-fed irrigation systems: furrow irrigation, board irrigation and pond irrigation.

Sprinkler irrigation is a system that mimics rainfall, although the intensity of water flows and the height from which the water falls is controlled. This technique is suitable for sandy soils with a high infiltration rate but it is not appropriate for growing crops on soils with a high infiltration rate. Sprinkler irrigation is less widespread in West Africa because of its high investment costs which are approximately two to three million FCFA per hectare (Aliti, 2012).

Drip irrigation, on the other hand, is still in the early stages of development in Burkina Faso. Preliminary tests with drip irrigation systems date back to the end of the 1990s. This type of irrigation was promoted by the International Crop Research Institute for Semi-arid Tropics (ICRISAT) through the African vegetable garden system and popularized by the DIPAC project. The Ministry of Agriculture, Hydro-Agricultural Development and Mechanization has mobilized technical and financial partners for the promotion and dissemination of this technology. Drip irrigation or micro-irrigation technology enables the direct watering of plant roots. This technology which has a flow rate of one liter per hour, enables efficient water use (up to 90 percent efficiency) and is not labor-intensive. It therefore does not require the continuous use of a pumping system with a high operating cost. In addition, a single tank can supply multiple irrigation kits (Sonou, 2010).

Farmers in Burkina Faso also use the California irrigation system. This system of buried pipes reduces seepage losses, allows water to be transported to a plot of land that is far from the pumping source or has irregular topography, and allows water levels to be monitored without additional pipes or handling. Irrigated areas range from 1,000 square meters (m^2) to two or more hectares, as the pumping rate determines the irrigable area. Improving irrigation efficiency with the California system results in the reduction of irrigation time (by 40 percent) and consequently reduces pumping costs by at least 25 percent following an initial investment of about 300,000 to 350,000 FCFA/ha (Sonou, 2010).

The belt irrigation system is another new technology in African countries. It involves generating precipitation that mimics natural rainfall. This system is suitable for vegetable crops and is popular with small-scale commercial growers.

Like the drip system, strip sprinkler systems are easy to use and operate autonomously, reducing the drudgery and time spent on irrigation. Strip sprinklers are connected to a PVC or PE pipe fed by a motor pump. The number of strips depends on the pump's flow rate. Maintenance of the strips is easy, even if charged water is used. To clean the strips, the clamp at the end must be removed and water run through it at full flow for a few minutes. The water flushes out the deposited materials and particles clogging the holes in the sprinkling strip. Installation costs are relatively low compared to other technologies. The sprinkler strips should be replaced every three to four years. The cost of acquiring 100 meters of sprinkler strip falls between 10,000 FCFA and 20,000 FCFA in Burkina Faso and Niger.

3. METHODOLOGY

This study followed a series of steps to examine the feasibility, scalability and impacts of small-scale irrigation (SSI) technologies in Burkina Faso. The first step explored the availability of water for irrigation in Burkina Faso using remote sensing satellite data. The second step involved identification of priority crops for SSI and their constraints based on existing practices and crop statistics. The third step estimated the feasibility of SSI across different geographic areas in Burkina Faso. The fourth step estimated the potential area that could be covered by the four irrigation systems identified for small-scale irrigation to show the scalability of the technologies. Finally, we predict the economywide ex-ante impacts of the technologies. The next sub-section describes the approach used to estimate the feasibility, scalability, and ex-ante impacts of the selected technologies.

3.1 Estimating the Feasibility of Small-scale Irrigation

Estimates of potential feasible areas for irrigation are available in many countries. However, these estimates vary widely from one source to another. Additionally, in many instances, they are only defined by water availability and other biophysical constraints. In this case, we estimated the SSI potential based on the method described in You et al. (2011). Unlike previous estimates of irrigation potential, this estimation method is based on biophysical and socio-economic factors using a three-step integrated, spatial method. In the first stage, geographical grids of 10 km are allocated to crops selected from a total of 20 crop groups found throughout Africa south of the Sahara. Allocation is based on topography and other biophysical factors of the grid. A country may only allocate a few crops based on its biophysical diversity.

The second step involves determining the runoff potential (surface water only) of each grid to predict the grid's suitability for irrigation. Depending on the availability of water and the command area, feasible areas are determined for large- or small-scale irrigation.

The third step is estimating the cost-benefit ratio of investing in water collection with a dam. This is done using the investment and operating costs obtained from existing SSI schemes and the prices and yields of the selected crops for each grid. Cost-benefit analysis makes it possible to predict the IRR (internal rate of return) of the investment in SSI in different sites. The objective of this analysis is to identify the best sites where specific technologies can be scaled up. The geographic distribution of feasible irrigation investments is then estimated based on an average investment cost of US$ 2,000/ha with US$ 80/ha directed toward operations and maintenance/management (O&M).

3.2 Estimating the Scalability of Small-scale Irrigation Technologies

The scalability of the selected technologies (sometimes referred as systems) such as treadle pumps, motor pumps, small reservoirs and communal river diversions was assessed using the method described by Xie et al. (2014). Estimation involved use of a four-step approach.

In the first step, the environmental and demographic suitability of a 500m geographical grid is evaluated for the four different SSI systems or technologies. The criteria for this suitability analysis were groundwater potential as determined by FAO, topography, runoff, market access, distance to surface water and population density (Xie et al., 2014).

In the second step, a Soil and Water Assessment Tool (SWAT) model is used to predict water availability and consumption, as well as crop yields at river basin level using topography, soil type and other biophysical factors.

In the third step, a DREAM (Dynamic Research Evaluation for Management) model is used to predict the effects of SSI expansion on product prices. Three market prices determination options are considered for different product groups. For vegetables and legumes, we assume that local market prices are determined at the river basin level. For peanuts, sugarcane, potatoes and sweet potatoes, we assume that prices are determined at the level of the domestic market. For maize, wheat and rice, we assume that these are internationally traded commodities with prices determined at the global level.

In the fourth step, we perform a cost-benefit analysis to estimate the optimal crop mix, irrigation expansion yield, population reached (direct and indirect beneficiaries), net incomes, exploitable areas, and water consumption levels. Crop combinations and yields are estimated based on yields and prices predicted by the SWAT and DREAM models, respectively. Net revenues, exploitable areas and water consumption are estimated based on investment costs, technology life spans and operating costs. Net technology yields per hectare and per 1,000 cubic meters (m^3) are calculated by dividing the annual net income by the total feasible area and total water consumption, respectively. Net returns vary across technologies, based on costs, yields and product prices.

Following these four steps, we determined the total potential feasible area for each irrigation system, the number of rural people who would benefit from these irrigation technologies, levels of water consumption and the economic returns (net value-added) that could be generated from these irrigation systems.

3.3 Estimating the Ex-ante Impacts of Irrigation Technologies

Once the potential irrigation areas for the four technologies were determined, we ran an integrated simulation model to predict the macro- and micro-level welfare impacts of the technologies. The analysis combined a Computable General Equilibrium (CGE) model and a top-down microsimulation (MS) model to assess the social and economic effects of small-scale irrigation expansion in Burkina Faso. The CGE model is dynamic-recursive and fits within the standard Walrasian framework in which economic agents make decisions (consumption and production) according to relative prices. Local producers arbitrate between domestic and international markets (CET function) and consumers arbitrate similarly between local and imported products following Argmigton hypothesis. Household consumption is accounted for using the demand system based on Stone-Geary preferences (utility function). The labor market is segmented according to place of residence (rural or urban), education level (skilled, semi-skilled or unskilled) and gender (male or female), and there is a wage curve between these segments. Public savings adjust to finance public spending, the balance of the external current account is assumed to be fixed, and the real exchange rate adjusts.

The model's specificity lies in the treatment of irrigated land in the agricultural sector. On the production side, irrigated crops are distinguished from rain-fed crops to highlight the yield gap between the two agricultural systems. Yields from the irrigated system are higher than yields from the rain-fed system (Table 1). The production function in each system has a constant elasticity of substitution (CES) at several levels. Output from an activity is derived from combined value-added and intermediate consumption based on fixed proportions. In addition, value-added aggregates efficient labor and land, always in fixed proportions. Land productivity is assumed to be considered in the value-added function to capture the productivity gap between irrigated and rain-fed systems. Efficient labor in turn replaces ordinary capital and aggregate labor. The latter combines various categories of work based on fixed proportions. On the demand side, perfect substitution between irrigated and rain-fed products is assumed, in other words, irrigated maize and rain-fed maize have the same market price.

Table 1: Productivity gap between irrigated and rain-fed systems by crop in 2019

Crops	Area (Ha)	Yield under rain-fed system (kg/Ha)	Yield under irrigation system (kg/Ha)	Ratio of irrigated to rain-fed system yields
Maize	1,014,907	1,673	3,671	2.2
Rice	177,256	1,508	3,386	2.2
All products	1,192,163	1,656	3,414	2.0

Source: General Directorate of Economy

The model is dynamic-recursive, i.e., exogenous variables change at a constant rate. Thus, labor supply increases with the rising growth rates of urban and rural populations, while total agricultural land expands at the average growth rate of the past five years. Irrigated land increases at a fixed rate imposed by the simulation scenario, and growth of rain-fed lands is determined in a residual manner. Private final consumption and public final consumption increase with the population growth rate. For endogenous variables such as ordinary capital, the standard capital accumulation formula is used, that is, new investments expand the existing capital stock, net of depreciation. Allocation of new investments by sector is influenced by sector-specific costs and returns on capital.

The CGE model is calibrated using the 2013 Social Accounting Matrix (SAM) updated to 2018 using the Global Development Indicators database. To highlight irrigated land in the SAM, official country data (Tables 1 and 2) are used. This information indicates that Burkina Faso's agricultural production systems are largely rain-fed. The total irrigated area was 64,298 ha in 2019 representing one percent at the national level. However, the yield gaps between production systems favor irrigation. Maize and rice were the only crops that were irrigated in 2019 and their productivity in that case was 2.2 times higher than that of the rain-fed system. These productivity gaps are used to consider the stylized facts presented above, in the calibration of the model. At this stage, additional economic and demographic data, as well as elasticity parameters available through the ReSAKSS toolkit are used.

Table 2: Cultivated areas in Burkina Faso, 2019

Rain-fed Area (ha)	6,360,270
Irrigated Area (ha)	64,298
Irrigated area, share (percentage)	1.0

Source: Agricultural Statistics Yearbook (2019)

The change in poverty levels is directly assessed using the MS model. Poverty is measured at the individual level and is based on micro-economic information, i.e., nationally representative household survey data. A given poverty level is associated with a certain income and its distribution among the population. Income inequality is an important determinant of poverty outcomes. The MS model captures changes in income distribution as well as measures of inequality within the population. The analysis was carried out with the MS model proposed by Fofana et al. (2019) based on the 2018 household survey in Burkina Faso.[1]

4. RESULTS

4.1 Irrigation Water Availability in Burkina Faso

Figure 1 shows the availability of surface water in Burkina Faso using four different indicators, i.e., water occurrence, water recurrence, seasonality and occurrence change intensity.

Water occurrence indicates where surface water was found between 1984 and 2020, and further provides information regarding overall water dynamics. This indicator captures both the intra- and inter-annual variability and changes. Permanent water surfaces (99 percent occurrence over 37 years) are represented in dark blue, while areas where water sometimes occurs are shown in color gradations from yellow to orange. The red points are areas where water occurs infrequently.

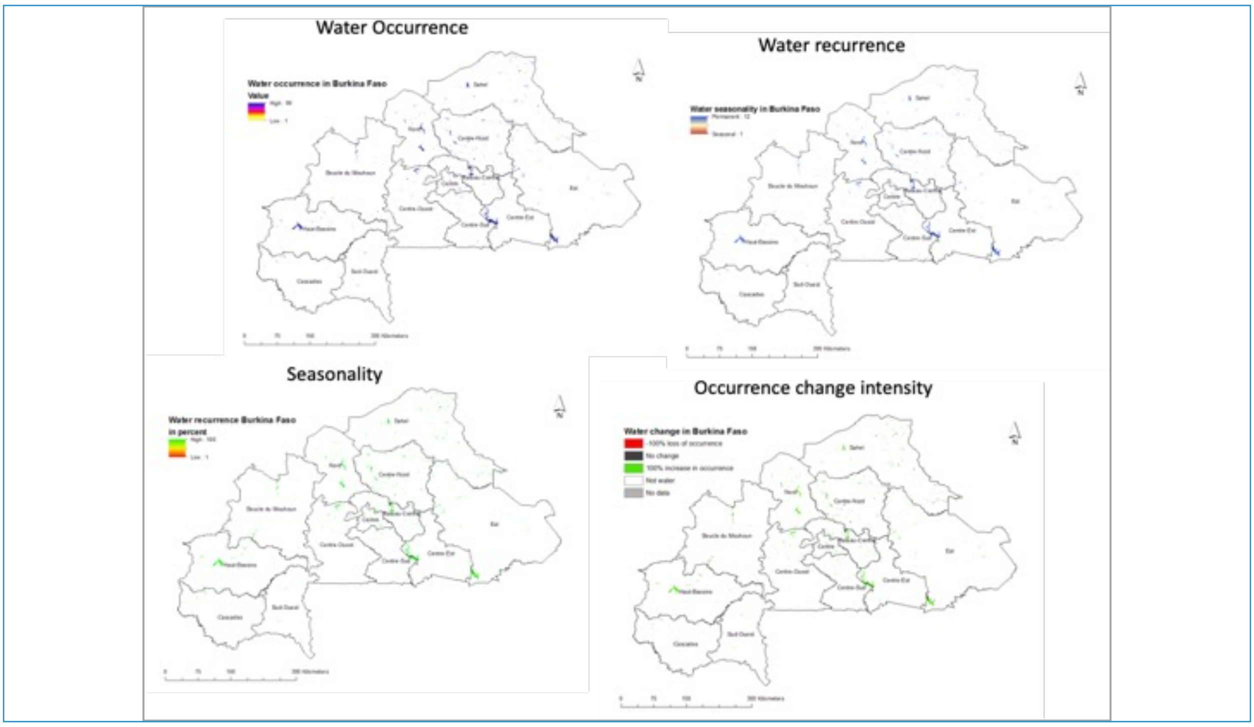
Water recurrence is a measure of the degree of inter-annual variability in the presence of water. This indicator describes how frequently water returned to a particular location from one year to another (expressed as a percentage). Recurrence specifically refers to the temporal behavior of water surfaces. Unlike occurrence, recurrence is not systematically computed over the full span of the records, because water may not have been present during certain periods from the start to the end of the records. In the Burkina Faso recurrence maps, areas that are inundated regularly (whether seasonal or permanent) are shown in green while areas that are occasionally flooded are shown in orange.

The seasonality map provides information concerning the intra-annual behavior of water surfaces for a single year, in this case for 2020. It shows permanent and seasonal water bodies as well as the number of months when water was present during that year. Permanent water is represented in dark blue and seasonal water is shown in orange.

The occurrence change intensity map provides information on where surface water occurrence increased, decreased, or remained the same in the 1984-1999 and 2000-2020 periods. Both the direction of change and its intensity are documented. Increases in water occurrence are shown in green and decreases are shown in red. Areas with no significant change in water occurrence during the 1984-2020 period are shown in black.

1 “Enquête harmonisée sur les conditions de vie des ménages ”(EHCVM, living standard measurements)

Figure 1: Water availability maps for Burkina Faso



Source: Authors' estimation based on satellite data

4.2 Priority Crops for Small-scale Irrigation in Burkina Faso

The development of irrigation, especially small-scale irrigation, enables the expansion of cultivated crops. In Burkina Faso, agricultural producers mainly use irrigation to grow horticultural crops and, to a lesser extent, cereals. Table 4 presents the main irrigated crops (cereals, rice, and maize) and the small-scale, commercially grown crops (onions and tomatoes) as well as traditional market crops (eggplants, chili, lettuce, cabbage, carrots, okra, strawberries, bell peppers, cucumbers, and garlic, among others). Green beans and potatoes are intended for export. Some plantations for fruits such as bananas, papayas, and citrus fruits are also irrigated. In the agro-industrial areas of Banfora, sugar cane is the main crop.

Rice cultivated with pump or gravity-fed irrigation is mainly grown in the valleys of Kou, Sourou and Bagré as well as in cultivated areas downstream from the dams. Irrigated maize and cowpeas have been popularized by the small village irrigation program and cover small areas. For example, for the 2001–2002 season, maize covered 566 ha and cowpeas 112 ha, and the 2002-2003 season covered 5,800 ha for the two combined.

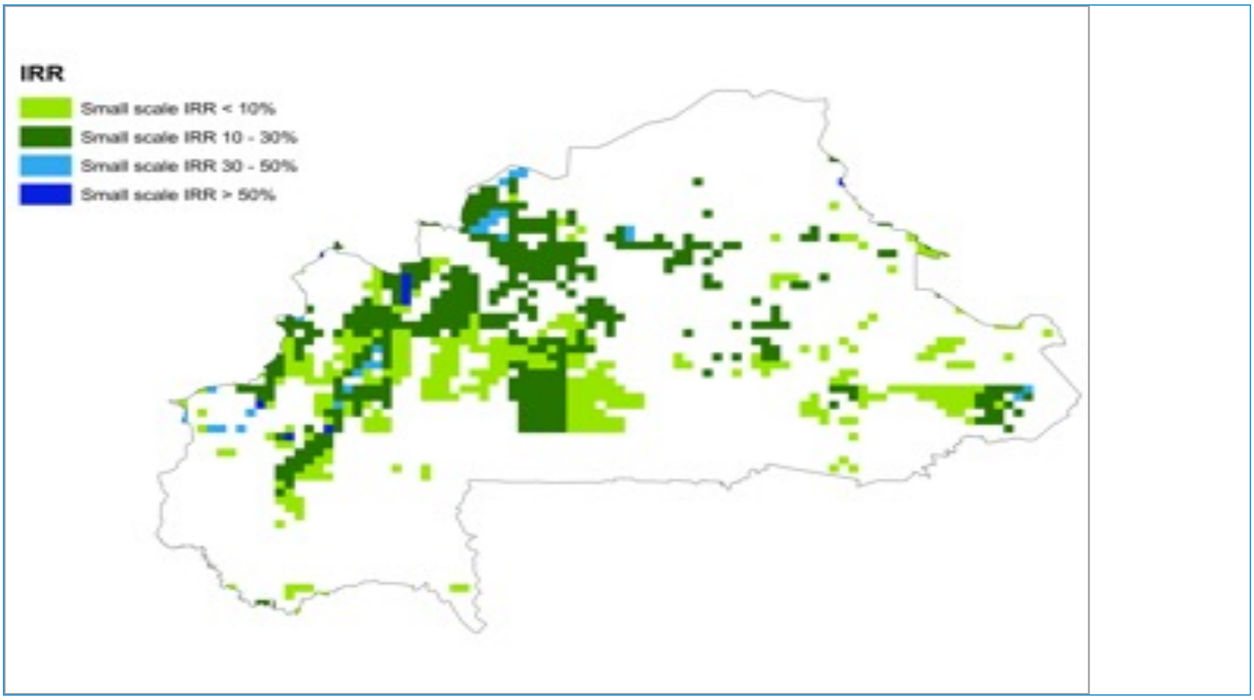
Based on experience, the priority crops identified for small-scale irrigation in Burkina Faso are onions, tomatoes, potatoes, bell peppers, and maize. These crops grow during both the rainy season and the off-season, and can generate cash incomes. In addition to generating cash incomes, potatoes and maize are used as food products for household consumption, which has important implications for food security.

4.3 Feasibility of small-scale irrigation in Burkina Faso

Figure 2 shows the feasibility of small-scale irrigation at pixel level measured by the internal rate of return (IRR) across the country. Potential feasible areas are located in the north and south-east of the country. The most potentially feasible areas generate a maximum IRR of 30 percent, but these are few. Most areas generate an IRR of less than 10 percent.

Most of the areas suitable for small-scale, surface water irrigation are found in four of Burkina Faso's thirteen regions. These are Boucle du Mouhoun, Centre-West Region, Hauts-Bassins and North Region. The relatively profitable areas (IRR > 10 percent) are in the northern parts of Boucle du Mouhoun, in the southern part of the North Region and in the central part of the Centre-West Region (Figure 8).

Figure 2: Feasible areas for small-scale irrigation in Burkina Faso



Source: Calculation updated based on You et al., 2011

4.4 Scalability of Small-scale Irrigation Technologies

Based on a review of studies on irrigation among African countries and the analysis on Burkina Faso presented above, four types of scalable water collection and/or extraction technologies have been identified: 1) Treadle pumps; 2) Motor pumps; 3) Small reservoirs; and 4) Communal river diversions. All these systems collect or divert surface water that is then used by smallholder farmers. The adaptability (or expansion) of these technologies depends on two main factors: the amount of annual runoff water and the economic viability of the investment. In addition to these factors, the adaptability of treadle and motor pump systems depends on the availability of surface water bodies such as lakes, ponds, streams, etc. Farmers could use pumps to extract groundwater, but this option is not considered here. Systems vary in terms of water use efficiency, environmental suitability, and economic viability. The potential for expansion of communal river diversions depends on the physical availability of small and medium-sized, non-seasonal rivers and their accessibility for the implementation of diversion works.

As shown in Table 3, in Burkina Faso, the net income per hectare of land appears to be higher with the use of small reservoirs and income levels increase further with the use of treadle pumps. These options (small reservoir and treadle pump) also allow for a higher net income per unit of water consumption. While the small reservoir generates the highest net income per hectare, the treadle pump generates the highest net income per unit of water. These two technologies are also used by many people, unlike other options. Of course, the total area of land irrigated with these two options is less than that irrigated with the other options.

More than half a million hectares of land can be irrigated with small reservoirs, which could generate a total additional income of nearly US$ 400 million per year. Similarly, an additional US$ 120 million can be generated through treadle pump irrigation in Burkina Faso. In general, a total of about three million hectares of land can be irrigated using these technologies. Given that one or more technologies can be scaled up in a particular area at the same time, the actual total irrigated area could be less than the sum of all the options.

Table 3: Scalability of selected small-scale irrigation technologies in Burkina Faso

Adaptability indicators	**Treadle pumps**	**Motor pumps**	**Small reservoirs**	**Communal river diversions**
Application area (thousands of ha)	849	1,066	572	632
Economic impact (billions of US$/year)	0.45	0.54	0.37	0.12
Rural population reached (millions of people)	11.4	8.9	12.8	4.7
Water consumption (billion m^3/year)	2.13	2.59	1.77	1.82
Net income (US$ per ha per year)	530.04	506.57	646.85	189.87
Net income (US$ per 100m^3 of water)	21.13	20.85	20.90	6.59

Source: Updated calculations from Xie, et al (2014).

4.5 Ex-ante Impacts of Scalable Technologies

This analysis was carried out to predict the likely impacts on growth and poverty reduction of the scalable technologies identified above, with the aim of showing the importance of small-scale irrigation at the macro-economic level.

4.5.1 Simulation Assumptions

The simulation scenarios are built on the assumption of expansion of irrigated areas with the four irrigation systems considered in this study: motor pumps, treadle pumps, small reservoirs, and communal river diversions. Information on the expansion potential by system is provided in Table 4. Projections indicate that irrigated land can increase by 89 percent to 165.8 percent over 2019 levels with all four irrigation systems. Expansion of irrigated land over a 10-year period corresponds to increases of between 6.6 percent and 10.3 percent annually (Table 4). The study applies annual increases using a 10-year, recursive-dynamic CGE model.

Table 4: Estimation of the potential feasible area of irrigated land using different systems

	Potential for expansion of irrigated land (000 Ha)	Potential for expansion of irrigated land, percentage ratio of irrigated land in 2019 (%)	Annual increase over 10 years to reach potential (%)
Motor pumps	1,066	165.8	10.3
Treadle pumps	849	132.0	8.8
Small reservoirs	632	98.3	7.1
Communal river diversions	572	89.0	6.6

Source: You et al. (2011) and Yearbook of Agricultural Statistics (2019).

Two Scenarios about the expansion of irrigated land are considered: (i) substitution of agricultural land; and, (ii) expansion of agricultural land. The assumption about agricultural land substitution is that the irrigated area expands to the detriment of the rain-fed areas with the four irrigation systems. While total cropland area increases at a rate of 0.385 percent, the increase in irrigated land area (6.6 to 10.3 percent) slows the increase in non-irrigated land area (0.116 to 0.245 percent) compared to baseline (0.392 percent) (Table 5).

The assumption on expansion of agricultural land considers that irrigation and rain-fed farming systems are complementary. In this case, the irrigation system is installed to supplement rainfall during periods of drought. In other words, the small-scale irrigation system extends agricultural practices beyond the rainy season. The cultivated area therefore extends with the four irrigation systems (0.522 to 0.644 percent) compared to baseline (0.385 percent) (Table 5).

Table 5: Area cultivated in Burkina Faso under the assumption of substitution and expansion, average annual change (percentage)

	Substitution			Expansion		
	All products	**Irrigated**	**Rain-fed**	**All products**	**Irrigated**	**Rain-fed**
Baseline	0.385	0.000	0.392	0.385	0.000	0.392
Motor pumps	0.385	10.269	0.116	0.644	10.269	0.392
Treadle pumps	0.385	8.782	0.173	0.590	8.782	0.392
Small reservoirs	0.385	7.085	0.229	0.537	7.085	0.392
Communal River Diversion	0.385	6.571	0.245	0.522	6.571	0.392

Source: Results of the CGE simulations.

In the baseline scenario, agricultural land productivity remains relatively constant, i.e., it declines slightly at an average annual rate of 0.007 percent (Table 6). Farmland productivity increases slightly (0.145 to 0.183 percent) on average annually, under the assumptions of substitution and expansion. The productivity effect is strongly related to the initial share of the irrigated area in the total cultivated area. Due to the faster expansion of the rain-fed area (with lower yields), agricultural land productivity increases at a slower rate under the assumption of expansion than under the assumption of substitution.

Table 6: Agricultural land productivity in Burkina Faso, average annual change (percentage)

	Land Substitution Assumption (%)	*Land Expansion Assumption (%)*
Baseline	-0.007	-0.007
Motor pumps	0.283	0.271
Treadle pumps	0.225	0.216
Small reservoirs	0.166	0.161
Communal river diversions	0.150	0.145

Source: Results of the CGE simulations.

4.5.2 Economy-wide effects

The expansion of small-scale irrigation leads to a reallocation of factors in the economy with a substantial increase in irrigated crop production (Tables 7-8). Rain-fed crop production declines due to the reduction in land use under the land substitution assumption and following the reallocation of non-land resources to irrigated crops under the land expansion assumption. However, net indirect effects are positive for other industries, including non-food crops, food processing and non-agri-food industries (Tables 7-8). In addition, the overall effects are positive for the agricultural sector and the national economy (Tables 7-8). The effects of value-added growth remain slightly larger under the land expansion and land substitution scenario. The adoption of motorized irrigation systems and treadle pump systems could allow farmers to grow crops during the dry season. Burkina Faso's rate of economic growth would increase by about 0.1 percentage points, while the rate of agricultural growth would increase by about 0.2 percentage points.

Table 7: Increase in value-added in Burkina Faso under the scenario of land substitution, annual average change over 10 years (percentage)

	National economy (%)	Agricultural sector (%)	Irrigated crops (%)	Rain-fed crops (%)	Non-food crops (%)	Processe food products (%)	Other industries (%)
Baseline	5.8	4.8	4.9	3.7	6.0	5.5	6.1
Motor pumps	5.8	5.0	11.1	3.3	6.1	5.5	6.2
Treadle pumps	5.8	4.9	10.3	3.3	6.1	5.5	6.2
Small reservoirs	5.8	4.9	9.3	3.4	6.1	5.5	6.2
Communal river diversions	5.8	4.9	9.0	3.4	6.0	5.5	6.2

Source: Results of the CGE simulations.

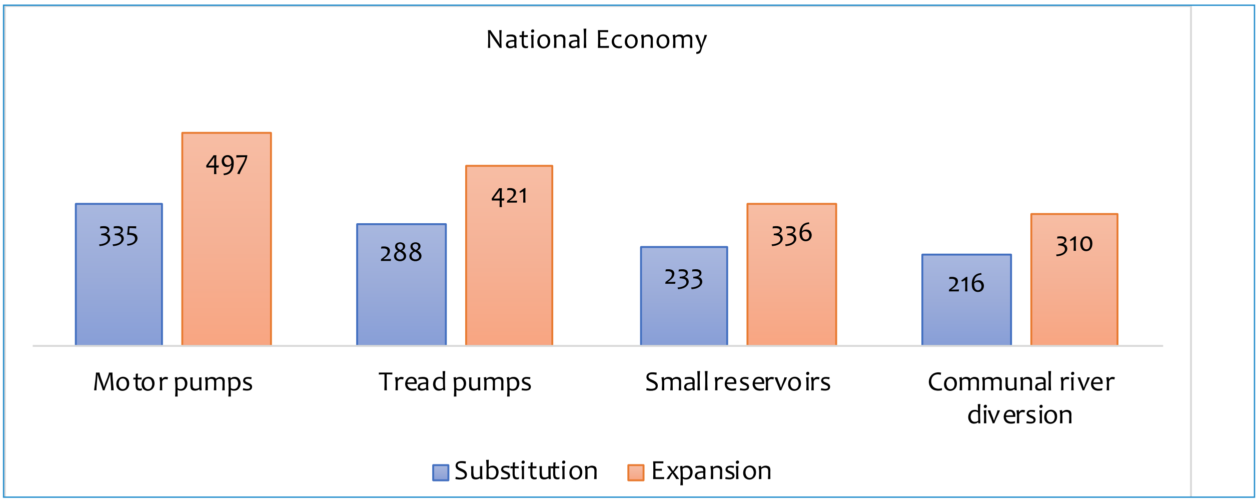
Table 8: Increase in value-added in Burkina Faso under the assumption of land expansion, annual average change over 10 years (percentage)

	National economy (%)	Agricultural sector (%)	Irrigated crops (%)	Rain-fed crops (%)	Non-food crops (%)	Processed food products (%)	Other industries (%)
Baseline	5.8	4.8	4.9	3.7	6.0	5.5	6.1
Motor pumps	5.9	5.0	11.0	3.4	6.1	5.6	6.2
Treadle pumps	5.9	5.0	10.2	3.4	6.1	5.6	6.2
Small reservoirs	5.8	4.9	9.2	3.5	6.1	5.5	6.2
Communal river diversions	5.8	4.9	8.9	3.5	6.1	5.5	6.2

Source: Results of the CGE simulations.

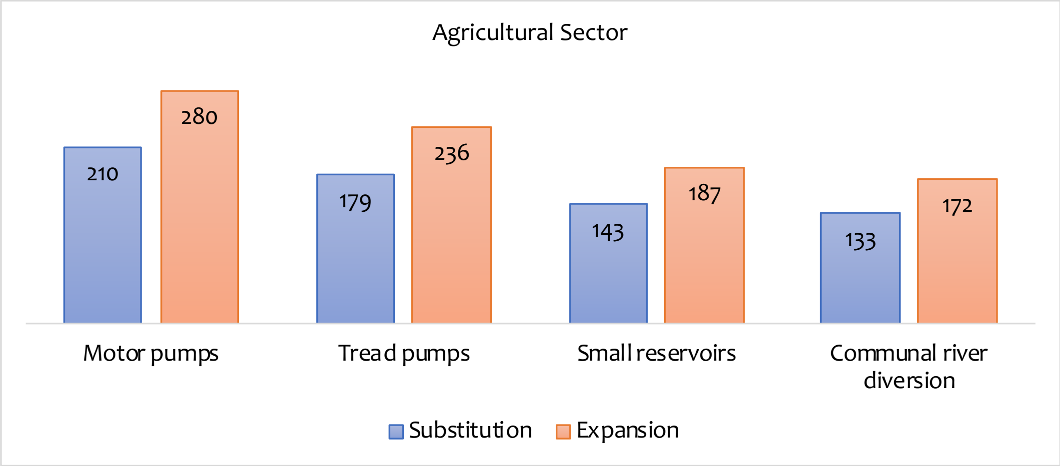
Expanding irrigated areas with the first three systems – motor pumps, treadle pumps, and small reservoirs – significantly increases the economy-wide value-added compared to baseline, i.e., without expansion of irrigation (Figure 3). The annual increase in additional value-added would be between 335 billion and 497 billion FCFA for the motor pump system, and between 288 billion and 421 billion FCFA for the treadle pump system. These two systems have the greatest potential for expansion of small-scale irrigation in Burkina Faso. Expansion of small reservoirs is expected to add an estimated 233 billion to 336 billion FCFA to the economy, while communal river diversions would generate 216 billion to 310 billion FCFA. The agricultural sector creates the largest share of value-added contributing between 55 percent and 63 percent (Figure 4). The agri-food and non-agri-food industries also increase their contributions to value-added (Figures 5-6).

Figure 3: Value-added in ten years by various irrigation systems to Burkina Faso's Economy, comparison to baseline values (Billion FCFA, 2019)



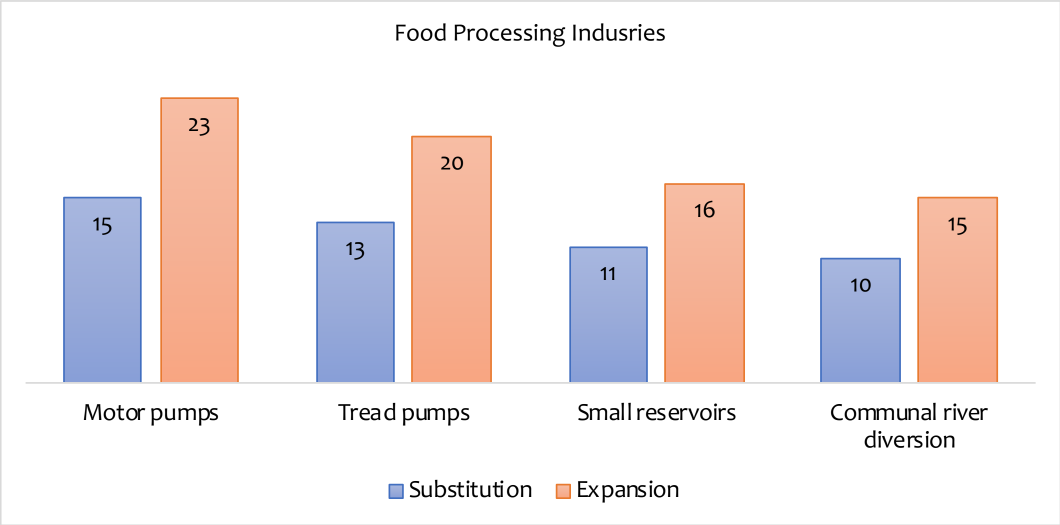
Source: Results from the CGE simulations.

Figure 4: Value-added in ten years by various irrigation systems to Burkina Faso's agricultural sector, comparison to baseline values (Billion FCFA, 2019)



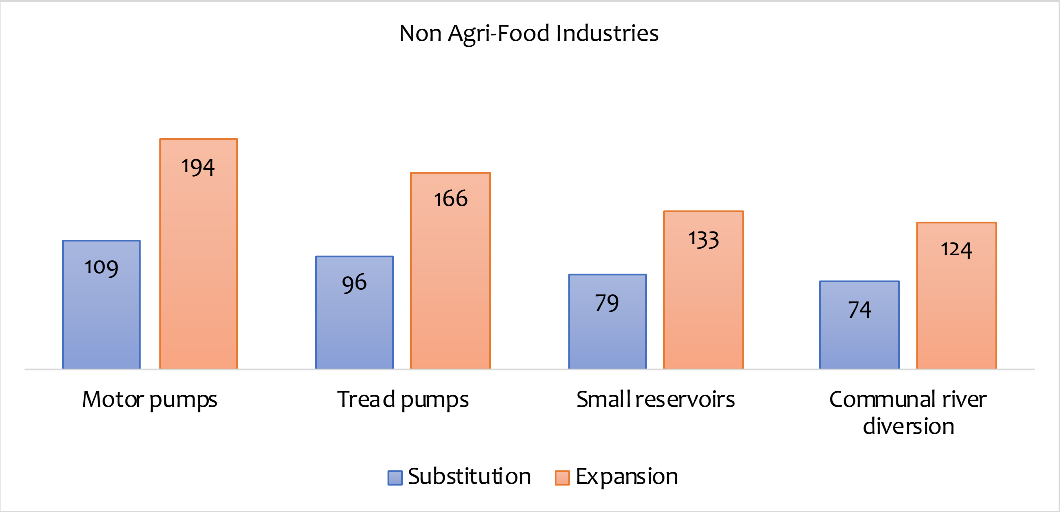
Source: Results from the CGE simulations.

Figure 5: Value-added in ten years by various irrigation systems to Burkina Faso's food processing industries, comparison to baseline values (Billion FCFA, 2019)



Source: Results from the CGE simulations.

Figure 6: Value-added in ten years by various irrigation systems to Burkina Faso's non-agri-food industries, comparison to baseline values (Billion FCFA, 2019)

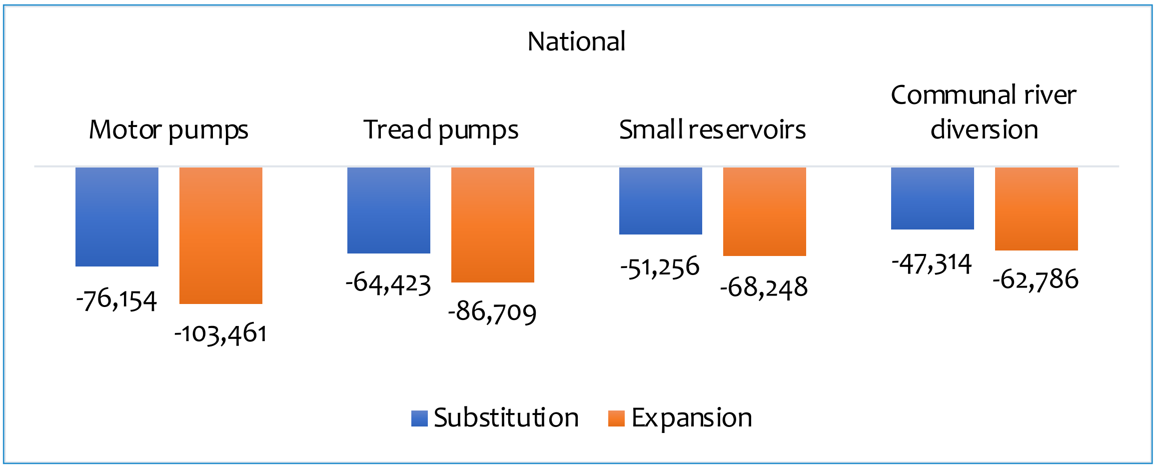


Source: Results from the CGE simulations.

4.5.3 Effects on Poverty Reduction

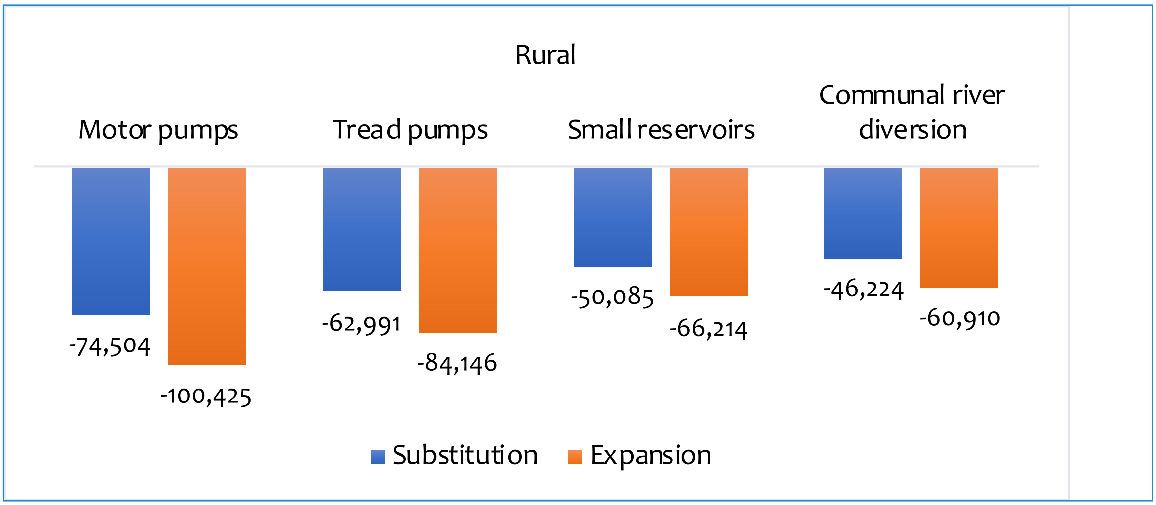
The rate of poverty reduction accelerates with the expansion of small-scale irrigation, driven by the reduction in rural poverty levels (Figures 7-9). The motor pump and treadle pump systems have the highest irrigation potential in Burkina Faso. Over a period of ten years, the expansion of motor pump systems is expected to lift to lift 76,000 to 103,000 people out of poverty, while treadle pump systems will lift 64,000 to 87,000 people out of poverty annually. The small reservoir system has the potential to lift 51,000 to 68,000 people out of poverty, while with communal river diversions, the numbers would range from 47,000 to 63,000 people. These figures are in comparison to the baseline, i.e., a situation without irrigation expansion. Rural poverty is expected to decline faster than urban poverty, and 97-98 percent of poverty reduction through the expansion of small-scale irrigation would be in rural areas.

Figure 7: Average annual change in the number of poor in Burkina Faso



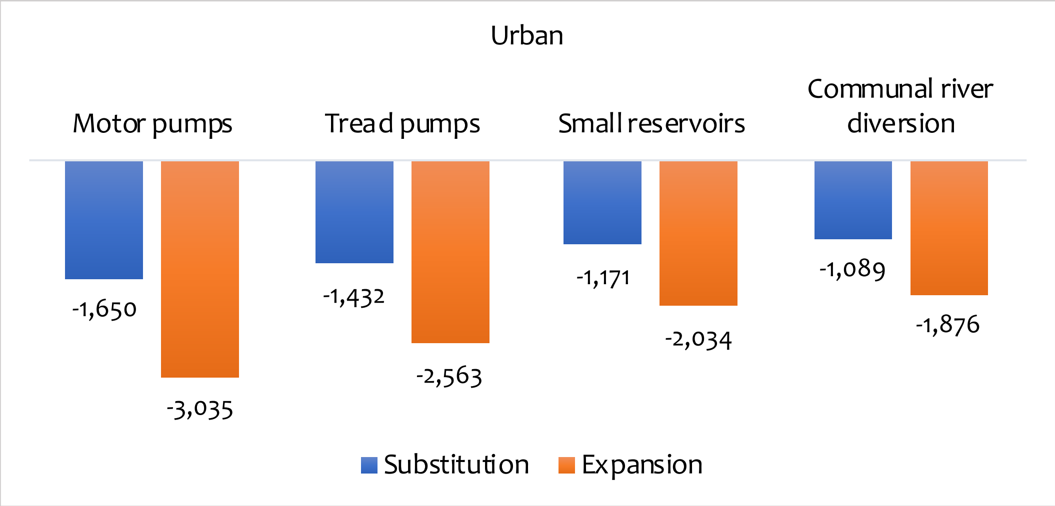
Source: Results from the CGE simulations.

Figure 8: Average annual change in the number of poor in rural Burkina Faso



Source: Results from the CGE simulations.

Figure 9: Average annual change in the number of poor in urban Burkina Faso



Source: Results from the CGE simulations.

5. CONCLUSIONS AND RECOMMENDATIONS

The various assessments and discussions presented above have shown that there is considerable interest, potential and opportunity to develop small-scale irrigation in Burkina Faso. The public and private sectors are more likely to get involved in SSI development given the opportunities for food production. In addition to the increased market opportunities for food production and processing, several SSI technologies have the potential to significantly scale-up, expand and evolve over time.

This paper examined the feasibility, scalability, and ex-ante impacts of small-scale irrigation development in Burkina Faso with special emphasis on the expansion of four selected technologies, i.e., treadle pumps, small reservoirs, motor pumps and river diversion irrigation systems. The study revealed that there are large areas of arable land which are feasible for small-scale irrigation with an IRR as high as 50 percent. Most of the feasible areas are located in four of Burkina Faso's thirteen regions. These are Boucle du Mouhoun, Centre-West Region, Hauts-Bassins and North Region. The study also revealed that most of these potential areas can be developed using the four technologies. Motor pump and treadle irrigation systems are both feasible and suitable for majority of the irrigable areas. Up to one million hectares can be irrigated using motor pumps. These technologies have the potential of reversing the declining overall agricultural growth seen in the business-as-usual scenario and creating opportunities for growth in the sector's productivity by about 0.28 percent an§nually. They also improve the sector's growth rate by about 0.2 percentage points, and GDP growth rate by 0.1 percentage points compared to the business-as-usual scenario.

In line with these findings, a strategy for the scaling up of small-scale irrigation development is critically important to reverse the declining or stagnant agricultural productivity and enhance economic growth. While focusing on the specificities of small-scale irrigation in the Sahelian context is essential, the proposed scaling-up strategy should be consistent with the main strategic reference frameworks for irrigation at the regional level. These include the Framework Document for Irrigation Development and Agricultural Water Management in Africa developed in 2020 by the African Union and the Strategic Framework for Agricultural Water in the Sahel developed in 2017 by the Inter-State Committee for Drought Control in the Sahel.

The strategy should consist of priority actions around five operational pillars defined as support systems that need to be created or strengthened for effective and sustainable expansion of small-scale irrigation in SSA in general and in Burkina Faso in particular. The five pillars are: 1) Strengthen the technological support system, 2) Streamline the technical advisory and extension system, 3) Diversify market access interventions, 4) Expand approaches and components of the program, and 5) Develop the institutional coordination framework.

These pillars could operate in push-pull mode to build capacity and encourage farmers to adopt the technologies and best practices identified in this document. The first three pillars act as incentives for creating a favorable environment and building the capacities of farmers and other stakeholders involved in SSI development, while the last two pillars act as pull factors, encouraging farmers to invest in and maintain irrigation systems.

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