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A case study of improved cookstoves and clean fuel use by selected Nigerian Households

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ABSTRACT

The implementation of the United Nations Sustainable Development Goals (SDGs) in Nigeria and many African countries seek evidence-based approaches to make business, health and socio-economic justification for increased public and private sector investments to achieve the goals. Yet, access to resources to engender food, energy, social, economic, and environmental security by over 62% of Nigerians living below the poverty line of $1.90 per day, remains a challenge. The aim of this paper is to use the SDG framework to analyze the inter-linkages between food security, social, economic, climate and environmental outcomes of a national clean cookstoves project that was effectively implemented in Nigeria between 2014 and 2018. The project distributed improved cookstoves and clean fuels to 1000 households with the aim of using it as a pilot to stimulate demand, contribute to the expansion of energy access for cooking, improve the livelihood of women and girls, reduce forest degradation and fuelwood-induced carbon emissions. Structured questionnaires were used to collect primary data from 161 households drawn from a randomly stratified experimental layout in Kwara state. Project variables were classified into economic security (SDG1), food security (SDG2), social security (SDG4), energy security (SDG7), climate variable (SDG13), and environmental sustainability (SDG15). Regression estimates reveal that all the representative SDG variables significantly impacted the food security of beneficiaries in the following order: SDG1 > SDG4 > SDG15 > SDG13 > SDG7. A conceptual framework consisting of pentagonal linkages was developed from Pearson correlation estimates. The study established a pentagonal nexus for SDG1,2,4,7,13,15 hinged on food security, social, economic, energy, climate, and environmental factors. We suggest strengthening of climatic and environmental frameworks such as the integration of SDGs into Nationally Determined Contributions and long-term national development plans to drive food security. The study calls on the private sector to make use of SDG policy analysis to direct investments to help build back better from the COVID-19 pandemic. A matrix of food security-based policy, research, project, and knowledge activities were recommended to better understand SDG synergies.
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1. Introduction

Nigeria, Africa's most populous country is ranked 159 out of the 162 countries on the Sustainable Development Goals (SDGs) index of 2019 Sustainable Development Report. This poor performance is arguably due to lack of investment, inadequate political support as well as poor implementation strategies at the sub-national, local government, communities, and household level. The ongoing global discussions about inter-linkages in the implementation of the United Nations Sustainable Development Goals (SDGs) include calls for integrated approaches to implementation, building more scientific evidence to attract investments, and awareness raising. Some of the approaches require synergies and trade-offs that are based on the three key dimensions of the sustainable development concept (economic, social, and environmental sustainability). The popular call for leaving no one behind in the implementation of the SDGs also requires a rethink about how to avoid the implementation of some SDGs at the expense of others. These reflections can be applied to the various types of instruments, policies and projects used as enablers to achieve the SDGs.

Nigeria's implementation of the SDGs commenced with political promises and launch of several awareness programmes which

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culminated into the selection and prioritization of economic security (SDG1), food security (SDG2), and social security (SDG4). According to the Nigeria Investment Promotion Council, NIPC (2017), the government initiated an ambitious social protection system called the National Social Investment Plan (NSIP) that helps prevent and reduce poverty as well as provide safety net for the vulnerable poor. The programme's effectiveness consisted of a home-grown school feeding intervention to encourage primary education of children, a multi-sectoral skills development project to empower youth and improve their employability, as well as the integration of NSIP into the most recent short-term national development plan called the Economic Recovery and Growth Plan (ERGP 2017–2020). Additionally, the government has placed a high premium on achieving SDG2 by investing in agricultural productivity enhancing policies and activities that can address multifaceted development challenges that is rooted in poor agricultural productivity, climate change, shrinking income of farmers and dwindling revenue because of the COVID-19 pandemic.

Consequently, the Food and Agriculture Organization, FAO (2018) proposed strengthening the resilience and adaptive capacity of small-scale and family-level farmers, whose productivity is systematically lower than all other food producers. Yet, they form a vast majority of the vulnerable poor. According to the United Nations SDG report of 2019, the share of small-scale food producers in terms of all food producers in countries in Africa, Asia and Latin America ranges from 40 to 85%, compared with fewer than 10% in Europe. This underscores the relevance of small-holder farmers living in rural poor households, in achieving food security goals in developing countries like Nigeria. Low public investment in human capital development and unfavorable policies to attract private sector participation are largely responsible for the slow pace of development in Nigeria. With expanding agriculture and uncontrolled cutting of trees for use as fuelwood for cooking, rising greenhouse gas emissions from forest degradation and climate change are occurring at rates much faster than anticipated. The combined effect of these factors is clearly felt by poor households, thus justifying why emphasis must be placed on effective implementation of SDG13 and SDG15. Despite giant strides been taken by the Nigerian government and partners to increase climate finance flows through the revision of her Nationally Determined Contributions (NDCs) – The Guardian, (2020), far more ambitious plans and accelerated actions are needed from other SDG sectors to achieve food security that can be sustained.

This study builds on some related studies. Fader et al. (2018) assessed trade-offs and benefits between arbitrary pair of SDG targets from a point of view of resource competition towards achieving pre-determined set of goals based on the assumption that the infrastructure developed for the achievement of one of the targets can also be used to achieve a second target. Tamee et al. (2018) assessed the SDGs from a water-food-energy nexus point of view with the assumption that water availability is a major factor constraining humanity's ability to meet the future food and energy needs of a growing and increasing affluent human population. However, both studies did not consider the role of ensuring environmental sustainability and did not analyze any specific SDG-related project that was aimed at addressing multiple goals within a developing African country context. Notwithstanding, Miyamoto (2020) derived clear and reasonable explanations for the causes of deforestation while assessing the effectiveness of REDD+ policies to halt deforestation, however, his suggestion did not relate empirically, how poverty reduction strategies can be a good justification for implementing forest conservation practices.

Meanwhile, Goozee (2017) reported that the SDGs clearly recognize the centrality of energy to economic and social well-being, as well as to issues such as health and climate change, and reflected former United Nations Secretary-General Ban Ki-moon's statement at the Rio+ 20 conference that "energy is the golden thread that connects economic growth, social equity and sustainable development". This study aligns with studies on energy consumption and poverty as observed in Keenan (2016), makes a good case for accelerated climate actions as contained in the Paris Agreement 2015.

Ekouevi (2013) and World Bank (2015) stated that traditional cooking method (three stone fire) is widely used at both urban and rural households, burning up to 90% more wood than is necessary, costing poor families time and money that could be put to better use on education, health, and nutrition. According to ICEED (2012), All Africa (2013), and Olopade et al. (2018), smoke from the traditional use of firewood is estimated to cause 95,000 deaths annually after malaria and HIV/AIDS; this was Nigeria's third highest killer mostly of who are women and children.

The Clean Cooking Alliance (2011) stated that over 2 billion people globally are relying on traditional forms of energy (fuel wood) for cooking. This has spurred several SDG7 and 15-related initiatives at the global, regional, national, and local levels. One of such interventions in Nigeria was the launch of the National Assembly Intervention on Clean Cooking Initiative (NAICCI) in 2014 which according to the Federal Ministry of Environment (2016), has one key strategic goal of improving the socio-economic status of beneficiaries (using income increases, gender, and reliance on forest resources such as trees for fuelwood as key performance indicators). NAICCI may have led to millions of improved cook stoves and clean fuel been deployed and adopted in several parts of Nigeria because of the ripple effect such a consumer awareness project may have in stimulating demand for clean cooking technologies. However, there are research gaps in understanding and measuring the SDG-related inter-linkages of this project in terms of socio-economic considerations, environmental sustainability, food security as well as the integration of these factors as an integrated policy model that may help in the achievement of SDG 1,2,4,7,13 and 15.

UNSD (2017) reported that Nigeria's 2017 National Voluntary Review shared the country's progress and good practices on SDGs implementation. However, the review did not take cognizance of realities in successful implementation of selected projects that could lead to the achievement of multiple targets. Therefore, this paper reveals linkages in the form of potential or real synergies and or trade-offs between food security, energy security, socio-economic security. The paper drew lessons from implementation of a climate change mitigation project in Nigeria, to support angulated nexus conceptual framework such as that of Tamee et al. (2018).

2. Methodology

The methodology of this paper is structured in four steps. Step 1 describes the choice and scope of study area, including description of geographic location. Step 2 describes study objectives, variables, hypothesis, and assumptions. Step 3 describes the study design, data, sampling, and step 4 describes model specifications.

Step 1 – Choice and scope of study area

During consultations with Nigeria's Federal Ministry of Environment in 2013 on their plans to reduce energy poverty in rural areas, it was found that a National Clean Cooking Scheme (NCCS) was being planned for rural women. The NCCS birthed a National Assembly Intervention on Clean Cooking Initiative (NAICCI) by the then Chairman, Senate Committee on Environment & Ecology in the 7th National Assembly (2011–2015). NAICCI was funded through the Federal Government of Nigeria's Appropriation Act (2013) for constituents of Kwara Central Senatorial District who have demanded for cooking energy support. The project

distributed improved cookstoves and clean fuels to 1000 households in the study area. Therefore, this study picked NAICCI as a good project example to achieve research objectives and aligned with the criteria upon which project beneficiaries were selected. The criteria include:

1. Level of poverty (low-income households).
2. Gender and marital status (poor widows were given preference).
3. Reliance on use of traditional cookstoves such as fuelwood or kerosene (forest degradation and carbon emission potential).

Fig. 1 shows the study area in Nigeria (Kwara state). Kwara state belongs to the North Central geo-political zone of Nigeria. It shares a boundary to its west with the Republic of Benin and has as its northern boundary with the Niger River in Niger state. It also borders Kogi state to the east, Oyo, Osun, and Ekiti States to the south. The spatial scope of this study is Asa, Ilorin East, West, and South Local Government Areas (LGAs) as shown in the purple-colored area in Fig. 1.

Step 2 – Objectives, variables, hypothesis, and assumptions

Based on the NAICCI project, the objective of this study is to assess the inter-linkages between food security (SDG2) and selected targets in the sustainable development goals that addresses poverty (SDG1), quality education (SDG4), affordable and clean energy (SDG7), climate action (SDG13) and life on land/environmental protection (SDG15).

Variables were selected based on their ability to contribute to achievement of set objectives. This supported cookstoves preferences used by Jeuland et al. (2015). Specific variables used in this study include:

1. Knowledge of the SDGs (variable 1).
2. Gender (variable 2).
3. Age of Respondent (variable 3).
4. Level of education (at least primary school) (variable 4).
5. Occupation of Respondent (variable 5).
6. Average family size (variable 6).
7. Average family income (variable 7).
8. Level of Urbanization (variable 8).
9. Use of NAICCI stove and fuel (variable 9).
10. Quantity of fuel used before and after project (variable 10).
11. Total area logged for fuelwood BAU (variable 11).
12. Willingness to sustain the use of NAICCI technologies and fuel (Variable 12).

Juan et al. (2019) established linkages between energy, economy, and environment. This research further probed Juan's energy-economy-environment nexus by making key assumptions to assess research hypothesis which states that food security as represented by average family size and income of small-scale food producers is related to other SDGs 1,4,7,13 and 15.

The computation of raw data further supports Louise Aukland's paper (2002) that established similar conceptual relationships in measuring avoided deforestation. They include:

1. SDG1 – No poverty (average of variable 5, 6, and 8).
2. SDG2 – Zero hunger (variable 7).
3. SDG4 – Quality education (average of variable 2, 3 and 4).
4. SDG7 – Affordable and clean energy (average of variable 9 and 10).
5. SDG13 – Climate actions (Emission factor * average of variable 9 and 10).
6. SDG15 – Life on land (variable 11 per hectare of total land area).

Onah et al (2019) estimated per capita fuelwood-induced carbon emission of 2.2 t CO_2e per annum. This study further transforms Onah's findings into an SDG13 related variable by using it as emission factor to arrive at values for SDG13.

For ease of thematic analysis, representative targets were selected from SDG goals identified for this study. The selected sustainable development goals and associated key targets of the SDGs was culled from UNSD (2020).

The selected specific variables for the study were categorized based on applicability with the selected SDGs, to derive customized targets from database of the United Nations Sustainable Development Knowledge Platform, UNSD (2020).

The following targets were matched: Target 1.4.1 (for SDG1), target 4.6.1 (for SDG4), target 7.1.2 (for SDG7), target 13.2.1 (for SDG13) and target 15.3.1 (for SDG15). However, due to data limitations, only part of the variables that makes up SDG2 is used for analysis, particularly target 2.3.2 which tries to increase the

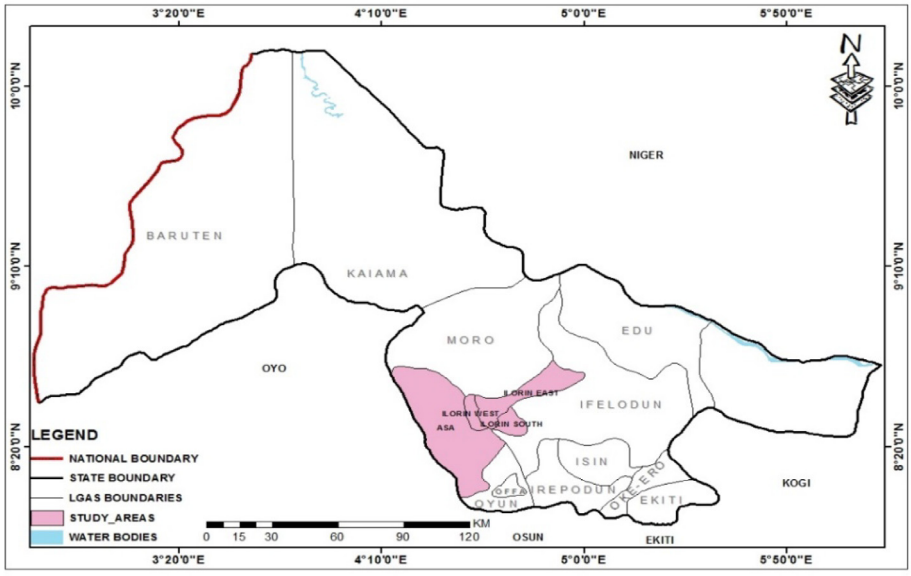


Fig. 1. Map of Kwara state showing Kwara Central Senatorial District.

average income of small-scale food producers by sex by 2030: for SDG13, we focused on GHG emission reduction because of the use of improved cookstoves and fuels. In summary:

1. Food security (SDG Target 2.3.2 – Average increase in income of a small-scale food producer).
2. Economic security (SDG target 1.4.1 – Proportion of population living in households with access to basic services poverty, access to basic services).
3. Social security (Target 4.6.1 – Proportion of population in each age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex).
4. Energy security (Target 7.1.2 – Proportion of population with primary reliance on clean cookstove and fuel).
5. Climate security (Target 13.2.1 – Integrate climate change measures into national policies, strategies, and planning to increase ability to adapt and mitigate impacts of climate change in a manner that does not threaten food production).
6. Environmental sustainability (Target 15.3.1 – Proportion of forest/land that is degraded over total land area).

The final choice of sustainable development goals used in this study also considered Government's SDG priorities and expected relationship with the NAICCI clean cookstove project design (inclusive of the criteria used in selecting project beneficiaries). They include the following:

1. Government SDG priorities (SDG1, SDG2, and SDG4)
2. The NAICCI project design (SDG1, SDG7, SDG13, and SDG15)

Fader et al. (2018) while assessing synergies and trade-offs between water, food and energy nexus within the SDGs revealed that over 82% of SDG2 targets are either consistent, enabling, reinforcing, or supporting of SDG7 targets. Therefore, the impact of energy access in this study is expected to be supportive of food security.

Step 3 – Study design, data, and sampling

The study was designed as a stratified random sampling design where 161 samples were drawn from a cluster of 1000 household samples stratified per local government area as shown in Table 1, representing 6% sampling size from each stratum – Krejcie et al. (1971).

The study population comprises of the four local government areas (LGA) in Kwara Central Senatorial District namely, Ilorin West, Ilorin East, Ilorin South, and Asa (representing approximately 40% of total population of Kwara state) as shown in Table 1. Structured questionnaire (Appendix 1) was designed to collect primary data covering identified variables already described in step 2. The data collected and computation is presented as Appendix 2 and 3.

Implementation of the research design employed an integrated framework for understanding the cooking energy transitions from wood burning to improved and clean ones. The study combined synergies from the energy ladder theory, theories of climate change (Carbon emissions, forest degradation and REDD+), theories of sustainable development and mapping techniques. A combination of primary and secondary sources of data were employed. The study kept an eye on NAICCI's key performance indicators which qualitatively and quantitatively estimated using appropriate statistical tool which were qualitatively and quantitatively estimated using appropriate statistical tools of analysis.

Step 4 – Model Specification

Although Jan et al (2017) measured adoption of improved cookstoves in Pakistan using a logit analysis, this study chose the linear correlation and regression model because it is focused on measuring relationships and impact. The model also supports Omar et al. (2000) who stated that switching from a single to multiple cooking options requires the consideration of fuel alternatives in the linear energy ladder model.

Correlation Analysis – The most familiar measure of dependence between two quantities is the Pearson product-moment correlation coefficient, or "Pearson's correlation." It is obtained by dividing the covariance of the two variables by the product of their standard deviations. The population correlation coefficient $\rho_{X,Y}$ between two random variables X and Y with expected values μ_X and μ_Y and standard deviations σ_X and σ_Y is defined as:

$$\rho X, Y = \frac{cov(X, Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \mu x)(Y - \mu y)]}{\sigma_X \sigma_Y}$$

where E is the expected value operator and cov means covariance. The Pearson correlation is defined only if both standard deviations are finite and nonzero. The Pearson correlation is 1 in the case of an increasing linear relationship, −1 in the case of a decreasing linear relationship, and some value between −1 and 1 in all other cases, indicating the degree of linear dependence between the variables. The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables.

Regression Analysis – The following linear equation in a multiple regression model in explicit form was used for analysis, expressed as:

$$Y_{(1,2)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_k X_k + \mu \quad (1)$$

Where

Y_1 = expected impact (household adoption of NAICCI in the beneficiary group)
Y_2 = expected impact (household adoption NAICCI in the non-beneficiary group)
β_0 = constant (intercept)
β_{1-k} = regression coefficients
X_{1-k} = SDG indicators
μ = error term

Table 1
Population, land area and representative sample of NAICCI by LGAs in Kwara state.

Local Government Area	Total Land Area (ha)	Population density (persons/ha)	Population (2011 Projected)	Representative LGA from Kwara state Population	Representative LGA from Sample Population	Representatives per LGA from Population of 1000 cook stoves * (Samples = 6% of Representatives per LGA)
Ilorin West	10,500	40.41	424,326	16.12%	40.2%	402 (65)
Ilorin East	48,600	4.95	241,036	9.11%	22.9%	229 (37)
Ilorin South	17,400	13.97	243,115	9.18%	23.1%	231 (37)
Asa	128,600	0.71	144,844	5.47%	13.8%	138 (22)
Total of 4 LGAs	205,100	5.14	1,053,321	39.9%	100%	1000 (161)
Total for Kwara state	3,682,500	0.72	2,649,384	100%	–	–

Sources: Adapted from Krejcie Robert V., Morgan, Daryts, W., 1971 and National Population Commission of Nigeria, Projected Population 2008–2011.
* Experimental samples in bracket.

Stepwise Regression Analysis - For this study, stepwise form of multiple linear regression analysis was employed to identify the most relational SDG indicator to food security expressed as SDG 2 while eliminating endogeneity and or heterogeneity between and amongst estimated coefficients. To estimate in a stepwise manner, four (4) regression equations were therefore deduced from equation one and are expressed as follows:

$$Y_{SDG2} = \beta_0 + \beta_1 SDG1 + \mu \quad (2)$$

$$Y_{SDG2} = \beta_0 + \beta_1 SDG1 + \beta_2 SDG4 + \mu \quad (3)$$

$$Y_{SDG2} = \beta_0 + \beta_1 SDG1 + \beta_2 SDG4 + \beta_3 SDG7 + \mu \quad (4)$$

$$Y_{SDG2} = \beta_0 + \beta_1 SDG1 + \beta_2 SDG4 + \beta_3 SDG7 + \beta_4 SDG13 + \mu \quad (5)$$

Block Regression Analysis - The block regression analysis was used to analyse the combined response of each of the selected SDG to food security. Therefore, equation six is deduced from equation one and written as:

$$Y_{SDG2} = \beta_0 + \beta_1 SDG1 + \beta_2 SDG4 + \beta_3 SDG7 + \beta_4 SDG13 + \beta_5 SDG15 + \mu \quad (6)$$

Where:

$$Y_{SDG} = ResponseSDG(FoodSecurity - relatedtargetsinSDG2)$$

$$\beta_1 SDG1 = RelationalSDG(Socioeconomicsecurity - relatedtargetsinSDG1)$$

$$\beta_2 SDG4 = RelationalSDG(Socioeconomicsecurity - relatedtargetsinSDG4)$$

$$\beta_3 SDG7 = RelationalSDG(Energysecurity - relatedtargetsinSDG7)$$

$$\beta_4 SDG13 = RelationalSDG(Climatesecurity - relatedtargetsinSDG13)$$

$$\beta_5 SDG15 = RelationalSDG(Environmentsustainability - relatedtargetsinSDG15)$$

β_0 = Constant term
μ = Error term

3. Results and discussion

The socio-economic characteristics of respondents in the study area were described and used to support the interpretation of socio-economic impacts using variables such as gender of primary fuel collector/user of stove, age of respondent, marital status, educational level, level of urbanization, occupational status, family income and source, quantity of fuel wood used before intervention and after, and expenditure on fuel.

Table 2 revels that respondents that the knowledge of the SDGs is skewed towards female compared with male. This means that a lot more awareness on the SDGs is required in the study area to be able to measure the responsiveness of citizens in engaging with the SDGs based on the "leave no one behind" principle.

Majority of the female respondents in the four targeted communities were above 40 years of age as presented in Table 2. This shows that older people tend to have more human-induced impact on choice of household use of cook stove and fuel including but not limited to tree logging for cooking. Age consideration, however, did not translate to knowledge of the SDGs in the study area during the period under review.

The educational level of respondents revealed that most of the women were uneducated and did not attend primary school with no proficiency in functional literacy nor numerical skills. It was also observed that respondents from Ilorin West LGA were more educated followed by Ilorin East, followed by Ilorin South and lastly, Asa LGA.

86% of respondents are small scale farmers of less than 1 ha of land cultivation per year followed by civil servants and traders. The distribution of food producers is highest in Asa, followed by Ilorin East, followed by Ilorin West and lastly, Ilorin South It was observed that majority of the small-scale farmers were also civil servants thereby engaging in multiple occupations. Thus, the expected occupational distribution of respondents provided important data for SDG analysis in aggregate terms.

Majority of the respondents have an average family size of between 1 and 6 people and an average family income of between 10,000 and 20,000 naira. No respondent was earning above the international poverty line of $1.92 per day. However, 52% of the respondents were living just within the national poverty line of $1.00 per day but certainly below the new national minimum wage of 30,000 naira per month. Family income at this level of analysis cannot be accurately estimated because it was observed that most of the respondents were economical with facts about their monthly income.

Over 76% of total respondents in the study area live in semi-urban centers. which may have implications on adoption of NAICCI because one key factor which was beyond the scope of this research is sustained access to clean cooking fuel markets, as some semi-urban/rural areas do not have LPG retail outlets within 5 km of their homestead.

Finally, there was a 90% likelihood of respondents willing to sustain the use of NAICCI improved cookstove and clean fuel use at project completion compared with a baseline scenario of 6%.

Reasons for adopting the NAICCI project. Table 3 revealed that food security is the primary motivator for adopting the NAICCI project followed by socioeconomic reasons and third by energy security as shown in Table 3. This means that more than 85% of the beneficiaries of NAICCI will adopt the use of improved cook stoves and clean fuel if it will improve their food security and improve their socio-economic lifestyles, while only 15% will be interested in improved cookstoves and clean fuels if the only expected benefit is improving their energy security for cooking, mitigating climate change, or ensuring environmental sustainability.

Correlation Results (Pearson correlation matrix between SDGs in the study) - Pearson correlation matrix in Table 4 showed statistically significant estimates for most SDG variables, notably SDG 1. Information given by a correlation coefficient is not enough to define the dependence structure between predictor variables, however, a good look at the pair wise covariates for SDG1 and SDG2; SDG1 and SDG4; and SDG1 and SDG13 showed strong collinear relationship at ($P < 0.01$) with absolute pairwise coefficient for SDG1 and SDG2. This means SDG1 and SDG2 are strongly and positively correlated and can be used to measure livelihood of households in the study area. The degree of correlation between the income of a small-scale food producer, level of poverty and access to basic services is significant. Therefore, they can be used interchangeably and thus move collinearly in this analysis. The pairwise coefficient between SDG4 and SDG1 with absolute value of approximately 40% at ($P < 0.01$), is another proof of negative but strongly correlated relationship between poverty and education. Therefore, the poverty level of households under study as indicated in SDG1 and SDG4 can be calculated from their food security situation or vice versa, which explains that food security can be determined by looking at the socioeconomic situations of households (access

Table 2
Characterization of select SDG targets by respondents.

Select SDG targets		Location of beneficiaries							
		ASA LGA		ILORIN EAST LGA		ILORIN WEST LGA		ILORIN SOUTH LGA	
Variable	Category	f	%	f	%	f	%	f	%
Knowledge of SDGs	Male (10–39 years)	1	5	0	0	2	3	0	0
	Male (>40 years)	0	0	0	0	0	0	0	0
	Female (10–39 years)	1	5	4	11	7	11	4	11
	Female (>40 years)	0	0	0	0	2	3	1	3
Gender of respondents	Male	1	0.20	1	0.30	0	0	0	0
	Female	21	99.8	36	99.7	65	100	37	100
Age of respondents	<10 years	0	0	0	0	0	0	0	0
	10–39 years	4	22.2	5	15.6	7	12.1	5	15.6
	>40 years	18	77.8	32	84.4	58	87.9	32	84.4
Educational level	No Primary	20	90	27	63	33	50.8	35	94.3
	Primary	2	10	10	37	32	49.2	2	5.7
	Secondary	0	0	0	0	0	0	0	0
	Tertiary	0	0	0	0	0	0	0	0
Occupation of respondent	Farmer (small-scale)	20	91	30	81	55	86	30	81
	Trader	0	23	4	11	1	0.4	2	5
	Civil servant	2	9	3	8	9	13.6	5	14
Average family size	1–6	20	90	35	95	63	97	34	92
	7–12	2	10	2	5	2	3	3	8
	>12	0	0	0	0	0	0	0	0
Average family income	1–10,000 (naira/month)	20	90	8	27:6	11	20.4	12	48
	10,001–20,000 (naira/month)	2	10	29	72.4	54	79.6	25	52
	>20,000 (naira/month)	0	0	0	0	0	0	0	0
Level of urbanization	(semi)Urban	1	4.8	37	100	65	100	37	100
	Rural	21	95.2	0	0	0	0	0	0
Willingness to sustain NAICCI	Before	0	0	3	8.1	10	15.4	0	6
	After	22	100	36	97.3	64	98.5	36	97.3

Table 3
Reasons for adoption of the NAICCI scheme in the study area.

Reason	Beneficiaries	
	f	%
SDG2- Food security (average income/month)	85	53
SDG1, SDG4 - Socio-economic security (gender, age, education, poverty, access to basic services)	52	32
SDG7 – Energy security (accessibility, affordability, ease of use, stove type, and energy type)	15	9
SDG13, SDG15 - Environmental/Climatic security (deforestation/logging, CO_2e emissions, cooking area, indoor/outdoor kitchen)	9	6
Total	161	100

to basic services, and ability to attain at least a fixed level of proficiency in functional literacy and numeracy skills.)

Estimates of Pearson correlation coefficient as shown in Table 5a showed relational association between some SDGs under study. However, the causes underlying the correlation may be indirect and unknown, and high correlations also overlap with identity relations, where no causal process may exist. The fact that the case study involves an energy access situation may also cast some bias in favor of SDG7 and SDG15. The regression results in Table 5b will further explain these relationships.

Regression Results were analyzed in five steps as follows:

Analysis of food security and socioeconomic security (SDG1) – SDG1 and SDG2 showed 85% correlation in Table 4. This step of the regression model also showed statistically significant relationship ($p < 0.01$) where a unit increase in average income of a small-scale food producer improves access to basic services and reduces poverty. This translates to improved socio-economic outcomes and access to basic energy services such as an improved cookstove and clean fuel for cooking, This also means that expansion of basic cooking energy access in the study area relates with the level of poverty and food security situation of beneficiary households. Therefore, the NAICCI intervention has promoted women as primary actors in household food security situation and provided an opportunity for reducing poverty.

Table 4
Estimated Pearson pair wise correlation coefficients for SDG variables.

	SDG2	SDG1	SDG4	SDG7	SDG13	SDG15
SDG2	1.000	0.851***	−0.146**	0.063	0.067	0.190***
SDG1	0.851***	1.000	−0.395***	0.121	0.187***	0.131**
SDG4	−0.146**	−0.395***	1.000	−0.100	−0.108	−0.165**
SDG7	0.63	0.121	−0.100	1.000	−0.100	0.142**
SDG13	0.067	0.187***	−0.108	−0.100	1.000	−0.003
SDG15	0.190***	0.227**	−0.165**	0.142	−0.003	1.000

(***P < 0.01, **P < 0.05)

Table 5a
Other useful pairwise correlations and interpretations.

S/N	Paired Variables	Significance	Interpretation	Attribution
1	SDG2 and SDG15	P < 0.01	food security (average income of small-scale food producer) and land degradation	19%
2	SDG1, and SDG13	P < 0.01	socioeconomic security (poverty, access to basic services) and climate security (Co2e emissions)	13%
3	SDG2 and SDG4	P < 0.01	food insecurity (average income of small-scale food producer) and socioeconomic security (education)	15%
4	SDG1 and SDG15	P < 0.05	socioeconomic security (poverty, access to basic services) and land degradation	13%
5	SDG4 and SDG15	P < 0.05	socioeconomic insecurity (education) and land degradation	17%
6	SDG7 and SDG15	P < 0.05	energy security (reliance of clean cookstove and fuel) and land degradation	14%

Table 5b
Summary or results of regression analysis.

S/N	Regression equation	Significance	Interpretation
1	Analysis of food security and socioeconomic security (SDG1)	P < 0.01	Increase in average income of a small-scale food producer improves access to basic services and reduces poverty. The NAICCI project promoted women as primary actors in household food security situation and provided an opportunity for reducing poverty
2	Analysis of food security and socioeconomic security (SDG1 and SDG4)	P < 0.01	Level of education determines and access to basic services improves food security and reduces poverty. In other words, the level of educational of respondents determines how food secure their household will be
3	Analysis of food security and socioeconomic + energy security (SDG1, SDG4 and SDG7)	P > 0.05	Increase in the average family income and food security may reduce dependence on NAICCI stoves because they were distributed for free. However, this may be a true reflection of short-term measures since an exponential market access to basic cooking services may trigger drastic reduction in poverty and illiteracy levels as shown by the significant and positive relational estimates between SDG 1 and SDG4
4	Analysis of food security and socioeconomic + energy + climate security (SDG1, SDG4, SDG7 and SDG13)	P < 0.05	This means that as food security improves alongside socioeconomic situation in the long-term, NAICCI technologies may be rapidly adopted because of income increases. This will eventually improve climate security by reducing carbon emissions. This estimate may be more significant in statistical and absolute terms in rural than urban areas because of the reliance of the former on natural resources to meet their basic household needs including fuelwood for cooking.
5	Analysis of food security and socioeconomic + energy + climate + environmental sustainability (SDG1, SDG4, SDG7, SDG13 and SDG15)	P < 0.01	An increase in food security may increase the average income of a small-scale producer, increase their socio-economic situation, ensure more energy security, and probably mitigate the impact of climate change through reduction in carbon emission. The significant and positive relationship between food security and SDG15 exposes the strong linkages between food production and forest/land degradation.

Analysis of food security and socioeconomic security (SDG1 and SDG4) – Inferences drawn from socio-economic characterization of respondents in Table 2 revealed age, gender and educational level as important socioeconomic parameters used in explaining the relationship between food security and socioeconomic security. Both SDG1 and SDG4 showed statistically positive and significant relationship with food security ($p < 0.01$) as shown in Table 6. The estimated coefficient for SDG1 improved as we include the educational variable in the model. This means that an increase in energy access for cooking may lead to an increase in the food security situation of households. In other words, the level of educational of respondents determines how food secure their household will be.

Analysis of food security and socioeconomic + energy security (SDG1, SDG4 and SDG7) – The case study of this research involves an energy access project that distributed improved cook stoves and clean fuel to households. Therefore, SDG7 which defines the energy security paradigm of this research is expected to be positively and significantly related to food security. Unfortunately, it was not the case. SDG7 was negative and insignificant. This means that an increase in the average family income and food security may reduce dependence on NAICCI stoves because they were distributed for free. However, this may be a true reflection of short-term measures since an exponential market access to basic cooking services may trigger drastic reduction in poverty and illiteracy levels as shown by the significant and positive relational estimates between SDG1 and SDG4.

Analysis of food security and socioeconomic + energy + climate security (SDG1, SDG4, SDG7 and SDG13) – The climate security variable (SDG13) was negative but significantly related to food security at $p < 0.05$ as shown in Table 6. This means that as food security improves alongside socioeconomic situation in the long-term, NAICCI technologies may be rapidly adopted because of income increases. This will eventually improve climate security by reducing carbon emissions. This estimate may be more significant in statistical and absolute terms in rural than urban areas because of the reliance of the former on natural resources to meet their basic household needs including fuelwood for cooking. Onah et al. (2019) stated that the use of improved cook stoves and clean fuels can reduce fuelwood induced carbon emissions by approximately 2.2 tonnes CO_2e per capita per annum in Nigeria. Therefore, the negative regression coefficient of SDG13 aligns with Onah's claims. Consequently, this research establishes that as we aim to achieve food, socioeconomic, and energy security, we should be mindful about climate impacts of increased production and consumption patterns at the household level. This finding is also consistent with recent research finding at the University of East Anglia in 2018 which stated that energy-producing and consuming cities, and cities with lots of population, may have higher CO_2 outputs than very rural and dispersed settlements.

Analysis of food security and socioeconomic + energy + climate + environmental sustainability (SDG1, SDG4, SDG7, SDG13 and SDG15) – This analysis is the same as a block regression that takes into consideration, the full complement of all the SDG

Table 6
Estimated stepwise linear regression equations for predictor variables.

Stepwise Inclusion of Predictor Variables	Equation	Regression Estimates					Other Parameters			
		β_1	β_2	β_3	β_4	β_5	β_0	*F*Value	R^2Value	$\bar{R}^2$ Value
SDG1	2	0.851***					1.269***	418.920***	0.725	0.723
		(0.021)					(0.2938)			
+ SDG4	3	0.940***	0.225***				0.499**	261.058***	0.768	0.765
		(0.021)	(0.029)				(0.163)			
+ SDG7	4	0.943***	0.223***	−0.030			0.547**	173.772***	0.769	0.764
		(0.021)	(0.029)	(0.033)			(0.175)			
+ SDG13	5	0.960***	0.219***	−0.041	−0.093**		0.568***	135.732***	0.777	0.771
		(0.021)	(0.028)	(0.032)	(0.004)		(0.173)			
+ SDG15	6	0.953	0.233***	−0.055	−0.091	0.111**	0.485**	115.549***	0.788	0.782
		(0.021)	(0.028)	(0.032)	(0.004)	(4.965)	(0.171)			

Computed by SPSS with primary data from 161 respondents collected drawn from Asa, Ilorin East, Ilorin West, and Ilorin South LGAs of Kwara State. Values in bracket () represent Standard error of Estimates ***P < 0.01, **P < 0.05.

relational variables under study. As shown in Table 6, the overall model (F statistic) was significant at p < 0.01, however only SDG1, SDG4 and SDG15 were significant at p < 0.01. All others were significant at p < 0.05 except SDG7 because of the bias of the case study on SDG7. The significant and positive relationship between food security and SDG15 exposes the strong linkages between food production and forest/land degradation. In most part of Nigeria, agricultural production and food systems are largely intensive in nature with lower yields when compared to food production systems in developed countries. Therefore, an increase in food security may increase the average income of a small-scale producer, increase their socio-economic situation, ensure more energy security, and probably mitigate the impact of climate change through reduction in carbon emission.

4. General discussion

The pairwise correlation matrix in Table 5 that pointed out the strongest attribution of 19% between food security and SDG15 is visible in the block regression model of this research because of the potential for synergies between food security and environmental sustainability. Meanwhile, this research is not oblivious of the fact that there are also similar input needs that can cause competition for resources. For example, Food and Agriculture Organization of the United Nations (2018) made a similar case that water, land, soil, electricity and fuel are all needed in mass amounts to produce the food necessary to address hunger, malnutrition and to double agricultural productivity (based on the assumption that the fight against rural poverty, malnutrition, and hunger in the framework of the SDG is likely to be addressed by increases in cheap food production and not by redistribution of resources, means, or food).

Although, this research did not disaggregate samples to determine the social stratification typical of most societies including Nigeria, however, this research argues that achievement of food security targets in SDG2 to be able to feed the world by 2030 must first begin at the household level with significant redistribution of resources such as an incentivized project or programme like the case of NAICCI. This argument is because when households who live below the poverty line are faced with hard choices that concerns their livelihood, environmental and climate concerns will be the least of their worries as indicated in our analysis in Table 3. This paper however supports Gupta et al. (2014) who stated that extensive technology advancements and policy implementation can help to achieve SDG targets in a sustainable manner.

The findings in this study have implications for SDG nexus because it emphasizes the critical role economics and environmental policies play in food production and energy access projects. If the demand for food increases in Nigeria and any similar country, the demand for unsubsidized energy resources will also increase thereby translating to increased household family income and reduction in poverty. The nexus approach to implementing the SDGs and understanding inter-linkages of the SDGs would benefit from a better understanding of the interactions of food, economic, social, climate, and environmental policy choices we make today.

Our analysis assumes that the SDGs cannot be implemented in isolation of each other. The quantification approach developed in this study was made for a specific case, based on implementation of a pilot project and assuming that the selected SDGs and targets are a part of a bigger programme that may be relevant to understanding the synergies being investigated. Accordingly, coarse assumptions on relational/predictor SDGs being held as constants were made for quantifying target interactions. The use of this approach requires defining the way a country or region aims at reaching the SDG targets, since SDGs establish what to achieve and when, but not how, so that countries and regions can develop different plans for doing so. This all means that the correlation matrix developed by this research can have quite different results when the approach is used in a specific context or with a specific implementation pathway.

Although the interaction matrix evaluates only the interconnection between two SDGs at a time, all six SDGs are intrinsically linked in many situations in Nigeria and perhaps around the globe. With a specific area in mind, and concrete development pathways from policy making, this approach can be further developed to account for cascading effects, i.e., the consequences of a synergic or conflicting interaction between two targets on a third, fourth, fifth, etc., Overall, the approach developed in this study offers a replicable, quantitative, and criteria-oriented methodology for evaluating synergies and conflicts between SDG aggregated targets.

In summary, the SDGs under study are inter-linked and have a significant combined impact on beneficiaries of the NAICCI intervention in the following order (from most significant to the least)

$$SDG2 = SDG1_{0.01} > SDG4_{0.01} > SDG15_{0.01} > SDG13^{-}_{0.05} > SDG7^{-}$$

Based on this study, the above equation is further explained as a pentagonal framework for SDG nexus as shown in Fig. 2.

Pentagonal framework for SDG nexus – A pentagonal framework nexus for the inter-linkages between food security and SDGs 1,4,7,13 and 15 is designed based on lessons learnt and success stories from the NAICCI intervention as shown in Fig. 2. The framework is based on five key considerations revealed by this study: food-socioeconomic-energy-climate-environment nexus. The nexus was identified during the implementation of NAICCI in

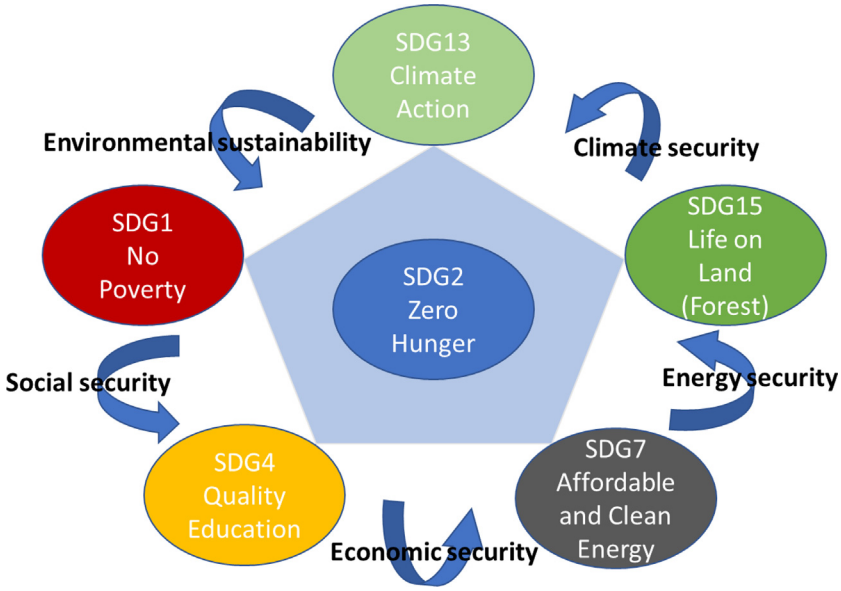


Fig. 2. Food-Socioeconomic-Energy-Climate-Environment nexus based on interlinkages between SDG1,2,4,7, 13 and 15.

Nigeria. The framework (Fig. 2,) is a diagram that illustrates the web of inter-linkages between food security, socioeconomic factors, energy security, climate security and environmental sustainability as stated in adoption documents of the United Nations Sustainable Development Goals. Though, there are various angles to understanding causality and project-based linkages, one of the most challenging technical issues associated with project-based mechanisms as considered in this research is that of real linkages or synergies or a lack thereof.

The pentagonal framework for SDGs nexus is proposed for the identification and analysis of inter-linkages potentially generated by a project. The term 'inter-linkage' in this study is used to refer to as food security-related unanticipated relationships (negative or positive) between SDGs 1,2,4,7,13 and 15 because of the implementation of NAICCI. For this reason, inter-linkages usually occur within and outside of the project's immediate boundaries, also referred to as an on and off-site effects. The framework shows that given the interaction between food security, energy, economic growth, climate change and environmental sustainability, research efforts has increasingly recognized the energy ladder theory, prevalence, and significance of energy poverty and most importantly, how all these fit into achieving the United Nations Sustainable Development Goals (particularly SDG2 – zero hunger).

The pentagonal framework for SDG synergies is an improvement on various food-related nexus approaches in recent times where climate models and environmental dimensions were not fully integrated. The United States Department of Agriculture for example, estimated that overall food-related energy use in the United States represented 16% of the nation's total energy budget – Patrick et al. (2010).

One can argue therefore that the energy use involved in the food system to some degree links food systems to GHG emissions and sources of the resources that was used to generate GHGs. However, what this framework does not tell, is indirect emissions, specificity of emissions, other household income that constitutes part of net income, extent to which the integration of the SDGs creates public good or a lack of, and consideration of all relevant SDG targets in the model. Therefore, there is bias in the selection of the SDG targets which was based on those that are most relevant to the NAICCI project outcomes.

The fact that cooking energy represents only a small fraction of household energy consumption could also create a shadow on research estimates. However, the relative impact of the SDGs under study on food security provides a good baseline for future research on SDG nexus approaches.

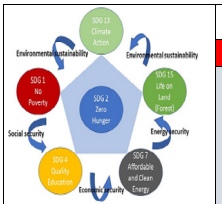
Therefore, a matrix of food policy recommendations of this research (Table 7) tries to minimize food insecurity problems from the stand-point of dissecting applicable onsite and off-site effects from NAICCI's experimental scenario as well as demonstrates that there is no universal causality or relationship between household income and cooking energy consumption but, rather, that there are substantial inter-linked differences that are usually determined by different factors and targets of the SDGs used in determining those relationships. The pentagonal framework and resulting matrix of food policy recommendations are applicable to any future SDG-related clean cooking technologies and fuels research in Nigeria and other countries with similar social and political, climate, environmental and economic realities.

Table 7 shows a matrix of policy and programmatic choices exposed by this research that researchers, development practitioners and policymakers can do, to change domestic food production patterns from a subsistence inefficient level to a high productive and sustainable pattern. In the medium to long term, the scope of action widens, where governments can implement price stabilization policies based on the use of reserves, tariffs, or subsidies; promote food production using subsidies; producer price supports or provision of agricultural support services; and extend social protection programs. It therefore makes sense to generally discuss the political-economic cost implications of adopted policies with the respective predictors as proxy.

5. Conclusion and recommendations

Evidence from results obtained in Tables 4–6 shows that the food security situation of the target group is inter-linked with access to basic services such as energy for cooking and education. Although the degree of synergy and trade-off was not empirically determined in this research, statistically speaking, observation of respondents showed that their food security situation as described by the average household income from farming is highly dependent on the ability of government to subsidize cheaper and cleaner cooking options for preparing their daily meals. The use of improved cook stoves and clean fuel in Nigeria is not only

Table 7
Matrix of recommended food security actions based on estimated Pearson pair wise correlation and regression coefficients for SDGs 1,4,7,13 and 15.

				Economic Security			Social Security	Energy Security	Climate security	Environmental Sustainability
				SDG1			SDG4	SDG7	SDG13	SDG15
				Target 1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location	**Target 1.2.1** Proportion of population living below the national poverty line, by sex and age	**Target 1.4.1** Proportion of population living in households with access to basic services	**Target 4.6.1** Proportion of population in each age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex	**Target 7.1.2** Proportion of population with primary reliance on clean fuels and technology	**Target 13.2.1** Integrate climate change measures into national policies, strategies, and planning to increase ability to adapt and mitigate impacts of climate change in a manner that does not threaten food production	**Target 15.3.1** Proportion of land that is degraded over total land area
Food Security	LINKAGES/SYNERGIES	**SDG2**	**Target 2.3.2** Average income of small-scale food producers, by sex and indigenous status	Programme of action on linking women small-holder farmers with subsidized farm input to ensure food security		Programme of action for the provision of rural infrastructure for improved food security	Policy on voluntary adult education for farmers in rural areas. Support for young female farmers as a post-secondary vocational skill for economic development	The use of renewable energy in food production: A programmatic approach to sustainable rural development	Establish a national climate change legislative framework with associated multi-sectoral policies on, sustainable biofuels, climate-smart agriculture, and low-carbon livestock production.	Programme of action to ensure sustainable agro-forestry and subsistence food production.
	POTENTIAL SYNERGIES	**SDG2**	Target 2.3.2 Average income of small-scale food producers, by sex and indigenous status	Study to demystify subsistence food producers based on common staple crop food per agro-ecological zone. Business road map for competitive agricultural export: The role of small holder farmers.		How much does it cost to provide basic services for small holder farmers? Implications on food security.	Food systems and the blue economy. What does a rural farmer need to know?	Greening energy use in agriculture: A case of small-holder food producers in rural to semi-urban areas.	Study on agricultural sector GHG emission: The use of GHG-efficient technologies. Mainstreaming climate adaptation as best practices in the agricultural sector.	Afforestation and secondary forests: The role of food security planning and budgeting

determined by the affordability, availability, and access, but also socioeconomic factors including gender considerations, age, employment status, family income, urbanization, etc. The nexus approach to implementing the SDGs and understanding interlinkages of the SDGs would benefit from a better understanding of the interactions of food, economic, social, climate, and environmental policy choices we make today. This study concludes that the SDG related socio-economic factors may ensure energy security and food security at the same time if carefully planned, budgeted, supported, and implemented systematically in a low-carbon development pathway.

In summary, the study recommends the following:

- Government should establish deliberate policies and programmes targeted at improving food security, fighting poverty, expanding energy access, improving human capital development, alongside strengthening climate resilience, and ensuring environmental sustainability of her citizens, especially the poor. This is because this study showed that when households who live below the poverty line are faced with hard choices that concerns their livelihood, environmental and climate concerns will be the least of their worries.
- There is need for deliberate policy for incentivizing the production of clean cookstoves and fuels to bring down the final cost for the final consumer. This could be more useful because it will benefit almost every Nigerian and free up capital for the private sector to invest in the development of LPG gas infrastructure.
- Government should pursue the implementation of the SDGs as an integrated framework that also considers gender dimension and the strong participation of the private sector.
- The achievement of SDG7,13 and 15 will largely depend on access to climate finance or subsidies and strengthened capacities of state and private sector actors in Nigeria. Therefore, attention should be given to achieving clean and affordable energy, climate actions and environmental protection.
- Government must take proactive steps to strengthen climatic and environmental policy frameworks such as the Nationally Determined Contributions and integrate SDG implementation into long-term development plans. This could be done immediately since the government is in the process of revising her NDC for 2020–2025. If done, this will attract investments, create jobs, and relieve many Nigerians currently under the burden of poverty and unemployment as they are able to also engage in sustainable production and consumption of resources to eliminate rampant inequality in income and access to basic services.
- The National Social Investment Programme (NSIP) of the government of Nigeria need to be reformed to allow free and holistic participation of the private sector. This will expand the available fiscal space and enable the Government to channel more financial resources to implementation of SDGs that are related to the social and economic sectors.
- Universities should support research on the interaction between food security and multiple sectors of the economy and generate new knowledge on strategies for accelerated implementation of the SDGs.
- Researchers should further evaluate the pentagonal SDG framework and resulting matrix of food policy recommendations revealed by this study to explore synergies created by the SDGs for the overall benefit of society.
- The private sector should make use of SDG policy analysis to direct investments to create jobs, expand their businesses and contribute to accelerated economic development to help in building back better from the impact of COVID-19 pandemic.

6. Ethics approval and consent to participate

Not applicable.

7. Consent for publication

Yes.

8. Competing interests

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Innocent Onah: Conceptualization, Formal analysis, Data curation, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Anthony Nyong:** Supervision, Validation. **Kuje Haruna Ayuba:** Data curation, Supervision, Validation, Writing - review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2021.105416.

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