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Research Article

Energy Demand Forecasting to Assure Food Security from Agricultural Sector of Niger

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Abstract

The objective of this work is to estimate the future energy needs of the agricultural sector in two key areas: fuel consumption and the specific use of electricity for operating agricultural machinery. Meeting these energy needs could significantly enhance agricultural production by improving the availability, accessibility, and utilization of food products. Ultimately, this would contribute to ensuring food security in Niger by 2035. The Model for the Analysis of Energy Demand (MAED) is used for the simulation. Four scenarios have been defined for this study: the reference scenario, the ambitious scenario, the modest scenario, and the target scenario. The results of the target scenario are as follows: 30.96 MWyr for total energy demand, 26.54 MWyr for fuel energy demand and 4.42 MWyr for electrical energy demand. The ambitious scenario presents a total energy demand of 26.92 MWyr, including 23.07 MWyr for fuel energy demand and 3.84 MWyr for electricity energy demand in 2035. The reference scenario records a total energy demand of 23.37 MWyr, including 19.97 MWyr for fuel energy demand and 3.51 MWyr for electricity energy demand in 2035. The modest scenario presents a total energy demand of 17.85 MWyr, including 15.97 MWyr for fuel energy demand and 1.88 MWyr for electricity energy demand in 2035. With the results of the target scenario set, the study's objective will be achieved by 2035, provided that efforts are made on the massive use of agricultural machinery, on increasing production under irrigation, on reversing the current process of soil degradation, and on developing irrigated cereals (corn, rice, wheat).

Keywords

Energy Planning, Energy Intensity, Agricultural Machinery, Food Security, MAED Software

1. Introduction

Over the past fifty years, Niger has endured two major crises: the great famine of 1973 and another in 2005. Both events exposed the country's fragility and tested its stability [1]. A chronic food deficit, coupled with a decline in regional

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supply due to reduced imports from Nigeria, a poor maize harvest in Ghana, and the closure of Mali and Burkina Faso's borders to cereal exports triggered a surge in cereal prices and a severe food crisis in Niger in 2004/2005 [2]. This instability is due to a combination of cyclical factors such as low rainfall and locust invasions, and structural factors such as archaic production methods [1]. The added value of the agricultural sector was estimated at 5.066 billion US dollars in 2021 [3]. Fuel consumption was estimated at 6.4 thousand tonnes of oil equivalent (ktoe), while electricity consumption was estimated at 1 ktoe [4]. Niger recorded an overall acute malnutrition rate of around 12.2% in 2021, slightly lower compared to the previous year (12.5%) [5]. Among these, 2.4% suffered from severe acute malnutrition and 9.8% from moderate acute malnutrition. According to the United Nations framework for March 2022, more than 4.4 million people were severely acutely food insecure during the lean season of 2022 (June-August) [5]. The prevalence of severe food insecurity in the population was 16.6% in 2019 [6], while the hunger index for 2022 in Niger is 32.6 [7].

Despite these challenges, Niger has significant natural resources that could considerably increase the contribution of the agricultural sector to the country's economy. Agricultural land is estimated at 19 million hectares, while pastureland covers around 62 million hectares or 45% of the territory. Water resources, with more than 32 billion cubic metres per year, mainly from the River Niger and its tributaries (30.75 billion m3, etc.), which offers a great potential for agricultural development [8].

Achieving increased agricultural production and food self-sufficiency requires a shift towards mechanized agriculture, involving expanded irrigated production and development of irrigated cereals (maize, rice, wheat), while phasing out traditional farming methods. This work aims to estimate the future energy needs of the agricultural sector in terms of fuel and the specific use of electricity for the operation of agricultural machinery, which could considerably improve agricultural production (availability, accessibility, and use of food products) to guarantee food security in Niger by 2035.

This study takes a novel approach by examining three key relationships: 1) the correlation between energy consumption and agricultural GDP, 2) the impact of energy intensity on agricultural output, and 3) the connection between agricultural production and food security.

Data collection for estimating fuel energy consumption was carried out on the main sites of the Aménagements Hydro Agricole (AHA) in Niger. According to a census carried out by ONAHA's Development and Economic Analysis Department, Niger currently has 85 AHAs, covering some 16,000 hectares (ha). Only 74 of these are operational. They employ over 40,000 farmers [9].

Various approaches have been explored to address the challenge of food security. Researchers such as [10] and [11] highlight the crucial role of the agricultural sector, which includes livestock and fisheries, in achieving food security and self-sufficiency. For [12], addressing Nigeria's food security challenge requires a restructuring of the agricultural sector by limiting food imports to promote local agricultural production and biofuel production; this approach aims to make food prices more affordable and accessible in the face of rising fuel costs. Niger's food insecurity is rooted in several factors, as outlined in [13] and [2]; these include soil deficiencies in organic matter and phosphorus, excessive reliance on food imports, and the use of outdated agricultural tools. A study in [14] believes that predicting energy demand is a key production factor in Iranian agriculture. It uses BoxJenkins methodology to model agricultural consumption of four main energy sources: gasoline, kerosene, diesel and electricity for the period 1988-2014. [15] underscores the critical role of agricultural mechanization in guaranteeing food security for the population. As highlighted in [16], energy plays a pivotal role in modern agriculture's efforts to ensure food security; the study delves into methods for assessing direct energy consumption, which encompasses the energy used to operate and maintain farm equipment and buildings; it also explores indirect energy or embodied energy, which represents the energy required to produce inputs such as animal feed, fertilizers, and the infrastructure itself. The author in [17] examines the causal relationship between energy consumption and agricultural technology factors, as well as electricity consumption and technology factors in Pakistan's agricultural sector. It also assesses four alternative but equally plausible hypotheses, each with different policy implications. These are: agricultural technology factors driving energy demand; energy demand driving technology factors; the existence of bidirectional causality between the two variables; and the fact that both variables are independent of causality. [18] analyzes energy consumption in Malaysia's agricultural sector for the period 1991-2000 from an economic perspective, using input-output methods to determine a production system that involves sustainable energy use in Malaysian agriculture. [19] claim that higher energy intensity yields higher agricultural yields. [20] and [21] propose energy-efficient solutions such as direct precision agriculture and low-energy technologies to address the growing energy demands of agriculture. As highlighted in [22], the volatility of the global market makes agriculture increasingly vulnerable to fossil fuel dependency. For [23], the use of green energy is essential to food security.

The materials and methods of the paper are presented in Section 2, followed by simulation results in Section 3, the discussion in Section 4 and Section 5 concludes the paper.

2. Materials and Methods

The Energy consumption is assessed by taking into account the energy used throughout the year to operate motorized agricultural equipment (motorized pumps, tillers, tractors, etc.) used to grow crops on the sites of the 74 hydro-agricultural schemes.

Equations 1 and 2 are used to determine the energy consumption [15].

$$E = T \times Ie \quad (1)$$

With

E: Total fuel consumption (litre/year)

T: Number of machines (unit)

Ie: Energy intensity of each type of machine (litre/unit/year)

$$Ie = O \times F \quad (2)$$

With

O: Working hours (hours/year)

F: Fuel consumed (litre/hour)

Table 1 summarises the details of the motorised equipment available at the hydro-agricultural development sites in Niger.

Table 1. *Fuel consumption of motorized equipment.*

Type of machine	Quantity	Fuel type	Fuel consumed (L/H)	Hours worked/year	Fuel consumption (L)
10 hp tiller	211	Diesel	1,75	720	265860
Water pumps	6600	Petrol	1	340	2244000
Water pumps	5000	LPG	1	340	1700000
Large MP high flow 900m^3/ha	7	Diesel	1,1	500	3850
Submersible pump	88	Diesel	1,1	340	32912
70hp tractors	1120	Diesel	7	500	3920000

Niger's economy and population are heavily dependent on agricultural activities, particularly livestock farming and subsistence crops such as maize and sorghum [24]. The available statistics show that in 1973, the year of the great famine, the value added of the agricultural sector represented 60.27% of GDP, illustrating the very high dependence of the Niger economy on agricultural activities [6]. In 2000, the agricultural sector contributed 33.01% to GDP, increasing to 34.48% in 2005, the year of the food crisis, and reaching 36.57% in 2021. Figure 1 illustrates agriculture's critical role in the Nigerien economy [3].

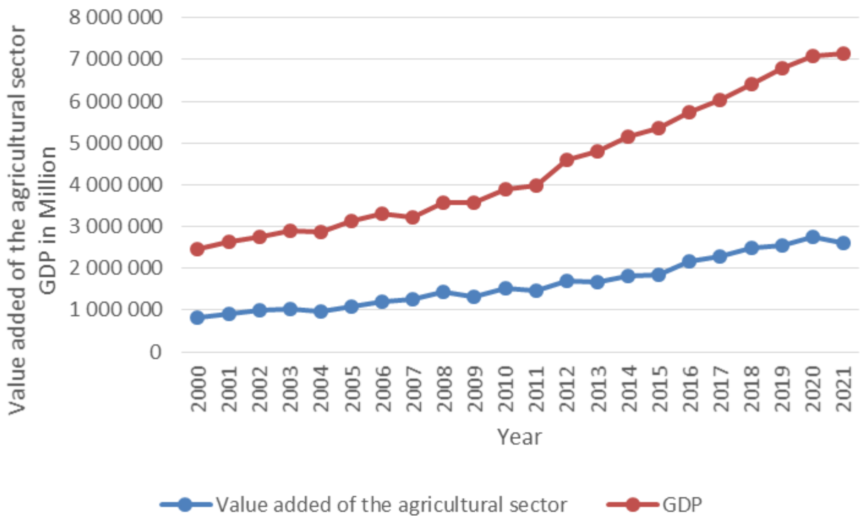

Figure 1. *The evolution of value added in the agricultural sector over GDP at constant prices in 2015 [3].*

The low level of mechanization in Niger's agricultural sector is reflected in its low fuel and electricity consumption. Figure 2. shows that average annual fuel consumption was approximately 5 Ktoe, and electricity consumption averaged 0.63 Ktoe between 2010 and 2021, indicating limited use of motorized agricultural equipment [4].

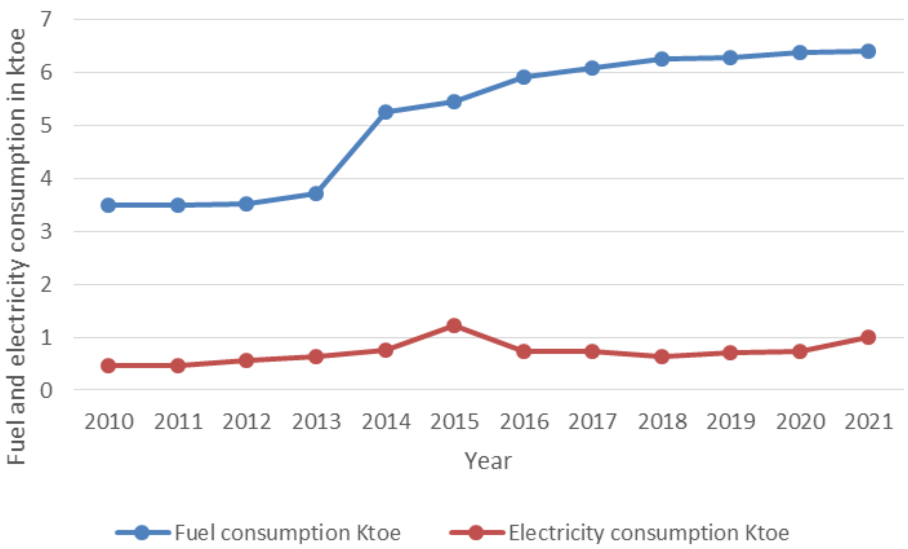

Figure 2. *Trends in fuel and electricity consumption in agriculture [4].*

Between 2010 and 2021, the agricultural sector's contribution to GDP grew from 1,513,897 million FCFA to 2,616,132 million FCFA, a 1,102,235 million FCFA increase. Concurrently, energy consumption (fuel and electricity) rose from 3.93 Ktep to 7.40 Ktep, a 3.47 Ktep increase (Figure 2.). This rise in energy consumption directly impacts the agricultural sector's value added. As energy consumption increases, so does the use of agricultural machinery, leading to higher energy intensity. The correlation between energy consumption and agricultural value added is a key factor in this study.

The MAED (Model for the Analysis of Energy Demand), developed by the IAEA, evaluates future energy demand considering medium- and long-term socio-economic, technological, and demographic development scenarios [25]. The socioeconomic data for the reference year are detailed in Table 2 and Table 3.

Table 2. *Demographic data. [6, 26].*

Object	Unity	2021
Population *	Million	23.59
Population growth rate *	%	-
Urban Population	%	16.80
Person/ urban Household	cap	7
Number of urban Households	Million	0.57
Rural Population	%	83.20
Person/ rural Household	cap	7.40
Number of rural Households	Million	2.65
Potential Labour Force	%	48.67
Participating Labour Force	%	73.86
Active Labour Force	Million	8.48
Population in cities with public transport	%	20
Population inside Large Cities	Million	4.72

Table 3. *Economic data. [3].*

Object	Unity	2021
GDP	US$ Billion	13.85
GDP growth rate	% p.a.	-
per capita GDP	US$/Cap	587.23
Distribution by sector of GDP		
Agriculture	%	36.57
Construction	%	5
Mining	%	8
Manufacturing	%	8.4
Service	%	40.3
Energy	%	1.73
Total	%	100

Table 4 Describes the four (04) scenarios selected for this study, covering the period 2021-2035. It is important to note that the results are given for five (05) years.

Table 4. Scenarios assumptions.

Scenarios	Assumptions
Reference	Demographics: social indicators are expected to improve slowly. The population growth rate will rise from 3.9% in 2021 to 4% in 2035. Economy: The poverty rate is not expected to change significantly. Niger's human capital is not expected to reach the minimum thresholds required for rapid economic growth. The rural sector should continue to dominate the economy, particularly the agricultural sector. GDP growth is expected to average around 6%. The rate of growth of added value in the agricultural sector is estimated at 4.75%. The continuation of current public policies would lead to a dead end and would not enable the prosperity that the people of Niger want to be achieved [26-28].
Ambitious	Demographics: Significant fall in the population growth rate from 3.7% in 2025 to 3.2% in 2035. Economy: Modernising the rural areas through the use of modern agricultural techniques, access to water, energy, infrastructure and the value chain would increase GDP growth in the rural sector by around 6% per year over the period. This increase in farm incomes, supported by pro-poor incentives and food security, would promote rapid economic development. By 2035, the quality of life in rural areas will have improved significantly, and the national production deficits that will have been absorbed, coupled with strategies for access to food, will make it possible to feed everyone, including urban areas whose population continues to grow. By 2035, thanks to better education, adequate food, access to water and sanitation and quality health services, Niger will finally see a steady decline in malnutrition rates and stunted growth in rural areas. The GDP growth rate will rise from 7% in 2025 to 7.5% in 2035. Growth in the agricultural sector will average around 6% [27, 29].
Modest	Demographics: Same as in the reference scenario. Economy: Political and institutional instability, a poor winter campaign and persistent insecurity are hurting people's living conditions. The economic growth rate will fall from 4.2% in 2025 to 3.3% in 2035. Growth in the agricultural sector will average around 3%. Risk: food crisis, drought [27].
Set Objective	Demographics: Same as the high scenario. The economy: The GDP growth rate is set at 9.5% in 2025, 10% in 2030 and 2035. This trend should be driven mainly by the agricultural and livestock sectors. The agricultural sector should benefit from the effects of the completion of major projects and programmes (MCC, Kandadji dam, regional poles, etc.). As for the livestock sector, it should be linked to good rainfall, which will have an impact on the availability of fodder, and to the measures taken to improve animal health. Economic growth is also being driven by the 2021-2025 Action Plan of the 3N Initiative, the cost of which is estimated/assessed at 2,693.942 billion CFA francs (US$4.46 billion). The 3N Initiative aims to increase the level of rainfed and irrigated crop production by improving the supply of inputs and equipment to increase cereal production from 5,596,575 tonnes in 2020 to 7,142,805 tonnes in 2025 and irrigated production from 1,032,000 tonnes of cereal equivalent in 2020 to 3,100,000 tonnes of cereal equivalent in 2025. The agricultural sector's growth rate will rise from 5.9% in 2025 to 7.5% in 2035, the target date for achieving food security [3, 8, 30]

3. Results

Figures 3 and 4 show respectively the energy intensity for motive power (fuel) and the energy intensity for the specific use of electricity projected across the four scenarios (2021-2035).

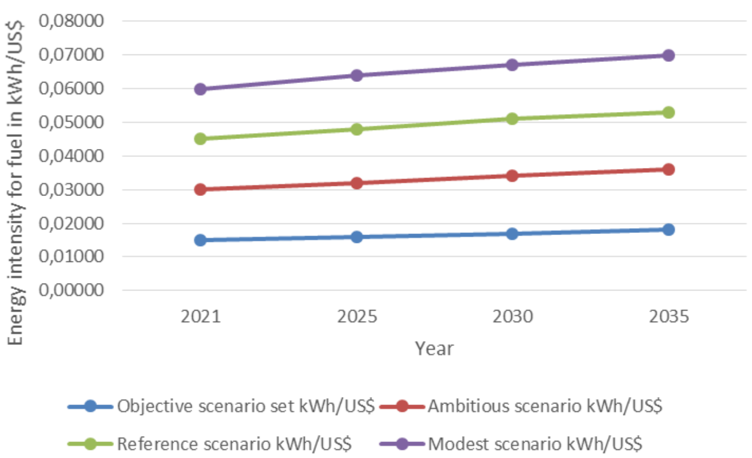

Figure 3. Energy intensity for fuel.

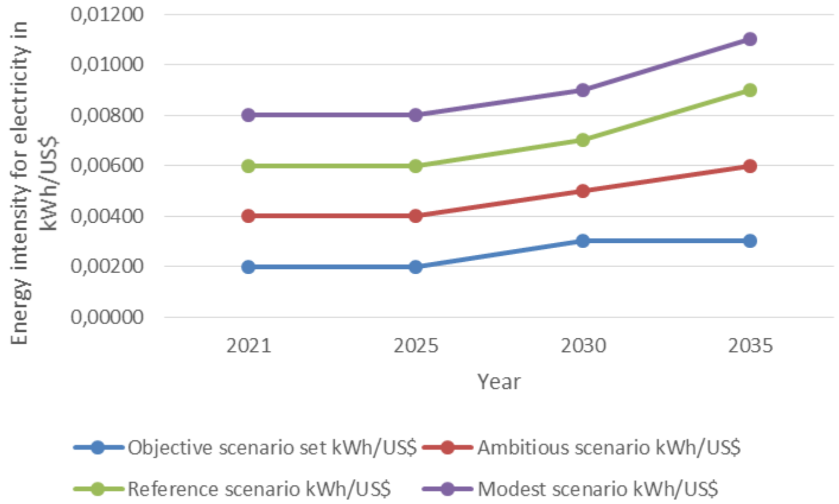

***Figure 4**. Energy intensity for electricity.*

At the end of the simulation on MAED, the results obtained for the four (04) scenarios are illustrated in Figures 5 and 6.

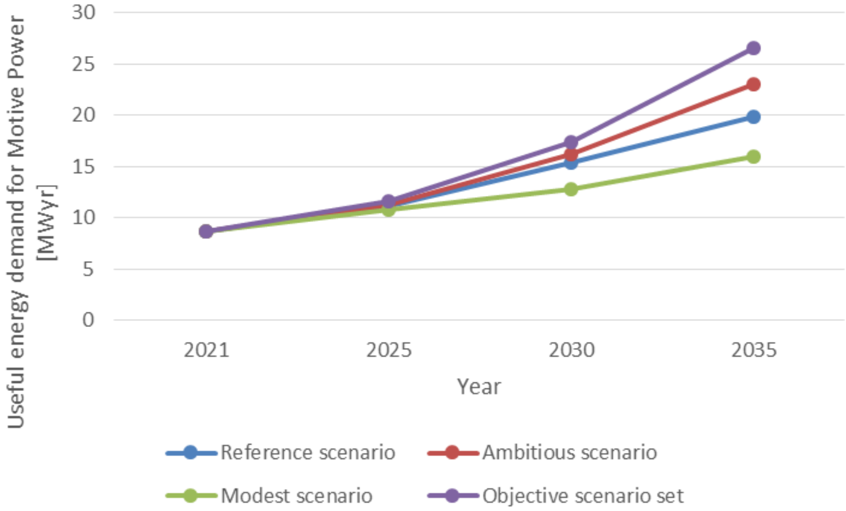

***Figure 5**. Useful energy demand for Motive Power.*

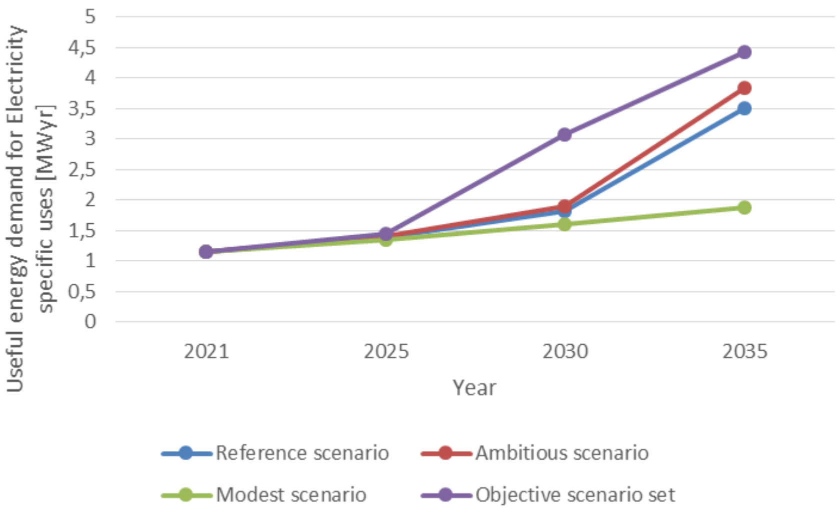

***Figure 6**. Useful energy demand for Specific Use of Electricity.*

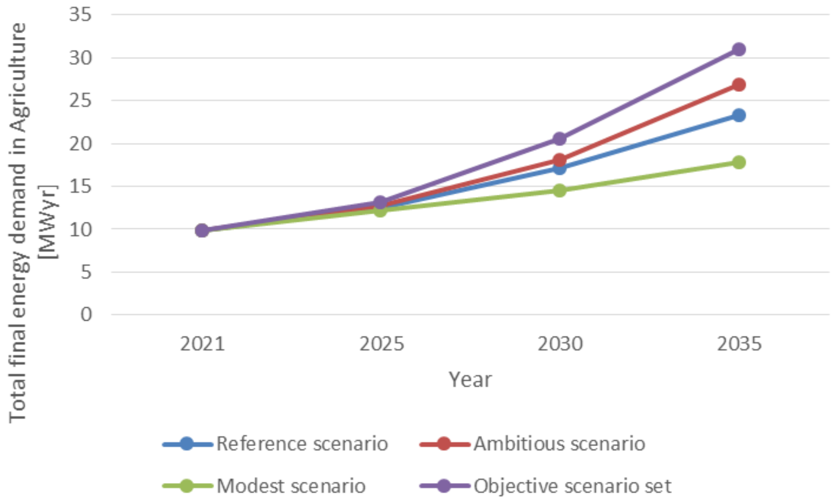

Figure 7. *Absolute total final energy demand in agriculture.*

4. Discussion

These results can be analysed as follows:

(1) For the established target scenario, the results for the horizon of 2035 are as follows: Total energy demand is estimated at 30.96 MWyr, of which 26.54 MWyr is for fuel energy demand and 4.42 MWyr is for electricity demand. In 2025, fuel energy demand is 11.64 MWyr and electricity energy demand is 1.45 MWyr. Indeed, over fourteen years, total energy demand is expected to rise from 9.83 MWyr in 2021 to 30.96 MWyr in 2035. These results highlight the growing use of energy in agricultural production activities through the massive use of motorized agricultural equipment [15]. These results on energy needs coupled with the sustained efforts over time by the State of Niger on the expansion of irrigated production and the development of irrigated cereals (maize, rice, wheat) through the 3N initiative action plan [8]; reversing current soil degradation, reducing underemployment and the exodus of labor, and promoting diversification of production, intensification of systems and integration of different sub-sectors (agriculture, livestock, environment, hydraulics) through the development strategy for inclusive growth Niger 2035, will help increase agricultural production and ensure Niger's food security by 2035 [27].

(2) Regarding the modest scenario, the total energy demand for fuel and electricity is 17.85 MWyr in 2035, of which 15.97 MWyr is for fuel energy demand and 1.88 MWyr is for electricity energy demand. Thus, from 2021 to 2035, the total energy demand increased from 9.83 MWyr to 17.85 MWyr, representing an evolution of 81.5%. These results illustrate a slow evolution of the total energy demand, and are explained by an underutilization of motorized agricultural equipment [13], a quasi-stationary growth of the added value of the agricultural sector, the impoverishment and continuous degradation of soils, drought, floods [27], locust invasions, etc. The risk of a food crisis and the persistence of the prevalence of severe food insecurity are not excluded.

(3) In the reference scenario, energy requirements for fuel and electricity will be around 23.37 MWyr, of which 19.97 MWyr for energy demand for fuel and 3.51 MWyr for energy demand for electricity in 2035. Between 2021 and 2035, total energy demand rose from 9.83 MWyr to 23.37 MWyr, a slight increase of 138%. Traditional production methods (animal traction and traditional tools) will persist, and the use of motorized agricultural machinery (the farm machinery fleet) is not effective on all agricultural sites. This is the continuation of current policies, and the maintenance of the current status quo.

(4) For the ambitious scenario, energy demand is estimated at 26.92 MWyr, including 23.07 MWyr for fuel energy demand and 3.84 MWyr for electrical energy demand in 2035. Between 2021 and 2035, total energy demand increases from 9.83 MWyr to 26.32 MWyr. With the ambitious scenario, the beginnings of structural change in the agricultural sector become visible, notably with the use of energy-intensive farm machinery in agricultural production. The agricultural sector's share of value added will fall from 36.57% in 2021 to 30% in 2035; the mining and manufacturing sectors will grow strongly during this period. The efforts undertaken (use of modern cultivation techniques, access to water, access to energy) remain insufficient to achieve food security by 2035.

The results of the target scenario, 30.96 MWyr for total energy demand, of which 26.54 MWyr for fuel energy demand and 4.42 MWyr for electricity energy demand, make it possible to achieve the objective of the study, which is to assess the energy needs of the agricultural sector to ensure Niger's food security by 2035, provided the necessary efforts are made.

5. Conclusion

This study aims to assess the future energy needs (fuel and electricity) of Niger's agricultural sector to enhance agricultural production both quantitatively and qualitatively, ensuring food self-sufficiency and security by 2035. Four scenarios were analyzed: reference, modest, ambitious, and target. The MAED model was used to estimate sectoral energy demand. Under the target scenario, total energy demand is projected at 30.96 MWyr, comprising 26.54 MWyr for fuel and 4.42 MWyr for electricity. Achieving this target by 2035 requires substantial investment in agricultural mechanization to prevent future food crises and famines, as reflected in Niger's historical challenges. The study emphasizes efficient energy use and the transition to clean energy within the Sahelian context.

Abbreviations

3N	Nigeriens Feeding Nigeriens
AGR	Agriculture
AHA	Hydro-agricultural Developments
CF1	Conversion Factor
CFA	African Financial Community
Hp	Horsepower
H	Hour
EI	Energy Intensity
ELS	Specific Electricity Uses
GPL	Liquefied Petroleum Gas
MWyr	Gigawatt-year
Ha	Hectare
Ktoe	Kilotonne of Oil Equivalent
KWh	Kilowatt Hour
L	Liter
MAED	Model for Analysis of Energy Demand
MCC	Millénium Challenge Corporation
MF	Motive Force
MP	Motor Pump
NSAGR	Number of Sub-sectors of the Agriculture Sector
ONAHA	National Office of Hydro-Agricultural Developments
GDP	Gross Domestic Product

Author Contributions

Aboubakar Amadou Yansambou Mohamed: Conceptualization, Investigation, Methodology, Software, Writing – original draft

Daouda Abdourahimoun: Resources, Supervision

Hamza Abarchi Halarou: Data curation, Visualization

Makinta Boukar: Project administration, Validation

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Aboubakar Amadou Yansambou Mohamed is a second-year doctoral student at Abdou Moumouni University of Niamey in the Laboratory of Energetics, Electronics, Electrical Engineering, Automation and Industrial Computing (LAERT-LA2EI), Abdou Moumouni University, Niamey, Niger in 2024. He holds a Master's degree in Electrical Systems Control from Ain-Temouchent University BELHADJ Bouchaib in Algeria, graduating top of his class in 2016. He participated in and presented a communication at the 6th congress of the West African Society of Physics at Abdou Moumouni University of Niamey in December 2024.

Research Field

Aboubakar Amadou Yansambou Mohamed: Energy demand, Energy supply, Energy transition, Smart grids, Automated systems.

Daouda Abdourahimoun: Energy quality, Resilience, Flexibility of electrical systems, Smart grid, Energy planning.

Hamza Abarchi Halarou: Electrical network stability, Green energy, Electrical demand planning, Energy supply strategies, Energy efficiency.

Makinta Boukar: Renewable energies, Energy efficiency, Energy planning, Electromagnetism, Smart grids.