IRRIGATION EXPANSION IN AFRICA – A COMPARATIVE ECONOMY-WIDE STUDY ON BENIN AND KENYA.

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Irrigation expansion in Africa – a comparative economy-wide study on Benin and Kenya

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Abstract

This study investigates the welfare implications of expanding irrigation schemes in Africa, taking Benin and Kenya as case studies. To this end, we apply a comparative static computable general equilibrium model. Through the setup of scenarios, we distinguish the effects of the (short-term) construction phase and (long-run) irrigation expansion. While outcomes for the two cases differ in the details, we find for both countries that the construction phase results in negative welfare effects for most households if the schemes are financed through increasing income tax rates. Yet, these losses can be overcompensated in the operation phase of the irrigation schemes, due to the expansion of export-oriented agriculture and related multiplier effects. To achieve a pro-poor distribution of welfare fair access for poor households to the newly irrigated land is crucial.

Keywords

Irrigated Agriculture, Agricultural Investment, Computable General Equilibrium Modelling

1 Background

Agriculture is a pivotal sector in most economies of Sub-Saharan Africa (SSA), sustaining livelihoods and contributing to national development. However, the vulnerability of rainfed crop production to climate risks and the anticipated decline in yields due to climate change in many regions, have prompted discussions on potential coping strategies. A key proposal is the expansion of irrigation schemes, recognized for facilitating more reliable and higher yields and the prospect of multiple harvests (Schuenemann et al. 2018). Also irrigated agriculture has been found to significantly enhance the techno-economic efficiency of farmers (Houngue and Nonvid, 2021) and thus has been found to allow for a manifold increase of income compared to rainfed agriculture (Hagos et al. 2009). Accordingly, investment in irrigation could contribute to improving GDP in SSA (Hagos et al., 2009) due to higher agricultural employment (Gosselin, 2010). While many researchers have shown the beneficial effects of irrigated agriculture in comparison to rainfed cropping on the farm-level, there are only few studies providing ex-ante assessments of the economy-wide implications of expanding irrigation schemes in SSA. Exemptions include Schuenemann et al. (2018), and Siddig et al. (2021), who investigate this for the case of Malawi and Sudan, respectively. However, in both studies the investment costs are not considered.

Two typical countries in SSA in which irrigation expansion is high on the policy agenda are Benin in the West of the continent and Kenya in the East. In the face of climate uncertainties and the imperative to enhance food security, both nations have set ambitious targets to expand irrigated agriculture.

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In Kenya vegetative agriculture accounts for about 12% of GDP (ELNOUR ET AL., 2022) while only 2.2% (216,000 ha) of the total cropland (9,8 Mio ha), were equipped for irrigation by 2020. The current plan of the Kenyan government is to increase this area by another 200,000 ha over the period from 2022 to 2026 (MWSI, 2022), while Kenya's total irrigation potential is estimated at 1,3 Mio ha (MWSI, 2022).

In comparison in Benin, crop production, even contributes to about 22% of the GDP (KINKPE ET AL., 2022) and is marked by substantial subsistence production (DRG-MAEP, 2016). In 2019, only 25,000 ha, constituting 0.6% of the total cropland, were equipped for irrigation (FAO, 2023). The Beninese government aims to triple the irrigated agricultural area by equipping an additional 50,000 ha by 2026 (PAG, 2021), while the total irrigation potential for Benin is estimated at 375,000 ha (DRG-MAEP, 2016).

The estimated budgets required to finance the establishment of the described irrigation schemes for both countries are detailed in Table 1. Given the high costs involved (about 4.3% and 10.5% of annual GDP in Kenya and Benin, respectively, this raises the question for a quantification of the benefits, which can be obtained from it.

As crop production is of high relevance to the overall economy and features strong forward and backward linkages with other sectors in both countries, we address this question using a computable general equilibrium (CGE) model. More specifically, this research aims at answering the following research questions: 1) To what extent will the planned irrigation development sustain agriculture, livelihoods, and economic growth in the two respective economies? 2) In how far these effects differ between the two countries and why? And finally, 3) What would be the effects of exploiting the overall irrigation potential on both economies.

Table 1: Estimated investment costs for developing the planned irrigated area in Benin and Kenya

Cost items	Mapping to sectors in database	Benin (50,000 ha)		Kenya (200,000 ha)	
		Total costs	Cost per hectare	Total costs	Cost per hectare
		[Million USD]	[USD]	[Million USD]	[USD]
Research and capacity development	Education	17.07	341	186.79	934
Management	Other Services/Public administration	76.80	1,536	269.72	1,349
Enhancing inclusivity	Social services		-	9.80	49
Construction	Construction	1279.97	25,599	3344.81	16,724
TOTAL		1373.84	27,477	3811.12	19,056

Source: Authors' compilation based on DOSSOUHOUI (2023), MWSI (2022) and expert estimates

2 Modelling Approach

2.1 Databases

This analysis is based on two recently developed, detailed social accounting matrices (SAMs) for Kenya and Benin. The SAMs are based on ELNOUR ET AL. (2022) for Kenya and KINKPE ET AL. (2022) for Benin. For this study, both SAMs have been extended and updated with support of the National Statistical Offices of both countries. The SAMs have been designed in a consistent way in order to facilitate comparison. Of special relevance for this analysis is the agricultural sector, which is depicted by about 20 activities and commodities in both SAMs. Further, both SAMs include eight production factors: two types of capital (agricultural and not), two land types (irrigated and not) and four labour categories, classified based on skill level (skilled and unskilled) and gender (male and female). Households are categorised into four groups, depending on location (rural and urban) and income level (poor and non-poor).

With respect to irrigated land, in Benin mainly maize, rice, vegetables & spices as well as pulses and tubers are grown under irrigation. In Kenya also wheat, other cereals and fruits are irrigated. In both countries the mentioned crops are also grown under rainfed conditions. Yet, irrigated land is more productive as a) it allows for multiple harvests for most crops and b) produces higher yields per harvest. The respective productivity factors have been determined based on expert assessments (multiple harvests) and published yield data (DSA-MAEP, 2022; FRIELER ET AL., 2017; MÜLLER ET AL., 2022) and range from 1.6 for tubers in Benin and 6.0 for oil seeds in Kenya. This difference in productivity is captured via satellite accounts.

In Kenya, irrigated land is almost exclusively owned by private and mostly rural households, while in Benin irrigated land is owned to 60% by farming enterprises and cooperatives and the remainder is split among household groups, with rural non-poor households owning the second largest share (17%).

2.2 Model setup

To analyse the economy-wide impacts of increasing the irrigated area, we use the STatic Applied General Equilibrium (STAGE) Model (MCDONALD AND THIERFELDER 2015), which is a CGE model, allowing to depict the economic transactions between different agents in one economy in a set of equations founded on microeconomic theory. In the model, production is depicted by a four-level nest of Constant Elasticity of Substitution (CES) and Leontief production functions. At the top level, aggregate value-added, and intermediate inputs are combined using a CES function with an elasticity of 0.5. On the second level, broad production factor categories (labour, capital and land) are aggregated using CES functions with an elasticity of 0.6, whereas the intermediate input component is aggregated using a Leontief production function. Aggregate primary factors (i.e., labour and land) are further differentiated using CES functions. Thereby, on the third level labour is composed of skilled and unskilled labour, and on the fourth level both classes are further subdivided into labour provided by female and male workers. On both levels relatively high elasticities of 2 and 3, respectively are assumed. Land is subdivided into rainfed and irrigated land, which are assumed to be very close substitutes (elasticity of 30), given that all irrigated crops are grown also on rainfed land in the base situation.

The final products are supplied to local and foreign markets, based on relative prices, as determined by a Constant Elasticity of Transformation (CET) function with an elasticity of 2, assuming a relatively high possibility for producers to switch between markets. The same holds true for imports which are considered relatively close substitutes for domestic products, modelled by an Armington-function with a substitution elasticity of 2.

Households supply production factors to productive activities through factor markets in exchange for wages that constitute a significant portion of their incomes. After paying taxes and making savings, households spend their income on purchasing products. Households maximise their utility subject to Stone-Geary utility functions, selecting the optimal mix of commodities and services while considering consumer prices, preferences, and income constraints.

2.3 Closure rules/ Macroeconomic assumptions

For both countries we assume that all production factors are fully employed and mobile between those sectors using them in the base situation. The model numéraire for the scenarios is the CPI and the model is savings-driven, meaning investments depend on available savings by households, enterprises, the rest of the world and the government. Yet, we assume that the government debts may not be further increased to avoid transferring welfare effects in future periods, which are not modelled. Thus, the government savings are fixed exogenously. This way, any additional any policy implemented in the model is financed through an endogenous, equiproportional increase of income tax on households[4].

2.4 Scenarios

We analyse three scenarios differentiated according to the time-horizon considered. Results are compared to the reference situation, representing the Kenyan and Beninese economies of 2019 as depicted in the respective SAMs (Section 2.1).

Short-run scenario (Invest): This scenario represents the phase of developing the additional irrigation schemes. In accordance with the respective development plans of both countries (for Kenya: NISS (MWSI, 2022) for Benin: PAG 2021-2026 (2021)), it is assumed that the investment period is 5 years. Further it is assumed that the total costs of 3.8 Billion USD for Kenya and 1.4 Billion USD for Benin are distributed equally over the years, while the benefits from the additional irrigated area only materialize after this period.

As the development of the irrigation schemes is realized by the respective governments, we implement this in the model by a shock to the government expenditure as detailed in Table 3. This results in a rise in government expenditure of about 6.5% in both countries throughout the five years. These additional expenditures are financed through an increase of the household income tax rates. This way, this scenario allows to capture and single out the economic effects of the investments required for expanding the irrigation capacity as indicated in the respective national plans.

Medium-run scenario (Irrigation): This scenario shows the effects resulting from the additional irrigated cropland (in Benin 50,000 ha, for Kenya 200,000 ha) on the respective economies. As the policy documents do not mention from where this additional cropland is sourced, based on national expert's assessments in this analysis it is assumed that: For Kenya the additional land is sourced from previously used rainfed land, while for Benin the additional land is sourced to 80% from unexploited areas (e.g. rangelands) and 20% from rainfed land. The ownership of the newly irrigated land is distributed among private households only and according to their shares of irrigated landownership in the base situation.

Long-run scenario (Potential): As a potential assessment, we additionally implement a long run scenario going beyond the current planning horizon. In this scenario it is assumed that the irrigated area is expanded to reach 310,523 ha in Benin and 1,116,720 ha in Kenya, which constitutes an expansion by 80% of the total additional irrigation potential of each country. As a potential-analysis, we do not directly consider the investment costs required to reach this potential, but apply the Pareto principle and assume that the marginal costs of increasing the irrigated area until this level would be constant (and might increase considerably only for the remaining 20% of the potential which are hence excluded from this analysis). This would mean, that the financing period (Invest scenario) would simply need to be extended accordingly (by 22.5 years for Kenya 28.6 years for Benin) to obtain the required funds.

The benefits from establishing the irrigation schemes are implemented in the model by land-shocks. Thereby the supply of irrigated land is increased, while rainfed land is decreased accordingly (Table 2). As the share of irrigated land is very small in the base reference situation (Kenya 2.2%, Benin, 0.4%), the sock is very large in relative terms, while the reduction of rainfed land is minor, especially in Benin where most of the additional irrigatable land is

[4] The only difference in model setup between the two countries refers to the exchange rate: while for Kenya we apply flexible exchange rate regime closure, Benin is part of a currency union (CFA franc). This currency again is pegged to the Euro. As Benin is only a small economy within the combined CFA franc-Euro-Zone, any changes in the Beninese economy will hardly impact the exchange rate. Thus, for Benin we apply a fixed exchange-rate-regime. To balance the foreign account the trade balance is kept flexible. A sensitivity analysis shows that domestic production and welfare are only marginally affected by the fixed exchange-rate regime.

sourced from previously unused land reserves. The land is distributed among households equi-proportionally.

Table 2: Percentage change in land availability

	Land type	Invest	Irrigation	Potential
Be-nin	Irrigated	0	203.1	1241.5
	Rainfed	0	-0.2	-1.1
Ke-nya	Irrigated	0	92.6	417
	Rainfed	0	-2.1	-9.3

Source: Authors' calculations

An innovation of this paper constitutes the capturing of the costs of water provision associated with the expansion of the irrigation schemes. As, according to national experts, the farmers themselves will be in charge of operating and maintaining the irrigation schemes once they are established, these costs need to be included in the production structure of the respective cropping activities. Instead of implementing separate rainfed and irrigated activities, which would require considerable additional work and data, we adjust the intermediate input consumption of the existing cropping activities, which benefit from the additional irrigation. Specifically, we shock the input-output coefficient of these activities, increasing the share of water expenditure in total intermediate consumption at the same rate as the increase in irrigated land.

All scenario setups have been developed in a transdisciplinary co-design process and the analysis has been co-conducted in the framework of a long-term capacity building project for policy analysis using economic models in Benin and Kenya. Finally, outcomes were discussed extensively with national experts of the two countries from the relevant ministries and national statistical offices.

3 Results

3.1 Domestic production

In the short run (*Invest* scenario), the construction sector substantially grows in both countries, driven by increased government demand for constructing irrigation projects. As shown in ***Figure 5***, for Benin this increase is more than 4 times larger than for Kenya in relative terms. While in both countries the construction sector constitutes about 6% of the GDP, the difference is mainly due to the stronger shock in case of Benin, where the additional government demand equals about 15% of the sector's output, while it is only 5% in Kenya.

With respect to the other sectors, Figure 1 shows that in Kenya also the forestry and the mining sector grow at similar rates. This is because in Kenya the construction sector consumes 96% of forestry and 79% of mining outputs as intermediate input. Similarly, in Benin, the construction sector uses 44% of mining as intermediate input. Consequently, expanding the construction sector also drives up production in these sectors. In contrast, the output of other sectors (e.g., crops, livestock, fishing, and services) drops in both countries. This can be ascribed to the increased prices of production factors (see Section 3.2) and the declining demand from households, which face increased tax rates (see Section 3.3).

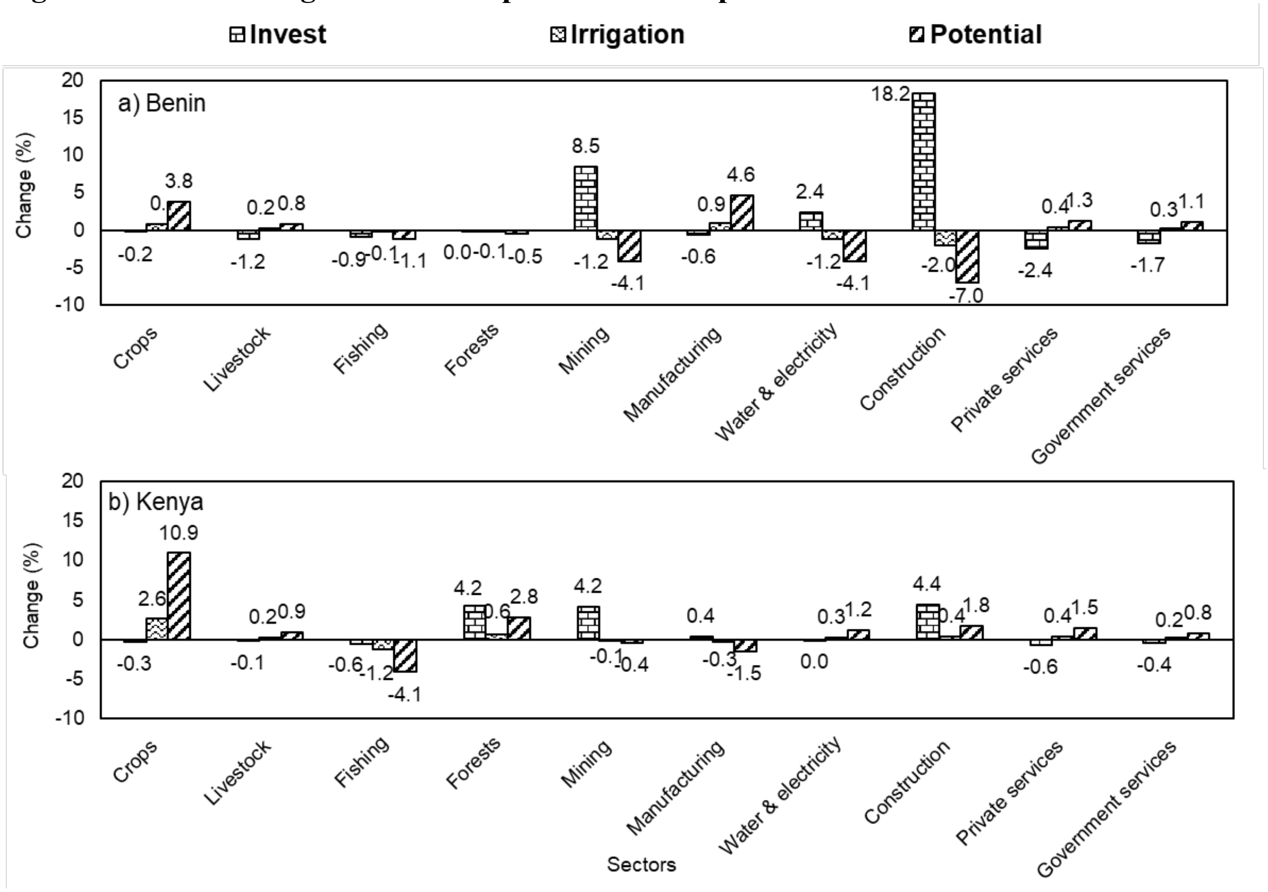
In the medium-run (*Irrigation* scenario), introducing irrigation schemes boosts crop production in both countries, particularly for land-intensive crops, which profit most from the additional supply of this factor (Figure 6). The overall expansion of crop production also triggers positive multiplier effects in upstream (e.g., food processing) and downstream (e.g., private services, mainly trade and transport) activities, as shown in Figure 1. These effects are more prominent for Benin. In both countries, the growth in crop sectors also contributes to a minor increase in livestock production due to cheaper feed (Figure 1).

Surprisingly, crops with a considerable export share experience substantial growth in both countries despite not being cultivated on irrigated land. These crops benefit indirectly from the drop in the price of rainfed land (Section 3.2) and a stable producer price, which remains relatively unaffected by the decline in domestic prices caused by the expanded supply. For Benin, these crops are cashews and cotton, cultivated on rainfed land, with 75% and 96% of their total production being exported, respectively. Similarly, tea is grown in Kenya on non-irrigated land, with approximately 65% of the total production being exported.

The long-run effects (*Potential* scenario) mirror the direction of the medium-run impacts in both countries, but with greater magnitude. When comparing the long-run effects in both countries, it is evident that overall crop production grows by 4% in Benin and almost 11% in Kenya. The latter is mainly attributed to a significant increase in tea production, which accounts for 37% of total crop production and is largely exported. The overall higher growth in crop production in Kenya compared to Benin is also due to the higher land intensity of cropping compared to Benin, where crop-production is more labour intensive.

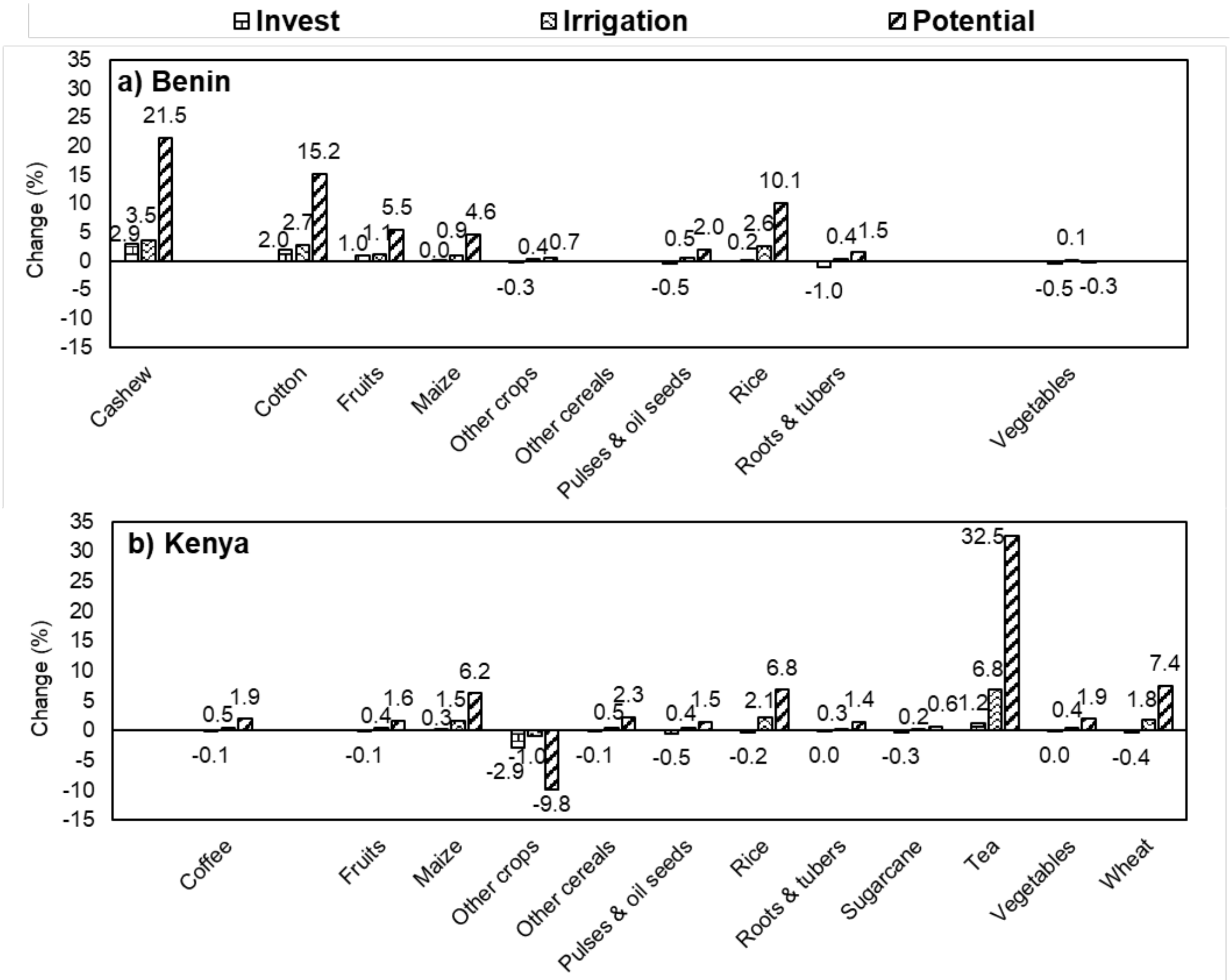
With respect to other sectors, similar impacts on livestock, fishing, and mining in both countries can be observed, yet the magnitude varies between the two countries. For instance, the decline in the fishing sector is less pronounced in Benin than in Kenya. This difference can be attributed to the significant rise in agricultural factor prices (labour and capital are extensively used by the fishing sector) in Kenya compared to Benin. The impacts on other sectors (forests, manufacturing, water and electricity, and services) vary between the two countries. This outcome can be attributed to distinctions in the input-output linkages between crop production sectors and these industries (intermediate inputs), as well as competitive effects in factor markets influenced by the expansion of crop production. For instance, in Benin, manufacturing production rises due to the growth of processing sectors, particularly cashews and cotton. Conversely, in Kenya, manufacturing production declines due to an upsurge in the price of non-agricultural capital, which is intensively utilized by this sector.

Figure 1: %-change of domestic production compared to the reference scenario



Source: Author's calculations based on simulation results

Figure 2: Change of crop production compared to the reference situation



Source: Authors' calculations based on simulation results

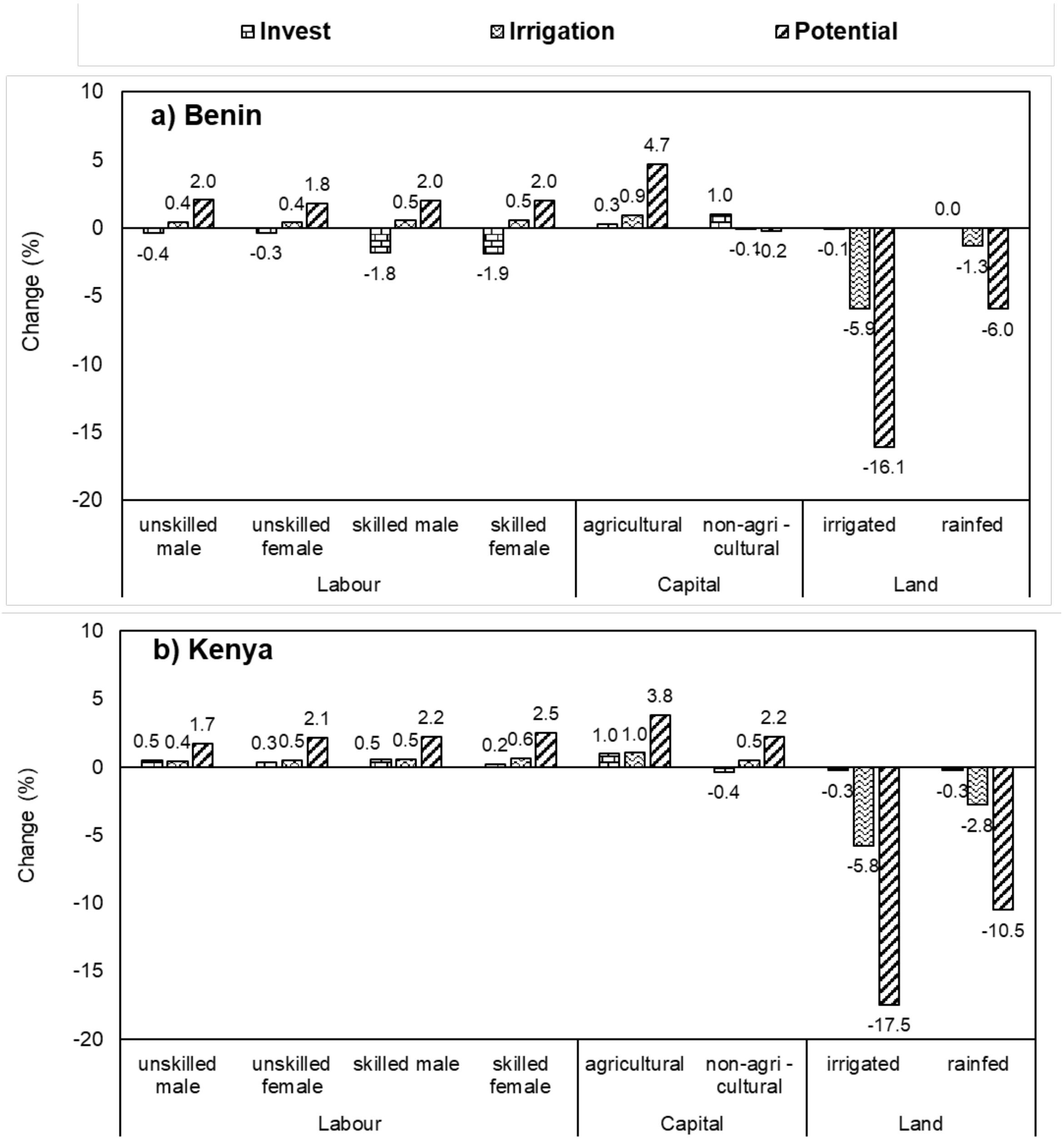
3.2 Factor prices

In the *Invest* scenario, factor prices experience only minor changes, as illustrated in Figure 3. Given the differences in factor intensity of the expanding construction sector between the two countries, the price of non-agricultural capital in Benin increases, in Kenya mainly labour is demanded more and thus becomes more expansive. Kenya's construction sector is typically labour-intensive and therefore, the investment phase will be accompanied by large absorption of mainly unskilled labour. However, the price of agricultural capital increases even more in Kenya. This is a second-round effect caused by the increase of the forestry sector, which is quite capital intensive.

In the *Irrigation* scenario, labour and capital prices experience a slight increase due to the growth in crop production. In contrast, due to the expansion of irrigated area, land prices for irrigated and rainfed land fall strongly in both countries (Figure 3). The latter is due to the high substitutability between the two types of land.

The long-run effects (*Potential* scenario) align with those observed in the medium-run (*Irrigation* scenario). Yet, the effects are much stronger in both countries, with irrigated land prices dropping by more than 15% and rainfed land prices falling by 5-10%, due to the much higher expansion of irrigated land.

Figure 3: Change of factor prices compared to the reference situation



Source: Authors' calculations based on simulation results.

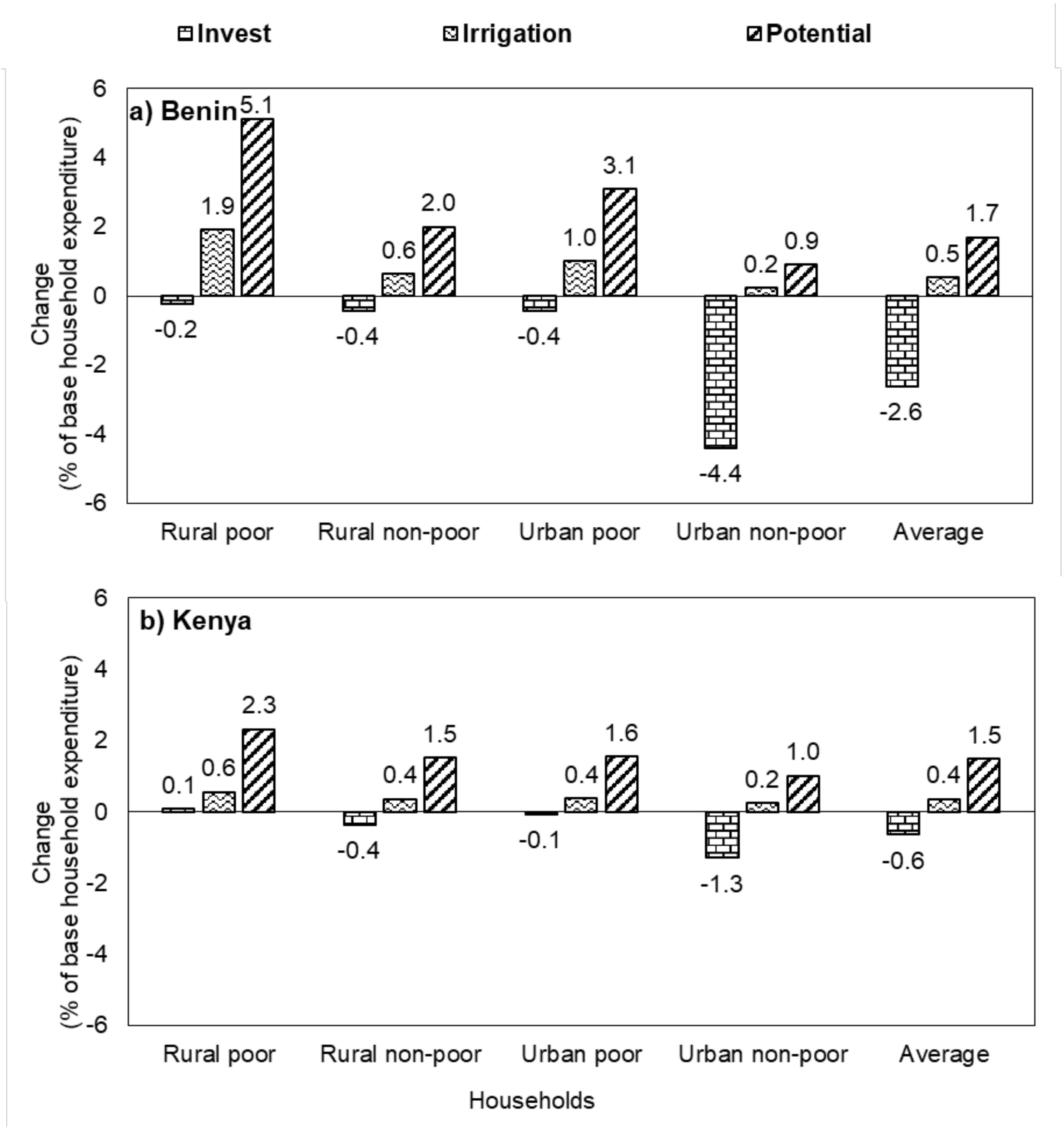
3.3 Household welfare

Figure 4 illustrates the three scenarios' impacts on household welfare measured as a change of Equivalent Variation (EV)[5]. As can be seen, the *Invest* scenario, largely impacts negatively on households' welfare. This is due to the increase in income tax-rates required to fund the expansion of irrigation schemes, while their benefits are not yet realized. The tax rates increase by 2.6 percent-points in Benin and 0.5 percent-points in Kenya, reducing the disposable income available to households for consumption. As in both countries urban non-poor households carry the highest tax burden, this household-group experiences the strongest reduction in welfare. In Kenya, rural poor households experience marginal gains. This is because of the slight increase

[5] EV refers to a change in income that would have an equivalent effect on utility as all observed price and income changes combined.

in unskilled labour wages due to the expanding construction sector and hence income, outweighing the negative impact of the raised tax rates, given the low average tax rate (or limited tax base) within this household category.

Figure 4: Change in equivalent variation as a share of household expenditure in the reference situation



Source: Authors' calculations based on simulation results

In the *Irrigation* scenario the tax-rates are again lowered close to the reference rates. As Figure 4 shows, the increased supply of irrigated land enhances household welfare in both countries. The highest welfare gains are observed among rural poor households, as they benefit most from the additional factor income from irrigated land, which in relative terms contributes most to the income of this household group in both countries. Additionally, the decline in crop prices contributes to the positive effects, particularly benefiting poor households with a significant share of expenditure on food.

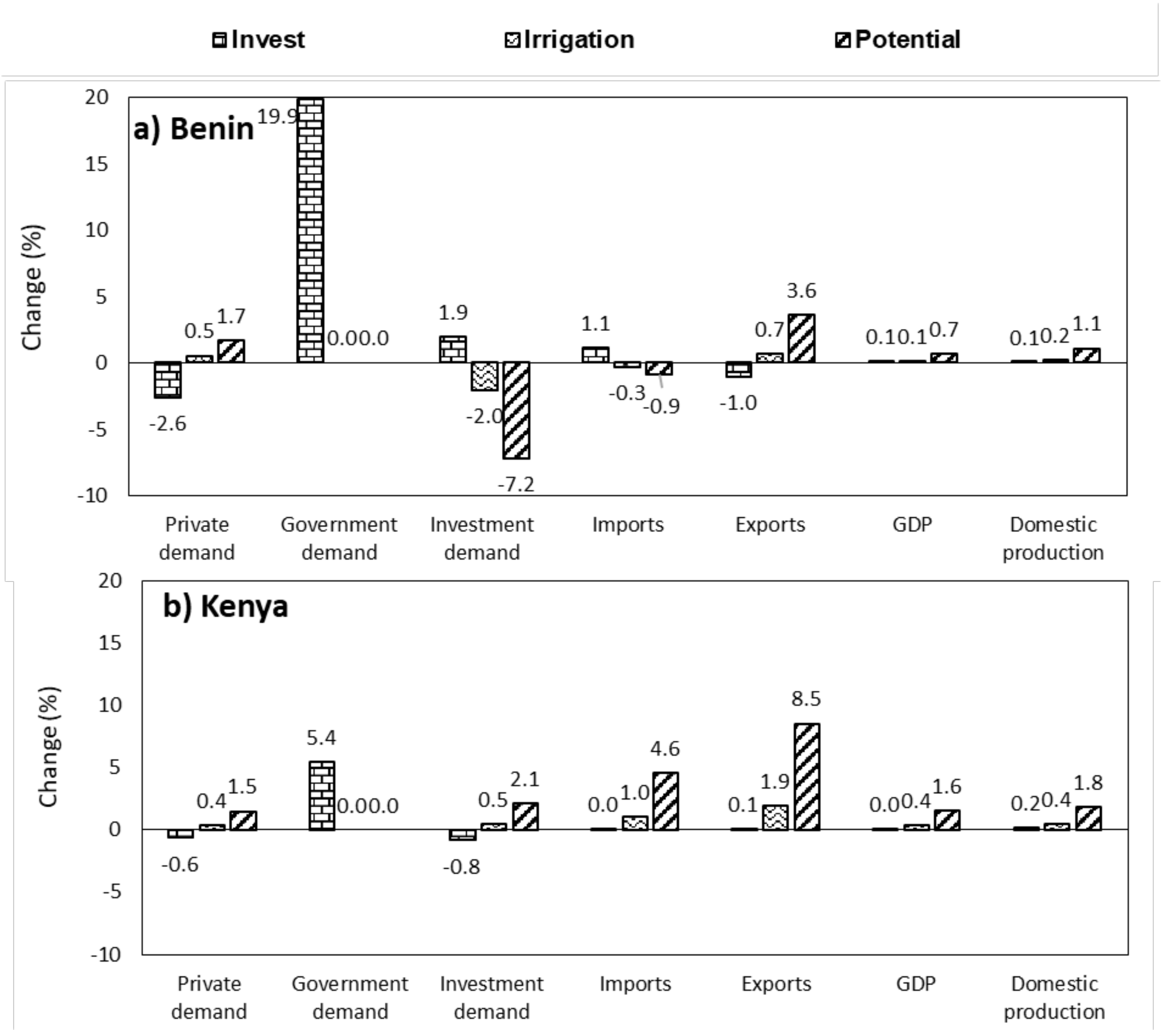
In the *Potential* scenario the effects become more pronounced, with welfare gains reaching up to 5.1% and 2.3% of base expenditure for rural poor households in Benin and Kenya, respectively (Figure 4). These welfare gains are mainly driven by the positive income effects, due to the additional irrigated area becoming available. The variation between the countries can mainly be explained by the relatively higher irrigation potential in Benin, where irrigated land supply grows more than 12-fold, while it only grows about 4 times in Kenya (compare Table 2)[6].

3.4 Economy-wide indicators

Turning to macroeconomic indicators, Figure 5 shows how in the *Invest* scenario government demand rises strongly due to additional allocations for constructing irrigation schemes. To fund these expenditures, income taxes on households are raised, leading to a decrease in private demand.

In the medium-and long run (*Irrigation* and *Potential* scenarios), with the establishment of the irrigation project government demand falls back to levels as observed in the reference situation in both countries. Simultaneously, private household demand rises slightly due to increased household income and relatively stable consumer prices.

Figure 5: % change of economy-wide indicators, compared to the reference situation



Source: Authors' calculations based on simulation results

Furthermore, exports grow in both countries, primarily driven by expanding shipments of agricultural products. In the case of Benin, the exports of cotton and cashews increase, improving

[6] To test this, we ran an additional scenario for Benin in which we applied an equal land supply shock as in Kenya and found the results to be much more similar: EV of poor rural households would reach 3.0% of base expenditure in this case.

the trade balance and given the closure setup with a fixed exchange rate reducing capital inflow from the rest of the world. In Kenya, predominantly exports of tea expand, providing the means to finance additional imports, particularly in the categories of petroleum, chemicals, and manufactured goods.

The positive impacts on household income also contribute to the growth of domestic production and hence also gross domestic product (GDP). For Kenya both indicators increase stronger, despite the relatively lower expansion of irrigated land (Table 2). This is caused by the exchange rate regime in Benin resulting in lower capital inflow and hence lower investments.

4 Discussion and Conclusions

Different from findings of previous research for Malawi (SCHUENEMANN ET AL, 2018), the outcomes of this study suggest that expanding irrigated agriculture in Benin and Kenya is promising for economic growth and improved household welfare. Both countries experience positive impacts post-establishment of irrigation schemes. The distribution of welfare impacts is largely driven by the allocation of the newly irrigated land. To achieve a pro-poor distribution as suggested by this study, it will be crucial for policy makers to ensure that poor households participate fairly in the allocation of the newly irrigated land[7]. In line with. SIDDIG ET AL. (2021) and HIGGINBOTTOM ET AL. (2021), this study shows that focussing on the production of export crops on the newly irrigated areas brings about the highest welfare effects, as these crops do not face a downward sloping domestic demand curve and hence falling prices with increasing production. Yet, the benefits of developing additional irrigation schemes do not only stem from the expansion of irrigated agriculture, but also from rainfed agriculture, benefiting indirectly from the increased availability of highly productive irrigated land. Also, multiplier effects in downstream and upstream sectors as well as an increased household demand for services and other commodities contribute to the overall positive economic effects. A sectoral analysis would miss these implications.

Yet, the *Invest* scenario suggests that in the short term, during the development of the irrigation schemes the welfare effects are negative for most household groups. It needs to be considered, however that this scenario stands for a period of five years, while the *Irrigation* scenario represents the several decades long lifetime of the irrigation schemes, as maintenance is included in the irrigation costs. Further, if a share of the required funds can be sourced by international donors as anticipated in the government plans, the short-term losses can be further reduced. To build more irrigation schemes as simulated in the *Potential* Scenario, the investment period simply would need to be prolonged accordingly.

While overall outcomes are similar and positive for both countries, nuanced differences exist particularly in gender dynamics and environmental considerations. In Benin, men marginally benefit more from employment patterns, whereas in Kenya, women, who are especially engaged in tea harvesting, stand to gain slightly more. Also, the equitable ownership distribution of newly irrigated land among sexes remains pivotal in both contexts. This shows that despite of similarities between countries in terms of relevance of the agricultural sector and irrigation potential, each case needs to be analysed individually to derive meaningful conclusions.

Also, environmental risks, including carbon release and biodiversity loss, differ based on the characteristics of the converted land—rangelands in Benin and savanna-land in Kenya—requiring tailored strategies for sustainable development. Yet, potential adverse environmental implications of increasing the agricultural area, e.g. on water resources are not considered in this

[7] In fact, a sensitivity analysis for the case of Benin shows, that if the newly irrigated land was distributed according to the distribution in the reference situation (60% belonging to enterprises), the overall welfare gains for households would be much smaller and welfare impacts would be even negative for poor rural households, as 64% of the additional enterprise income is invested and 24% goes to owners abroad, while only 6% to mainly non-poor domestic households, leading to much lower multiplier effects.

study. If, different from what is anticipated, larger areas of savanna-land are converted into irrigated crop land, negative implications in terms of carbon release, biodiversity loss and ecosystem services would need to be studied in more detail. In fact, it has been estimated that up to 248 tons of $CO2$ are emitted from turning one hectare of African savanna-land into crop land (WEST ET AL., 2010; SEARCHINGER ET AL., 2015). Yet, authors also found that turning sparsely vegetated areas into irrigated croplands could also result in more carbon storage (WEST ET AL, 2010).

To achieve the positive effects shown in this paper and avoid eventual bottlenecks, governments of these countries could work on implementing mechanisms to ensure overproportional access to the newly irrigated land for poor households, aligning with national development plans. Diversifying funding sources by raising some funds from international organisations, donors, and the private sector (enterprises) would help to mitigate negative impacts on household welfare during the construction period. Additionally, careful consideration of environmental effects through thorough analyses and compensatory measures is recommended in both countries to address potential negative externalities associated with the expansion of irrigated agriculture. One measure to be further investigated in this context could be the establishment of agroforestry systems, which have been found to reach higher carbon sequestration rates than annual crops or natural grasslands (MUTHURI ET AL. 2023).

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