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Assessing the Capacity of the Water–Energy–Food Nexus in Enhancing Sustainable Agriculture and Food Security in Burundi

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Abstract: In Burundi, a significant portion of the population heavily relies on agriculture for both sustenance and income. However, persistently low agricultural yields place approximately 1.8 million people at immediate risk of food insecurity. The purpose of this study was to explore the potential of the water–energy–food (WEF) nexus approach to strengthening agricultural sustainability and improving food security in Burundi. This study employs both the ARDL model and the ARIMA model to analyze the impact of water, energy, and land on agricultural yield while also projecting their future dynamics in Burundi. The results highlight a positive correlation between these resources and agricultural yield, demonstrating that a 1% increase in each of these variables would collectively result in a 3.74% increase in agricultural yield. Furthermore, the predictive findings reveal an anticipated decrease in agricultural yield by approximately 74.9 kg ha^{-1} and a reduction in agricultural land spanning up to 11.9×10^4 hectares by the year 2030. As a contribution to the body of knowledge, this study introduces a framework for the WEF nexus and sustainable agriculture, providing fresh perspectives to the literature on resource nexus studies in Burundi and among other practitioners in Africa.

Keywords: nexus approach; agriculture; sustainability; water; energy; food; food security

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1. Introduction

Agriculture is the mainstay of Burundi's economy, accounting for about 40% of the gross domestic product (GDP), employing 84%, providing 95% of the food supply, and accounting for more than 90% of foreign exchange earnings [1]. However, agricultural productivity in Burundi is hampered by several issues, including land degradation [2], climate impacts [3], economic factors [4], lack of access to agricultural infrastructure [5], and inefficient use of water resources [1], all of which contribute to the increasing food insecurity in Burundi. According to the 2020 Global Report on Food Crises [4], 5 of the 10 worst food crises in 2019 were from Sub-Saharan Africa (SSA), with Burundi scoring the sixth lowest place worldwide on the Global Food Security Index (GFSI), with more than 40.6% of the population being chronically food insecure [6].

Moreover, in recent years, several initiatives have been implemented in Burundi to promote sustainable agriculture and improve food security, including the Great Lakes Regional Integrated Agriculture Development Projects [7], the Agricultural Production Intensification and Vulnerability Reduction Project, the Project to Support Agricultural and Rural Financial Inclusion, and the Rural Entrepreneurship Development Program [8]. These creative projects, together with government policies such as the Strategic Poverty Reduction Paper, offer viable options to improve Burundi's food security [9]. Furthermore, there have been gradual mechanization techniques integration in Burundi's agricultural sector along with agricultural land expansion in order to tackle the aforementioned concerns [10]. However, progress is still slow as the country strives to achieve its SDGs, and the developed strategies are hampered by natural resource depletion and degradation [11].

The complex links between water, energy, and food systems have drawn substantial attention in the field of sustainable development due to the rising global population, climate change, and resource scarcity [12,13]. The nexus approach, which emphasizes the interconnectedness and interdependencies of these critical sectors, has emerged as a pivotal framework to address the complex challenges arising from these intertwined systems [14]. Nowhere are these challenges more pertinent than in countries such as Burundi, where a substantial portion of the population relies heavily on agriculture for livelihoods and sustenance. Therefore, the WEF nexus approach can offer a useful framework for analyzing the potential of water–energy–food linkages in enhancing sustainable agriculture and food security in Burundi to address the aforementioned challenges.

Some researchers have carried out their studies in the context of Burundi regarding the WEF nexus, considering only food security, such as Heidi Elisabeth and Sanctus [11], who conducted a study about the challenges of food security and the WEF nexus in Burundi. Other researchers have focused on food security [15,16], while others have focused on agriculture [9,17,18]. However, even though a lot of research has been conducted in this context, Africa as well as Burundi lag behind within the empirical studies arena [19,20]. Therefore, little is known about the WEF nexus approach considering both agriculture and food security interconnectedness in Burundi. To fill this gap, the authors found it vital to employ the ARDL model. However, unlike the aforementioned studies, this study aims to assess the capacity of the WEF nexus to enhance sustainable agriculture and food security in Burundi. Additionally, this study seeks to look into the forthcoming potential changes in agricultural yield, use of land, water, and energy in farming in Burundi. Therefore, this study also uses the ARIMA model to forecast agricultural yield, agricultural land, agricultural water, and energy use in agriculture.

Understanding the underlying dynamics and trade-offs across these sectors allows for the formulation of holistic solutions that not only improve food security but also advance Burundi's larger sustainable development goals. Moreover, as the global community strives to achieve the United Nations Sustainable Development Goals (SDGs), it is imperative to unravel the complexities of the WEF nexus in specific national contexts. This study endeavors to add to the body of knowledge by providing a nuanced analysis of the challenges and opportunities in the context of Burundi, ultimately guiding the formulation of evidence-based policies and practices that can drive transformative change in the pursuit of sustainable agriculture and food security.

2. Literature Review

To feed the continuous growth of the world's population, which is forecast to reach 9 billion by 2050, food production must increase from 70% to 100% [21,22]. As such, many researchers have conducted studies focusing on different factors influencing the achievement of food security in developing countries and emphasizing a causal relationship between agriculture and food security [23–25]. These researchers stressed that farming is a key factor in determining food security, particularly in countries such as Burundi that rely significantly on agriculture. In fact, 80% of East Africans rely on agriculture for their livelihood [24]. However, agricultural production differs from country to country as well as from crop types in East Africa. For example, as presented in Figure 1, Kenya produces more wheat than other countries, while rice, sorghum, maize, and beans are produced in large quantities in Tanzania. However, Burundi still lags behind in agricultural production compared to other East African countries (Figure 1).

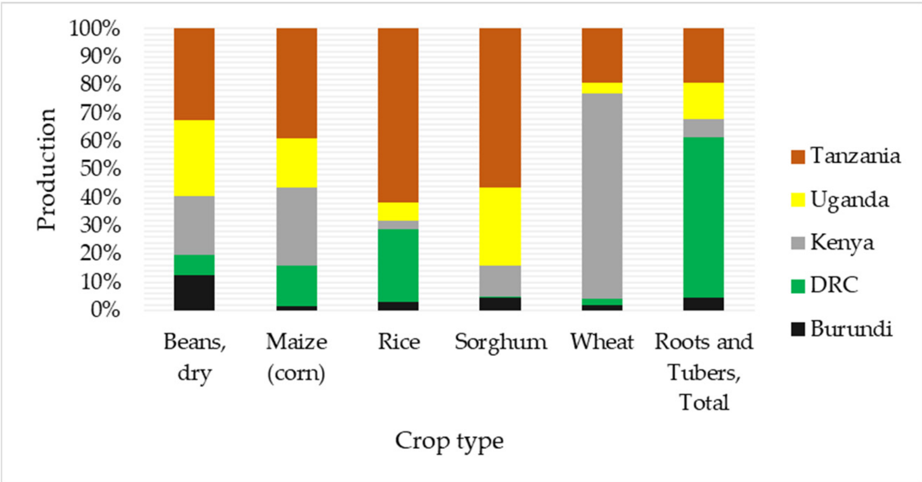

Figure 1. Share of the total agricultural production of some East African countries in 2021. Note: DRC: Democratic Republic of the Congo. Source: FAO: FAOSTAT [1].

Table 1 summarizes several studies on the causal relationship between the WEF nexus, agriculture, and food security in various countries and regions. To reach that conclusion, some researchers have employed the autoregressive distribution lag (ARDL) model. Ceesay and Ben Omar [2], using the ARDL model, investigated the connection between food security and agriculture in Gambia and found that an increase in food security is strongly correlated with an increase in agricultural production. Similarly, Ragif Huseynov [3] used the same methodology to study the dynamics of different determinants of food security and found that food imports, exchange rates, and climate change influence national food security in Azerbaijan. Additionally, in Nigeria, Romanus et al. [4] examined food security using the ARDL model and found that there is a high level of food insecurity in agriculture and suggested a social protection policy improvement for agriculture. Furthermore, Ceesay and Momodou [5] used ARDL to assess the effects of agriculture, food security, food imports, and climate change on economic growth and revealed that climate change and food security have a positive and insignificant impact on economic development in Bangladesh. However, although these researchers emphasized the importance of agriculture in boosting food security, in countries such as Burundi, agriculture faces different challenges than those already mentioned. In Burundi, agriculture is heavily dependent on regular rainfall, but due to climate change, rainfall has become unpredictable and irregular [6,7], which can negatively affect production, leading to food security. Agriculture is the key to increasing food production to meet rising food demand, especially in countries that heavily depend on agriculture, such as Burundi.

Table 1. Summary of literature on determinants of food security in different regions.

Reference	Research + Region	Determinants of Food Security
[8]	Determinants of WEF nexus in Africa	GDP per capita, Policy, foreign direct investment
[9]	Determinants of Food Security in Sub-Saharan Africa (SSA), South Asia and Latin America	GDP per capita; infrastructure; agriculture, Access to drinking water;
[10,11]	Household level determinants of food security in the City of Tshwane, South Africa	Education, Household size, economy, agriculture
[12,13]	Determinants of Food Security in Kenya	Access to credit, Agriculture,
[14,15]	Food security in Zambia	Agriculture
[16]	Food insecurity and agricultural productivity in Nigeria	Agriculture
[17]	Agriculture and household food security in rural Ghana	Agriculture
[18]	Food security and its determinants in Bangladesh	Agriculture
[19]	Food security in Africa	Access to land, water, and other resources; agricultural productivity; conflict and instability; climate change
[20]	Food insecurity in Ethiopia	
[21]	Food-energy-water security in the Middle East	Conflict and political instability; water scarcity and irrigation; food trade and imports; climate change

There is a need to adopt an approach that considers sustainable agriculture and food security in order to meet the needs of present and future generations for health, social, and economic equity. As such, the WEF nexus, by ensuring water and energy availability for farming purposes, can improve the sustainability of agriculture and food. Gabriele et al. [22] analyzed the interconnections between water, energy, and food systems as well as agriculture. They found that the WEF nexus has the potential to improve the sustainability of agriculture by aiming to produce food in a way that minimizes negative environmental impacts and promotes long-term viability. In fact, agriculture accounts for 70% of the total global freshwater withdrawals, making it the largest user of water, where it is used for agricultural production, forestry, and fishery along the entire agri-food supply chain, and it is used to produce or transport energy in different forms [23]. In return, energy is also useful in agricultural activities such as farm power and machinery. Therefore, sustainable agriculture practices must consider the WEF nexus and strive to balance the needs of each system.

Therefore, it is clear from the literature reviewed above that previous studies tended to focus on the connections between agriculture and food security in various locations without providing a dynamic evaluation of the nexus method and its potential to enhance sustainable agriculture and food security. Thus, this study adopts the ARDL model to assess the dynamic interconnections between land, the WEF nexus, and agricultural yield. At the same time, using the ARIMA model, the study forecasts resources such as water, energy, and land allocation for agricultural purposes, along with agricultural yield. The study therefore proposes the framework of the WEF nexus and sustainable agriculture for the maximization of their potential towards food security enhancement.

3. Data and Methodology

3.1. Variables and Data

Six indicators were used in this study, three of which represent key resources used in sustainable agriculture. These resources include land [24], water [25], and energy [26]. Therefore, planted areas (hectares) were selected to represent agricultural land, while agricultural water withdrawal (m^3/year) in this study was selected to represent water. In addition, modern agriculture requires an energy input at all stages of agricultural production, such as the direct use of energy in farm machinery, water management, irrigation, cultivation, and harvesting, while post-harvest energy use includes energy for food processing, storage, and transportation to markets. In addition, there are many indirect or sequestered energy inputs used in agriculture in the form of mineral fertilizers, chemical pesticides, insecticides, and herbicides [27]. Therefore, variables such as energy use in agriculture (terajoules) and pesticides (tons), and fertilizer usage (tons) were used in this study. Moreover, since a large number of people depend on agriculture as a source of food and income, as established by Ochilo et al. [28], the total agricultural annual yield (kg/ha) of the main crops such as maize, corn, wheat, sorghum, casava potatoes, bananas, beans, coffee, rice, soya beans, and millets was selected as a variable in this study as these are directly related to food security. The annual data were collected from the Food and Agriculture Organization (FAO) of the United Nations [1] and Our World in Data [29] from 1978 to 2021.

3.2. Methodology

3.2.1. Stationary Test

It is crucial to check the stationarity of the data before running the time series model. Therefore, in this study, we examined the stationary of all variables by using the augmented Dickey–Fuller stationarity test (ADF) [30] and the Phillips–Perron (PP) [31] test. Both tests are necessary because the ADF and PP are used at the level form as well as the first difference in each series, and in the ADF test, the lag length is included to solve the issue of robustness and autocorrelation [32]. The ADF and PP equations are shown below

$$\nabla T_1 = \alpha_0 + \alpha T_t + \sum_{i=k}^{OP} Q_i \nabla T_{t-1} + \varepsilon_t \quad (1)$$

where ∇ stands for the first operator difference, T_t denotes timespan, α_0 is the constant, OP is the maximum lag numbers on the dependent variable, and ε is the error term.

3.2.2. Autoregressive Distributed Lag (ADRL) Model

This study analyzes the impact of some resources used in improved agriculture such as water, food, and energy on food security in Burundi. Although it is proven that agriculture affects food security, the purpose of this current article is to examine the impact of every single resource (water, energy, and land) allocation for agricultural purposes on food security by using the ARDL model. The equation for the selected model can be expressed as:

$$LAGY_t = \alpha_0 + \beta_1 LPA_t + \beta_2 LAGW_t + \beta_3 LEUA_t + \beta_4 LPST_t + \beta_5 LFTL_t + \varepsilon_t \quad (2)$$

where, t is time period, AGY is agricultural annual yield; PA is planted area; AGW is Agricultural water withdraw; EUA is energy use in Agriculture; PST is pesticides use, and FTL is fertilizer use.

ARDL was used to examine the long run and short run association among the variables. ARDL can be performed without considering the order of integration of the series, even in a small sample, and it provides an unbiased long-run estimate [33].

The ARDL model is expressed as:

$$\begin{aligned} \Delta LAGY_t = {} & \alpha_0 + \sum \beta_1 \Delta LAGY_{t-1} + \sum \beta_2 LPA_{t-1} + \sum \beta_3 LAGW_{t-1} + \\ & \sum \beta_4 LEUA_{t-1} + \sum \beta_5 \Delta LPST_{t-1} + \sum \beta_6 \Delta LFTL_{t-1} + \vartheta_1 LAGY_{t-1} + \vartheta_2 LPA_{t-1} + \\ & \vartheta_2 LAGW_{t-1} + \vartheta_3 LEUA_{t-1} + \vartheta_4 LPST_{t-1} + \vartheta_5 LFTL_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

Moreover, the Error Correction Model (ECM) was also employed to check short-term correlation and the equation is expressed as:

$$\begin{aligned} \Delta LAGY_t = {} & \alpha_0 + \sum \beta_1 \Delta LAGY_{t-1} + \sum \beta_2 LPA_{t-1} + \sum \beta_3 LAGW_{t-1} + \\ & \sum \beta_4 LEUA_{t-1} + \beta_5 LPST_{t-1} + \beta_6 LFTL_{t-1} + \delta ECM_t + \varepsilon_t \end{aligned} \quad (4)$$

3.2.3. Autoregressive Integrated Moving Average (ARIMA) Model

The ARIMA model is a flexible and widely used method for forecasting time series data [34,35]. An ARIMA model is commonly denoted as (p, d, q), where p is the number of the autoregressive terms, q denotes the number of moving average terms, and d indicates the number of differences required for stationarity [36]. In this study, six different tentative ARIMA models: ARIMA (2, 1, 1), ARIMA (2, 0, 1), ARIMA (0, 2, 3), ARIMA (1, 1, 0), ARIMA (1, 0, 0), and ARIMA (0, 2, 3), were fitted to the data.

Where for ARIMA (2, 1, 1): p = 2, d = 1, q = 1; for ARIMA (2, 0, 1): p = 2, d = 0, q = 1; for ARIMA (0, 2, 3): p = 0, d = 2, q = 3; for ARIMA (1, 1, 0): p = 1, d = 1, q = 0; for ARIMA (1, 0, 0): p = 1, d = 0, q = 0; and for ARIMA (0, 2, 3): p = 0, d = 2, q = 3.

4. Results and Discussion

4.1. Results

4.1.1. Stationarity Test

Furthermore, in order to check the stationarity of the construct, the augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were used. We applied the unit root test at the level and the first difference of the natural logarithms of the variables, as shown in Table 2. The results indicate that PA, AGW, EUA, and FLT are stationary at level, while AGY is stationary at first difference (Table 2).

Table 2. Stationarity test results.

	ADF		PP	
Variables	**Level**	**First Difference**	**Level**	**First Difference**
LAGY	−0.964	−8.945 ***	−1.933	−9.229 ***
LPA	−2.081	−2.748 *	−1.391	−2.748 *
LAGW	−2.042	−3.851 ***	−10.537 ***	−3.966 ***
LEUA	0.656	−5.061 ***	0.553	−5.058 ***
LFTL	−0.246	−5.147 ***	0.216	−5.154 ***
LPST	−2.745 *	−5.723 ***	−2.756	−8.862 ***

Note: * and *** statistically significant at 10% and 1% levels, respectively.

4.1.2. Diagnostic Test

Diagnostic tests were conducted in order to check the functionality of the model. The results confirm the correct functional form of the model. Moreover, the findings indicate that there is no heteroscedasticity and no serial correlation (Table 3).

Table 3. Diagnostic test results.

Test	F-Statistic	Probability	Outcome
Breusch–Godfrey Serial Correlation LM	3.926	0.094	No serial correlation
Breusch–Pagan–Godfrey Heteroskedasticity test	0.755	0.708	No Heteroskedasticity
Ramsey test	0.078	0.941	Correct Functional form

4.1.3. Bound Test

Furthermore, the cointegration among constructs was tested through an ARL bound test to check the essentiality of the ARDL application. The results (Table 4) show that F-statistics (11.1) were greater than the critical values at 10%, 5%, and 1% significance levels, which implies the fitness of the ARDL model for this study.

Table 4. Bound test of ADRL model results.

Model	F-Statistic	Level of Significance		Bound Test Critical Values
			I (0)	I (1)
AGY/(PA, EUS, AGW, FLT)	9.702	1%	3.41	4.68
		5%	2.62	3.79
		10%	2.26	3.35

4.1.4. Long-Term Estimation

The results of the long-term coefficients presented in Table 5 indicate that agricultural land, agricultural water withdrawal, fertilizer and pesticide utilization, and energy use in agriculture in the long run have a positive correlation with agricultural yield.

Table 5. Long-term coefficient results.

Variable	Coefficient	Std. Error	t-Statistic	Probability
LPA	3.030323	1.707056	1.775175	0.1191
LAGW	0.208663	0.291242	0.716457	0.4969
LEUA	0.24147	0.309855	0.779301	0.4613
LFTL	0.086438	0.187595	0.460771	0.6589
LPST	0.185414	0.086189	2.151246	0.0685
C	−5.07472	2.510434	−2.021453	0.083

4.1.5. Short-Term Estimation

The results of the short-term coefficients (Table 6) show that agricultural land and pesticide and fertilizer utilization in the short term have a positive correlation with agricultural yield. The results also show that agricultural water withdrawal and energy use in agriculture have a negative correlation with agricultural yield in the short term.

Table 6. Short-term coefficients.

Variable	Coefficient	Std. Error	t-Statistic	Probability
D (LPA)	1.99209	0.875609	2.27509	0.057
D (LAGW)	−2.94432	0.362833	−8.114808	0.0001
D (LEUA)	−0.12016	0.067194	−1.78829	0.1169
D (LFTL)	0.032798	0.028519	1.150053	0.2879
D (LPST)	0.049001	0.01223	4.006571	0.0051
CointEq (−1)	−0.89416	0.08951	−9.989488	0.000
R-squared	0.966535	Mean dependent var		0.007944
Adjusted R-squared	0.927492	S.D. dependent var		0.114269

4.1.6. Predictive Results for Agricultural Yield, Land Allocation, Fertilizer Usage, and Pesticide Application

The ARIMA prediction results presented in Figure 2 and Table A1 show that there will be a decrease of about 74.9 kg/ha in agricultural yield between 2022 and 2030. In addition, the findings show that there is a continuous decrease in agricultural land (Figure 2) from 2020 to 2030. Furthermore, the findings show that the energy consumption of agriculture through fertilizers and pesticides will increase in the period from 2021 to 2030. On the other hand, the results show that agricultural water withdrawal and energy use in agriculture will remain constant up to 2030.

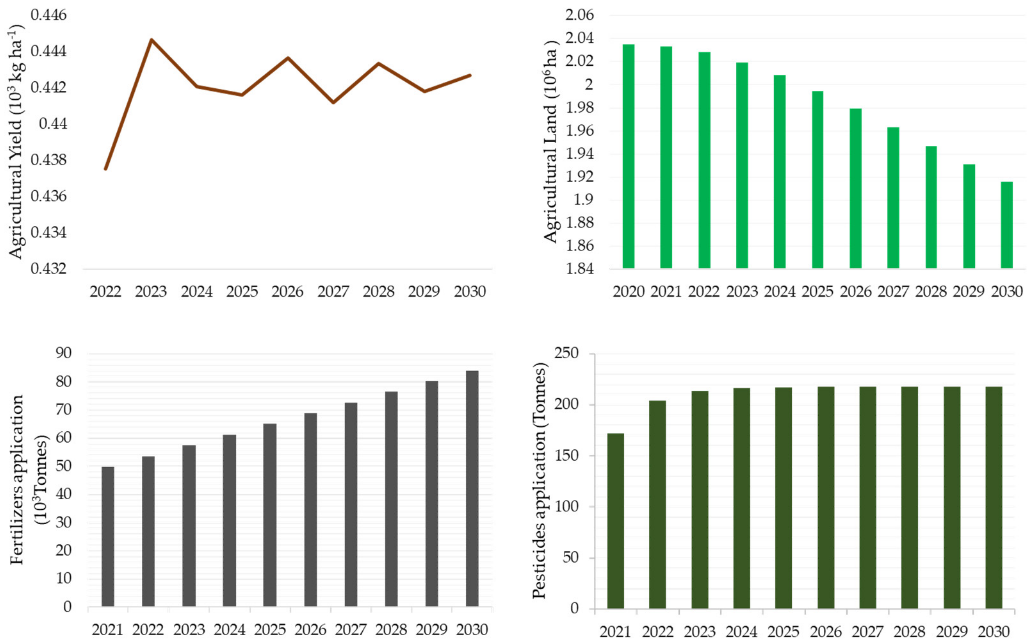

Figure 2. Prediction results of agricultural yield, land allocation, fertilizers and pesticides application.

4.2. Discussion

4.2.1. The Causal Relationship between Land and Agricultural Production

The results indicate that agricultural land is positively correlated with agricultural yield in both the short and long term, which means that land is an important component of farming in Burundi. According to the findings, a 1% increase in agricultural area would result in a 3% increase in agricultural output. Given the significance of land in boosting agricultural productivity, our results suggest that improved management of agricultural land could boost agricultural yield and thus contribute to food security. The study results are in line with those of Oshunsanya Joseph and Suarau Odutola [37], who conducted a study on the management of agricultural lands for sustainable crops and emphasized that the management of agricultural lands is highly imperative for sustainable crop production. Recent research about agricultural transformation and food security also confirmed that land management initiatives, including land consolidation, significantly contribute to the nonmanagement of land and harvest costs, increase farm income, and reduce poverty [38,39]. However, the forecasting results show that agricultural land will decrease to 11.9×10^4 ha by 2030. The decrease in agricultural land is due to urbanization and population growth. Similarly, Berry David [40] confirmed that urbanization's direct effects are an increase in population and a conversion of farm areas into urban areas.

4.2.2. WEF Nexus for Sustainable Agriculture

Energy and Agriculture Yield

The results show a positive correlation between energy and agricultural yield, which means that energy is a crucial factor to ensure the enhancement of food security through farming in countries such as Burundi that rely on agriculture. As such, the findings reveal that fertilizer and pesticide utilization are positively correlated with agricultural yield in both the short and long term, which means they strongly affect agricultural yield in Burundi. According to the results of this study, the increase in the use of fertilizers and pesticides by 1% would increase the yield by 0.086% and 0.185%, respectively. Regarding this point, Gatien et al. [41] confirmed that fertilizer use can improve both household food security and regional food production in East Africa, which is where Burundi is located. Likewise, Muyesaier et al. [42] highlighted that pesticides play a critical role in reducing diseases, increasing crop yields, and eventually contributing to food security. Given the importance of energy in agriculture, further study has highlighted the essential role that direct renewable energy sources play in promoting sustainable agriculture. These sources offer a clean, sustainable supply of energy that can be used to power agricultural activities while lowering greenhouse gas emissions [43,44]. Renewable energy sources such as solar, wind, and hydropower can be used to power irrigation systems, lighting, and other farm equipment [45]. This reduces the reliance on fossil fuels and helps to mitigate the negative impact of agriculture on the environment. Moreover, renewable energy sources can also provide additional income streams for farmers through the sale of excess energy back to the grid. This can help increase the economic viability of sustainable agriculture practices [46]. Overall, the integration of renewable energy sources in agriculture is an essential component of achieving sustainable agriculture and mitigating the negative impact of agriculture on the environment.

Water and Agricultural Yield

The results show that agricultural water withdrawal and energy use in agriculture are positively correlated with yield over the long term. Our results indicate that an increase in water and energy use during farming by 1% would increase the yield by 0.21% and 0.24%, respectively. Wang et al. [47] also highlighted irrigation as the largest sector of water use and an important option for increasing crop yield. In light of this, they suggested that more water diversion projects should be put in place, considering the potential of irrigation to mitigate climate change impacts. In addition, Shi et al. [48] and Thomas Daum [49] emphasized that the use of energy would improve agricultural yield and therefore contribute to achieving food security. However, the results show a negative correlation between agricultural yield and energy use. The negative correlation is due to the fact that agricultural mechanization, which includes the use of machinery in agriculture such as irrigation as well as machinery for ploughing and harvesting, is still in its early stages in Burundi [50]. On the other hand, the prediction results show that agricultural water withdrawal (0.222×10^9 m^3/year) and energy use in agriculture (575.9498 terajoules) will remain the same until 2030 (Table A1). These results imply that the improvement in the performance of mechanization practices such as irrigation techniques is slow in Burundi. The findings are consistent with those of Thomas et al. [51], who revealed that the performance of large-scale irrigation has not improved in decades and that they have found limited relationships with commonly stated causes of failure, such as scheme size and climate. Therefore, water accessibility has a great potential to assess agricultural sustainability, as sustainable agriculture is based on the principle of using natural resources, including water, in a way that preserves them for future generations. Farmers may need to modify their methods to ensure that they are using water properly and efficiently when water supply is reduced due to causes such as drought or misuse. According to Thomas et al. [51], one way that farmers can adapt to changes in water availability is by implementing water conservation measures such as drip irrigation or rainwater harvesting. These techniques can ensure that crops receive the water they need and prevent water waste. Another way that changes in water availability can impact sustainable agriculture is through the types of crops that are grown. In areas where water is scarce, farmers may need to shift from water-intensive crops, such as rice or corn, to crops that require less water, such as drought-resistant varieties of wheat or barley [52].

5. Proposed Framework and Implications

5.1. Policy Implications

The WEF nexus approach can assist in locating and addressing trade-offs and synergies across the three sectors, as well as promoting integrated and coordinated policies that improve resource efficiency, agricultural and environmental sustainability, and human well-being. Therefore, our study proposes a framework to maximize the potential of the WEF nexus approach and sustainable agriculture for food security (Figure 3). Additionally, the Sustainable Development Goals (SDGs) and national development priorities should be taken into consideration when implementing policies that promote the nexus approach.

Water resource management, the growth of renewable energy, the extension of irrigation, soil conservation, crop diversity, food loss reduction, and social protection are some of the major policy sectors that might profit from the nexus approach to support sustainable agriculture. Policy-makers should also consider the transboundary and regional dimensions of the nexus, as Burundi shares water and energy resources with its neighbors in the Nile Basin and the East African Community. Regional cooperation and coordination can enhance the opportunities and reduce the risks of the nexus approach.

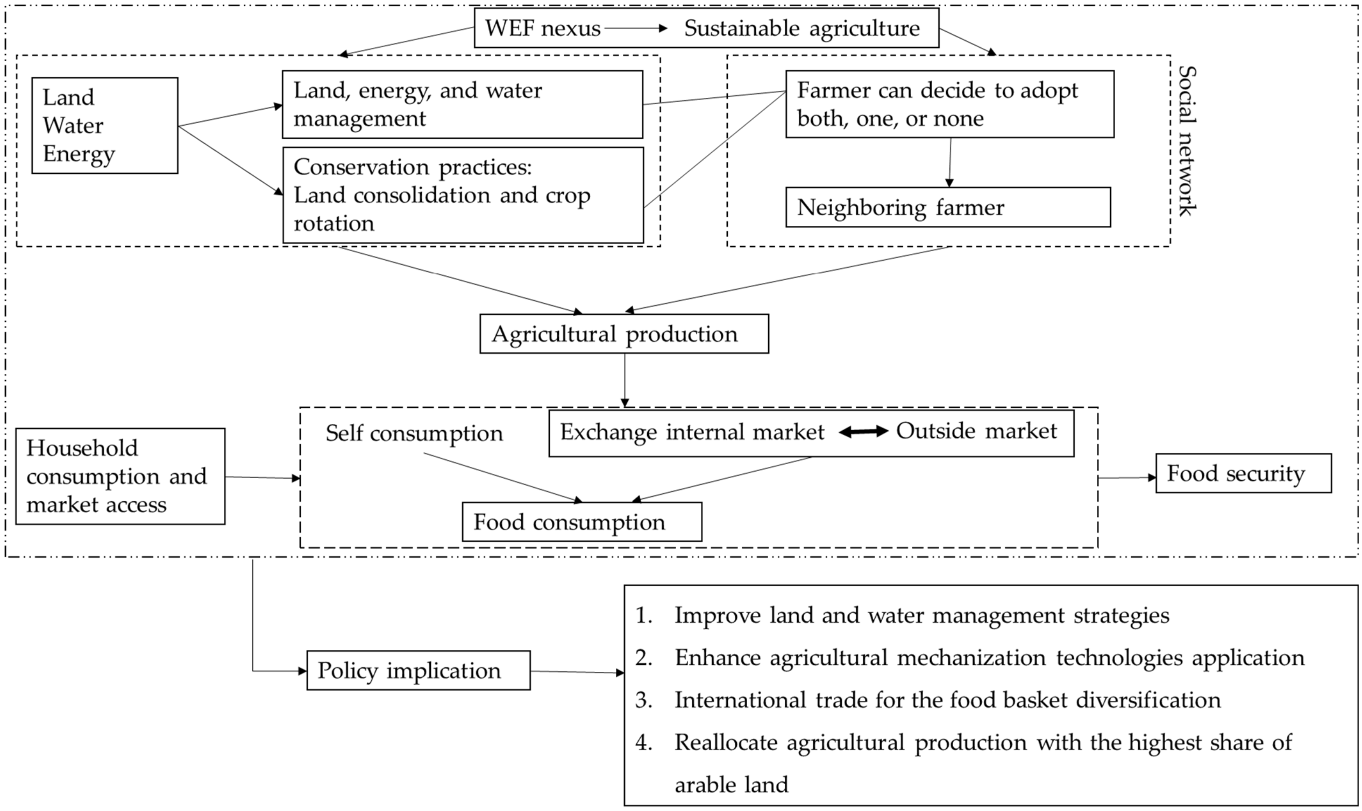

Figure 3. Proposed framework and policy implication.

5.2. Research Implications

This study contributes to the existing literature on agricultural sustainability and food security in Burundi and other developing countries by examining the allocation of resources such as water, energy, and land and the use of fertilizers and pesticides in agriculture to increase crop production. However, further research is needed to address some of the gaps and challenges identified, such as the scalability and replication of sustainable agricultural practices and the role of policy and governance in creating an enabling environment for sustainable agriculture and food security. Therefore, there is a need for more empirical and quantitative studies on the WEF nexus in Burundi, as most of the existing literature is qualitative and descriptive. Such studies may offer more factual and contextually relevant insights into the nexus interactions and effects in Burundi. Moreover, the current article contributes to the literature on social representation theory. Regarding this point, the authors emphasized the role of different resources (water, energy, and land) management during farming in improving sustainable agriculture and the enhancement of food security in Burundi. However, as the nexus comprises complex and dynamic interactions across various actors and scales, future research on the significance of the nexus approach to sustainable agriculture and food security should also embrace a multi-level and multi-stakeholder perspective. Research on the nexus approach should also explore the potential of innovation and technology in enhancing the nexus performance and resilience in Burundi. Future researchers should also address the knowledge gaps and challenges in data availability, quality, and accessibility in Burundi.

6. Conclusions and Limitations

This study quantitatively analyzed the influence of resources used in improved agricultural practices, such as agricultural water withdrawal, energy, land, fertilizers, and pesticide application, on agricultural yield. The results indicate that land, agricultural water withdrawal, energy, fertilizer, and pesticide applications are positively correlated with yield. The results indicate that proper land management practices are key to attaining sustainable food security. However, the projection (Figure 2) shows a decrease of 11.9×10^4 ha in agricultural land by 2030. Additionally, this study found that the use of pesticides and fertilizers is strongly correlated with boosting yields, making them the key to improving Burundi's food security. Regarding this point, the findings also indicate that by 2030, the use of fertilizers and pesticides will each need to increase by 39.909 and 45.816 tons, respectively. On the other hand, several contemporary agricultural practices, such as irrigation, that require energy utilization are improving slowly. In this regard, the findings indicate that agricultural energy consumption (575.949 terajoules) and water withdrawal (0.222×10^9 m^3/year) will not change by 2030. Therefore, considering its significance in achieving food security, it requires substantial financial input during its implementation. Additionally, given that agriculture is Burundi's main economic sector, boosting agricultural sustainability through the use of land, water, and energy during farming would help ensure both economic growth and food security.

There are certain limitations to this study that need to be properly addressed going forward. One of them is the fact that this study examined the effects of water, energy, and land as well as using them as an illustration of the key resources that may support sustainable agriculture. However, there are additional contributing elements that might be taken into account in order to address these points, such as land consolidation and related governmental policies. In addition, data availability has been a limitation because this study used the available data during the time of the research. Moreover, this study only investigated the situation in Burundi, therefore resulting in data limitations. To address this drawback, numerous cross-country studies should be conducted to assure data accessibility and study validity in order to achieve sustainable development goals.

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Appendix A

Table A1. ARIMA model prediction results.

Year	AGY (10^3 kg/ha)	PA (10^6 ha)	AGW (109 m^3/year)	EUA (Terajoules)	PST (Tons)	FTL (103 Tons)
Model	ARIMA (2, 1, 1)	ARIMA (2, 0, 1)	ARIMA (0, 2, 3)	ARIMA (1, 1, 0)	ARIMA (1, 0, 0)	ARIMA (0, 2, 3)
2022	0.437534	2.028127	0.222	575.9498	204.100961	53.646152
2023	0.444668	2.019641	0.222	575.9498	213.644405	57.447189
2024	0.442075	2.008326	0.222	575.9498	216.467165	61.248226
2025	0.441626	1.994726	0.222	575.9498	217.302081	65.049263
2026	0.443645	1.979472	0.222	575.9498	217.549032	68.850300
2027	0.441198	1.963260	0.222	575.9498	217.622076	72.651336
2028	0.443356	1.946809	0.222	575.9498	217.643680	76.452373
2029	0.441818	1.930838	0.222	575.9498	217.650071	80.253410
2030	0.442688	1.916032	0.222	575.9498	217.651961	84.054447

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