MODELING RENEWABLE ENERGIES FOR BETTER FOOD SECURITY: THE CASE OF THE RURAL COMMUNE OF ANTEHIROKA IN ANALAMANGA REGION

Anselme RAKOTOMANANA[1], Romaine RAMANANARIVO[12], Sylvain RAMANANARIVO[2], Hery Tiana RAKOTONDRAMIARANA[3]

[1]*Ecole Doctorale Gestion des Ressources Naturelles et Développement. Equipe d'Accueil Agro-Management, Développement Durable des Territoires, Université d'Antananarivo, Madagascar*
[2] *Ecole Supérieure de Management et d'Informatique Appliquée, Antananarivo, Madagascar*
[3] *Institute for the Management and Energy – Université d'Antananarivo, Madagascar*

ABSTRACT

Climate change is a major threat to the planet. This is the result of the use of fossil fuels responsible for emitting greenhouse gases into the atmosphere. Renewable energies generate fewer emissions and play a key role against global warming. The latter is known as one of the factors blocking the achievement of food security. Are there really interactions between the exploitation and use of renewable energy and the dimensions of food security? This article aims to provide some answers to this problem through the impact study of the energy transition at the communal level. The hypothetico-deductive approach was adopted combining bibliographic analysis, a survey of 50 households in the Rural Commune of Antehiroka[1] and data processing. The results of the statistical analyses revealed 4 distinct classes grouped according to their energy mix, often dominated by biomass. The 4 dimensions of food security: food availability, access, utilization and stability are all impacted by the energy transition. Between 58 and 65% of the variability in the dependent variable food security is explained by the significant explanatory variables. The energy-lighting variables candle and Jirama are the most influential. The prospective analysis predicts a permanent increase in the use of renewable energies until the 6th year. Endogenous and exogenous factors will disrupt this trend in the future. In-depth studies of the structures and operating methods of potential actors in the energy and food sectors are key to ensure sustainability purposes.

Keywords : *Energy mix, food security, prospective and sustainability*.

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1. INTRODUCTION

The shocks caused by the Covid-19 pandemic, accompanied by the consequences of the wars in Ukraine and the Middle East, are affecting the daily lives of humanity and threatening future generations. Conflict contributes to food insecurity due to the disruption and degradation of food systems. The war in Ukraine has led to a surge in the prices of commodities including wheat, oil, and soybeans; this has exacerbated food insecurity around the world. The consequences of this food crisis are more difficult for some parts of the world, notably Africa, the Middle East and Asia, which depend on Russian and Ukrainian wheat imports for more than 50% of their needs. In addition to these conflicts, several other factors also affect food security, such as climate change, natural disasters, government policies, etc. (Abby Zeith, 2023).

Climate change represents a major threat for decades to come, especially in Africa, where economies are more climate-sensitive than any other continent. The intensive use of fossil fuels has had a negative impact on the environment. The most dangerous and global consequence is the phenomenon of climate change (Dencer, 1999).

[1] *The geographical coordinates of Antehiroka are approximately 18⁰51' South Latitude and 47⁰29' East Longitude*

Indeed, the energy consumed in the world is largely based on fossil fuels, such as oil, natural gas, and coal, which emit greenhouse gases (GHGs). It is among the main causes of global warming (IPCC, 2007).

Renewable energy plays a vital role in the fight against climate change. Renewable energy production generates far fewer emissions than burning fossil fuels. Thus, the challenge for all countries is to implement a transition to a more secure and less CO_2-emitting energy system without impeding economic and social development. In order to meet the goals of the Paris Agreement, it is important to urgently phase out fossil fuels, develop decarbonized and low-carbon energy sources, strengthen CO_2 capture, and improve all aspects of energy management, from production to utilization. One of the key outcomes of the 28^{th} Conference of the Parties (COP28) on global climate action is the acceleration of the just, orderly, and equitable energy transition. This implies drastic measures in the implementation of the recommendations agreed upon by the stakeholders.

Therefore, the question posed by this article is “how to ensure an effective energy transition that facilitates the achievement of food security”. The objectives are to assess the impact of the energy transition on food security components and to establish the evolution of the energy mix to define strategies for food systems sustainability.

2. MATERIALS AND METHODS

The methodological approach adopted is hypothetico-deductive combining bibliographic analysis, socio-demographic study, and data collection through a survey of 50 households of 7 Fokontany[2] in the Rural Commune of Antehiroka followed by statistical processing.

2.1 Characteristics of energy used and households needs

The verification of the hypothesis that "knowledge of the characteristics of the energy used by households contributes to understanding their needs" required two steps: the development of the typology of households and the analysis of their energy mix through benchmarking and scheduling.

2.1.1 Typology of households

Multiple Correspondence Analysis (ACM) allowed the identification and visualization of discriminating variables reflecting the characteristics of the groups; Hierarchical Ascending Classification (CAH) grouped individuals into classes according to their similarity. Both tools were complemented by Discriminant Factor Analysis (DFA) to identify group characteristics based on explanatory variables, with significant variables having a p value <0.27. The variables used in this study consist of quantitative and qualitative variables, namely: Sex (S), Age (A), Marital Status (CM), Household Size (T), Profession (P), Energy-Cooking (EC), Energy-Lighting (EE), Knowledge of Renewable Energy (CER), Definition of Renewable Energy (DER), Environmental Impact Renewable Energy (IER), Source of Information Renewable Energy (SER), Renewable Energy Use (UER), Energy Used (EU), Reason of Choice (RC), Energy Expenditure Cost (DE), Number of Coal Bags/Month (SCB), Source of Satisfaction Energy Used (SEU), Solar (S), Biomass (B), Fossil (F), Hydraulic (H), Low Purchasing Power (PA), Load Shedding Relief (SD), Lack of Information (MI), Non-Priority (NP), Food Frequency (FA), Dietary Diversity (DA), Availability (D), Access (Ac), Utilization (U), and Stability (S) (Table 1).

[2] *Fokontany is a traditional Malagasy village. It includes either hamlets, villages, or neighborhoods.*

Table 1: Quantitative and qualitative variables used

VARIABLES	CODIFICATIONS	MODALITIES
Sex	S	Female =0 ; Male=1
Age	A	0-25 =1 ; 26-35 =2 ; sup 36 =3
Marital status	CM	Single=0 ; Married=1
Size of household	T	Less than 5=1 ; More than 5=2
Profession	P	Breeder, cultivator=1; Unemployed, self-employed, company CEO, technician, craftsman, welder=2; Civil servant, driver, teacher, educator, midwife, housekeeper, trader, restaurateur, police, wholesaler, hairdresser=3
Energy-Cooking	EC	Charcoal=C ; Firewood=B ; Electricity=E ; Gas=G
Energy-Lighting	EE	Candle=B ; Jirama=J ; Renewable Energy=ER
Knowledge of	CER	No=0 ; Yes=1
Definition ER	DER	Inexhaustible Energy=EI; Natural Energy=EN; Other Energy than Jirama=NJ; Environment=Env; Limited Energy=EL; Solar Energy=ES; Environmental origin=OENV
Environnemental	IER	Polluting Energy=EnPL; Clean Energy=EnP
Info source of ER	SER	Media mass=Mmed; Community=Com; School=Sek; Workplace=Trav; Community School=Com Eco; Mass media-School=MME; General knowledge=CulGé; Community School=Eco Com
ER use	UER	Util_yes=1 ; Util_no=0
Energy used	EU	Biomass=Bio ; Hydraulic=Hy ; Gaz=G ; Solar=Sol
Reason of choice	RC	Load shedding relief=SD; Low purchasing power=PAR; Lack of information=MI; No priority=NP; Jirama too expensive=JTC
Energy expenditure	DE	<10.000=1 ; [10.000-50.000]=2 ; [50.000-100.000]=3 ; >100.000=4
Number of Coal	SCB	Less than 1=1 ; Between 1 and 2=2 ; Between 2 and 3=3 ;More than 3=4
Source of Satisfaction	SEU	Unsatisfied; Not satisfied=2; Less satisfied=3; A little satisfied=4; Satisfied=5
Solar	S	No=0 ; Yes=1
Biomass	B	No=0 ; Yes=1
Fossil	F	No=0 ; Yes=1
Hydraulic	H	No=0 ; Yes=1
Low purchasing power	PA	No=0 ; Yes=1
Load shedding relief	SD	No=0 ; Yes=1
Lack of Information	MI	No=0 ; Yes=1
Non-priority	NP	No=0 ; Yes=1
Food frequency	FA	Once a day=1; Twice a day=2 ; three times a day=3
Dietary diversity	DA	No=0 ; Yes=1
Availability	D	No=0 ; Yes=1
Acces	A	Insufficient=0 ; medium=1; acceptable=2
Utilization	U	Insufficient=0 ; medium=1; acceptable=2
Stability	8	Insufficient=0 ; medium=1; acceptable=2

2.1.2 Analysis of the household energy mix

2.1.2.1 Benchmarking on energy used by households

The CAH allows us to group households into homogeneous classes. Then, the classes obtained were used in the AFD to determine the correlations between all the variables studied and to obtain the p-values. Variables with a value greater than 0.10 (risk of error α) were eliminated. Once the variables were sorted, the classification functions obtained from the AFD were used to keep the final variables and to derive the value of each variable (Table 2).

Table 2: Steps for representing variables in each class

STEPS	PROCEDURES	PURPOSES
Square submatrix extraction of significant variables	Eliminate rows and columns listing non-significant variables	Matrix containing significant variables
Relativization of variables in relation to their coefficients	If Fischer coefficient < 0, then **Function = $\mathbf{coef_i}$ − minimum coef** With $coef_i$: line coefficient. If Fischer coefficient < 0 then coefficient retained	Axis change
Relativization compared to the best	Convert coefficients to % Function= coefi /∑ coefi Calculate the so-called “ideal” maximum of the coefficients for each variable	Graphs on the characteristics of each class with the ideal
Graphical representation of the characteristics of each class	Form the set of variables. Build the graphs Ngraph= Nclass × Nlot With Ngraph: number of graphs; Nclass: number of classes; and Nlot: number of set	

Subsequently, stochastic matrices were developed. These stochastic matrices, verified by the sum of each line equaling 1, allowed us to present the energy mix of households in the form of a radar by positioning the energies used in relation to the reference value or benchmark.

There are 22 variables used, mainly composed of variables from the energy mix and the socio-demographic characteristics of households (**Error! Reference source not found.**e 3).

Table 3: Significant variables

VARIABLES	CODES	MOBILIZATIONS
Marital status - Single	CM-0	BENCHMARKING
Profession - Unemployed, entrepreneur	P-2	
Profession - Civil servant, independent	P-3	
Energy-Cooking - Coal, Firewood, Electricity	EC-CBE	
Energy-Lighting - Candle, Jirama, Renewable Energy (EnR)	EE-BJER	
Energy-Lighting - Candle, Jirama	EE-BJ	
Knowledge of EnR - Yes	CER-1	
Definition EnR	DER-NJ	
Environnemental impact of EnR – Polluting energy	IER-EnPL	
Information source of EnR - 0	SER-0	
Information source of EnR - Community	SER-Com	
Renewable energy use - Yes	UER-1	
Energy used Biomass Hydraulic	EU-Bio Hy	
Energy used Solar Gas	EU-Sol G	
Reason of choice – Load Shedding Relief	RC-S D	
Cost of energy expenditure<10,000 Ar/month	DE-1	
Fossil-non	F-0	
Food frequency - 2 times/day	FA-2	
Dietary diversity - Yes	DA-1	
Acces - no	Ac-0	
Insufficient stability	S-0	
Acceptable stability	S-2	

2.1.2.2 Scheduling of energy used by households

The energy hierarchy is done by classifying the variables selected for the benchmarking by degree of importance of the energies used by households and have been presented in the form of an ellipse. The AFD correlation matrix serves as the basis for the sequencing of these variables.

2.2 Energy mix and development strategy

The hypothesis states that "The prospective analysis of the energy mix in place helps to define the strategies to be implemented for better food security". The verification of this hypothesis required 3 steps: Analysis of variance, development of the strategic rectangle and prospective representation.

2.2.1 Analysis of variance

To determine whether households' use of renewable energy is significant in relation to one or more components of food security, an analysis of variance was conducted. ANCOVA is the appropriate statistical tool as the analysis relates to quantitative dependent variables with quantitative and qualitative explanatory variables.

- The coefficient of determination table R^2 gives the percentage of variability of the variable to be modeled, the 4 dimensions of food security. The closer this coefficient is to 1, the better the model.
- The analysis of variance table determines whether the explanatory variables, i.e. the energy used by households and their socio-economic characteristics, provide a significant amount of information to the model (null hypothesis H_0) or not.

ANCOVA uses the various energies used by households [Energy-Lighting (EE) and Energy-Cooking (EC)] as well as their socio-demographic characteristics [Sex(S), Age (A), Marital Status (CM), Household size (T), Profession (P)] as explanatory variables. The variables to be modeled consist of the 4 dimensions of food security, namely food availability (D), access (Ac), utilization (U) and stability (S).

The analysis of variance shows the significance of the mean squares validated by the Fisher test. The sum-of-squares Type III analysis visualizes the influence of the removal of an explanatory variable from the model, with all other variables being retained.

2.2.2 Strategic rectangle

The development of the strategic rectangle allows us to identify the relevant variables, which is a preliminary step in the prospective approach. The strategies to be implemented are based on the dominant and influential variables of the study area. This method gives an idea of the intervariable correlations.

The variables used in Table 3 were used again here. The strategic rectangle is presented in a table format showing the dominant and influential variables of the study area.

2.2.3 Prospective representation

A prospective representation was carried out to predict the evolution of the household energy mix over time. This is an important step to determine the actions to be taken. To do this, the matrix of class averages was taken to stochasticate by class; this matrix is called Matrix A. Then the intervariable correlation matrix was taken to be stochasticated to serve as a transition matrix, called Matrix B.

The multiplication of Matrix A with Matrix B was carried out and projected over the next ten years, in order to determine future developments. Both matrices come from AFD. The sparkline graph by class shows the curves of the future evolution of households' energy mix.

Prospective analysis uses relevant variables in the study area that have degrees of influence and importance greater than 1.

Table 4: Variables used in the study area

VARIABLES	CODES	MOBILIZATION
Energy-Lighting - Candle Jirama	EE-BJ	PROSPECTIVE
Energy-Cooking – Coal Biomass Electricity	EC-CBE	
Energy-Lighting – Candle, Jirama, Renewable energy	EE-BJER	
Profession : unemployed and independants	P-2	

The temporal evolution of these variables for each class is thus represented on graphs up to ten years.

3. RESULTS

3.1 Household categories in the study area

3.1.1 Typology of households

The typology carried out based on the survey of the 50 households in the Rural Commune of Antehiroka revealed four distinct classes (Figure 1). The differentiating variables considered are variables relating to the different types of combinations of energy used, the components of food security, the socio-demographic characteristics of households, knowledge of renewable energies and household energy consumption and expenditure.

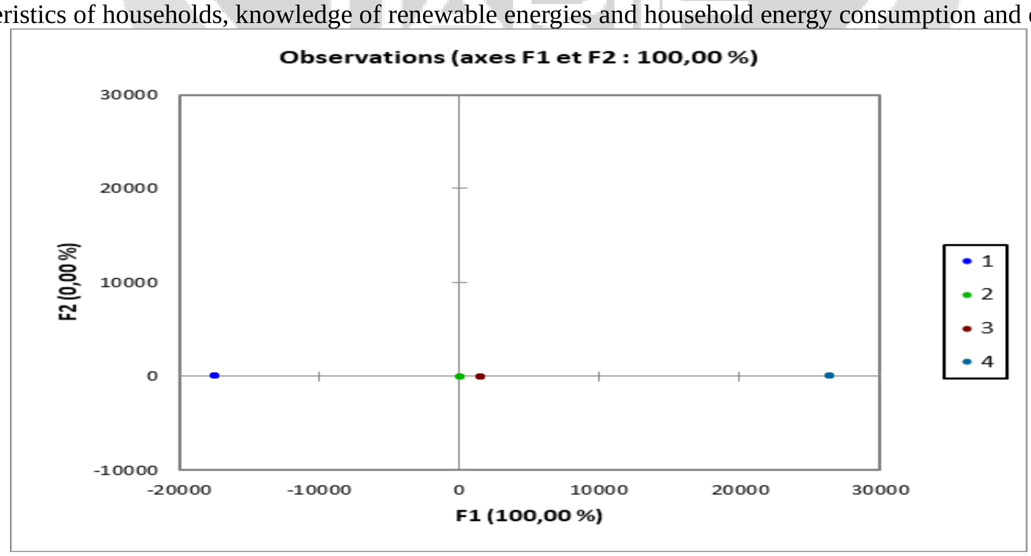

Figure 1: Position of the 4 classes from AFD's axes

The proportion of households in each class is as follows: Class 1: 30%; Class 2: 22%; Class 3: 30%; and Class 4: 18%.

3.1.2 Characteristics of the 4 classes

As a result of the data analysis, 22 variables are judged to be statistically significant, and their characteristics are described in the graphs in relation to their ideal. The set of variables is similar for all classes, but in terms of significance, classes 1 and 4 are more significant than classes 2 and 3 which are almost the same**.**

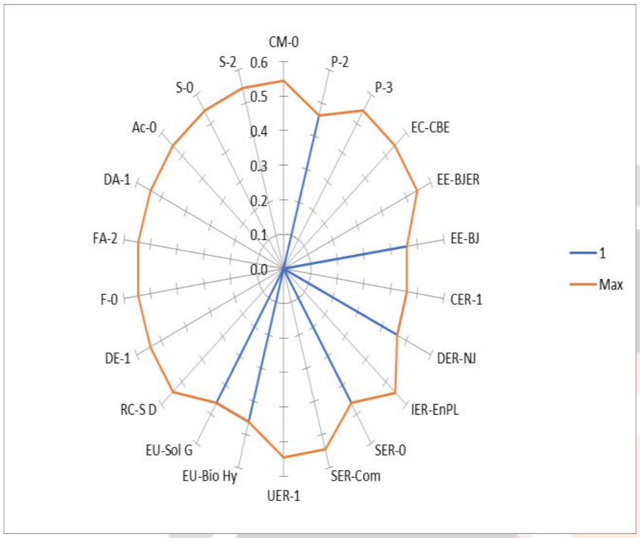

Figure 2: Set of variables describing class 1

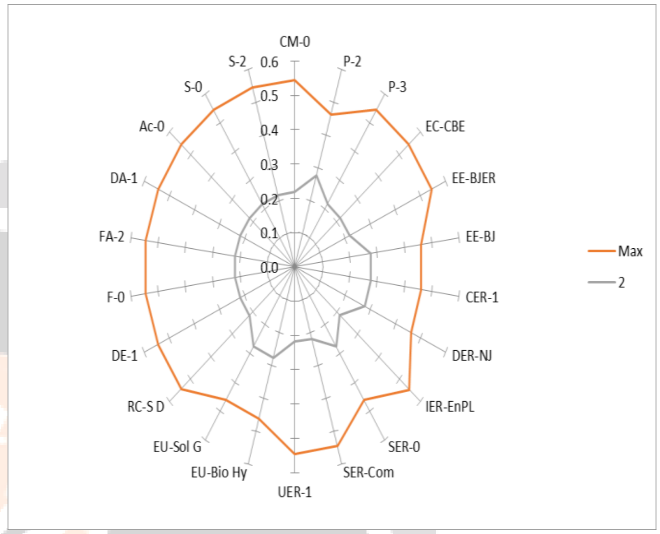

Figure 3: Set of variables describing class 2

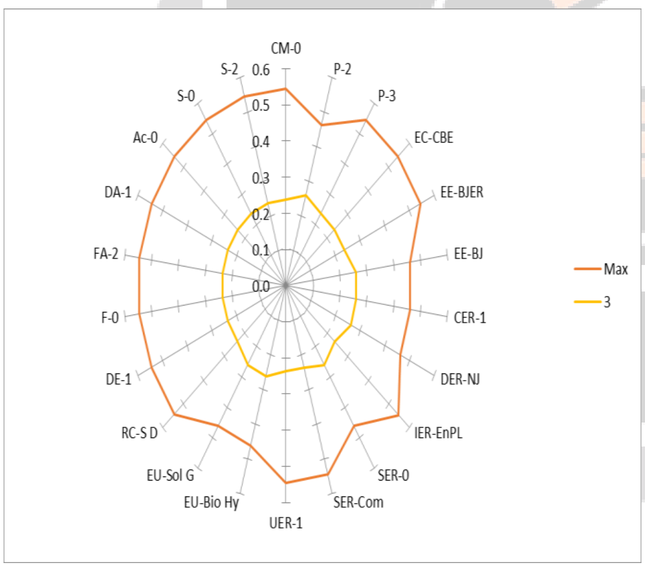

Figure 4: Set of variables describing class 3

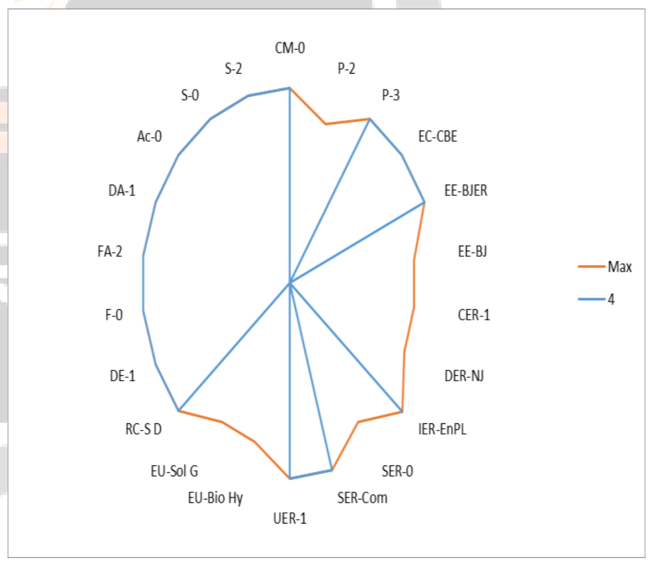

Figure 5: Set of variables describing class 4

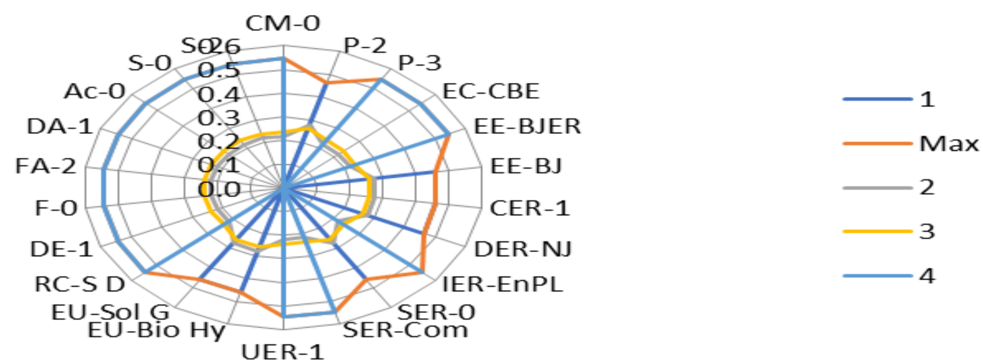

Figure 6: Variables describing the 4 classes

Legends :
EE-BJ : Energy-lighting energy Candle, Jirama ; EC-CBE : Energy-cooking Coal, firewood, Electricityé ; EE-BJER : Energy-lighting Candle, Jirama, Renewable energy ; P-2 : Profession unemployed, entrepreneurs, artisans ; CER-1 : Renewable energy knowledge Yes ; IER-EnPL : Environnemental impact ER ; CM : Marital status ; P-3 : Profession ; EU-SOL G : Energy used Solar Gas ; UER-1 : Renewable energy use Yes ; EU-Bio Hy :Energy used Biomass Hydraulic ; EU-Sol G : Energy used Solar Gas ; Reason of choice Load shedding relief ; DE-1 : Cost of energy expenditure <10,000 Ar; F-0: Fossil no; FA-2: Feeding frequency 2 times/day; DA-1: Dietary diversity yes; Ac-0: Access no; S-0: Insufficient stability; S-2: Acceptable stability.

Class 1 regroups households who are unemployed, entrepreneurs and craftsmen using candle and Jirama for energy-lighting. They define renewable energy as an energy other than Jirama and regularly use the combination of solar-gas or biomass-hydraulic. This class is characterized by single individuals with relatively stable positions in public administration or in the education, commerce, or entrepreneurship sectors. These individuals use charcoal, firewood and electricity as energy for cooking and use candles, Jirama and renewable energies as energy-lighting. They learned from the community that the use of renewable energy limits pollution. These individuals spend less than Ariary 10,000 per month on energy and do not use fossil fuels. They eat a variety of foods 2 times a day and feel that their level of access and stability in food is insufficient.

Class 2 is also composed of individuals who are unemployed, entrepreneurs and craftsmen and their main source of energy-lighting is the combination of candle and Jirama. They do not have any source of information regarding renewable energy but define it as energy other than Jirama. They do not use fossil fuels.

Class 3 regroups mainly individuals working in public administration or as independent using candle, Jirama and renewable energy as energy-lighting. They use charcoal, firewood and electricity for cooking.

Class 4 is mostly composed of unemployed people, entrepreneurs and craftsmen who exclusively use candles and Jirama as energy-lighting. They define renewable energies as energies other than Jirama and use the biomass-hydraulic and solar-gas combination on a daily basis.

The results do not mention any information on the level of food security of individuals belonging to classes 2, 3 and 4. More clarification on the energy mix of households seems to be necessary to predict their evolution and to obtain much more visibility on future actions to be undertaken for better food safety.

3.1.3 Hierarchization of influencing factors

Correlation analysis from the correlation matrix led to sequencing. In the study areas, Energy-Cooking: Charcoal, Firewood and Electricity (EC-CBE); Energy-Lighting: candle, Jirama, renewable energy (EE-BJER); Energy-Lighting: Candle, Jirama (EE-BJ); Renewable Energy Knowledge (CER-1); and the use of Renewable Energies are the most influential factors of the model. The Availability dimension, characterized by food diversification (DA-1) and acceptable meal frequency (FA-2), is the most impacted dimension of food security (Figure 7).

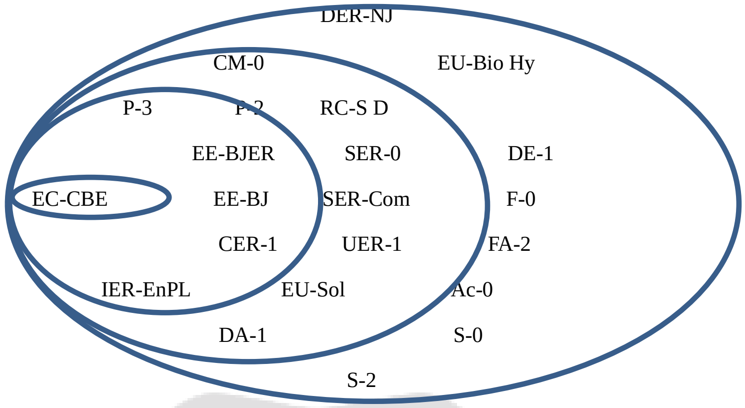

Figure 7: Energy mix sequencing

3.2 Household energy mix

3.2.1 Impacts of the energy transition on food security components

ANCOVA led to a table of adjustment coefficients model showing a specific coefficient of determination R^2 to each food security dimension: 0.652 for Availability, 0.634 for Access, 0.582 for Utilization and 0.584 for Stability (Table 5). This means that 58 to 65% (depending on the dimension considered) of the variability of the dependent variable food security is explained by the 7 explanatory variables of the model (Table 6).

Table 5: Synthesis of Type III Sum-of-Squares Analysis Results

		AVAILABILITY	ACCES	UTILIZATION	STABILITY
R²		**0,652**	**0,634**	**0,582**	**0,584**
F		2,503	2,316	1,856	1,873
Pr > F		0,012	0,019	0,063	0,060
S	F	4.662	3,298	0,825	3,402
	Pr > F	0,040	0,080	0,371	0,076
A	F	0,638	0,490	0,091	0,499
	Pr > F	0,431	0,489	0,764	0,486
CM	F	7,295	11,371	1,111	3,884
	Pr > F	**0,012**	**0,002**	0,301	0,059
T	F	4,761	0,562	1,582	8,775
	Pr > F	0,038	0,460	0,219	**0,006**
P	F	2,753	0,032	1,693	3,176
	Pr > F	0,108	0,858	0,204	0,086
EC	F	0,405	0,839	1,855	1,342
	Pr > F	0,942	0,605	0,091	0,254
EE	F	2,240	2,391	3,854	2,376
	Pr > F	0,078	0,063	**0,009**	0,064

Legends
F : Fisher-Snedecor distribution ; Pr>F : Probability of exceeding F
S : Sex ; A :Age ; CM: Marital status ; T : Size of household ; P : Profession ; EC : Cooking energy ; EE : Lighting energy

Table 6: Analysis of variance results

Dimensions	Source	DDL	Sum of squares	Mean of	F	Pr > F	P-value meaning
Availability	Model	21,000	7,321	0,349	2,504	**0,012**	*
	Error	28,000	3,899	0,139			
	Corrected total	49,000	11,220				
Acces	Model	21,000	12,237	0,583	2,316	**0,019**	*
	Error	28,000	7,043	0,252			
	Corrected total	49,000	19,280				
Utilization	Model	21,000	5,634	0,268	1,857	**0,063**	.
	Error	28,000	4,046	0,144			
	Corrected total	49,000	9,680				
Stability	Model	21,000	8,693	0,414	1,873	**0,060**	.
	Error	28,000	6,187	0,221			
	Corrected total	49,000	14,880				
	Calculated against the model Y=Average(Y)						
	*Meaning codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*						

Legends
DOF: Degree of freedom; F: Fisher-Snedecor distribution; Pr>F: Probability of exceeding F

Given the p-value associated with the F-statistic calculated in the analysis of variance table, and given the 27% significance level chosen, the information provided by the explanatory variables is significantly better compared to that explained by the average of the dependent variables alone. However, this study only considers type III sums of squares which provide significant information to explain all dimensions of the food security dependent variable: Sex, Age, Marital Status, Household Size, Profession and Energy-Cooking, Energy-Lighting.

3.2.2 Strategic rectangle: influence and dominance of factors linked to the types of energy used

To define sustainability strategies for each class, it is essential to determine the variables that have an influence and dominance in the study area. The study on the dominance and influence effects of factors linked to the types of energy used and the socio-demographic characteristics of households led to the strategic rectangle (Table 7).

Table 7: Effects of dominance and influence variables

	Variables	Abbreviations	X=L/P	Y=L*P
Dominant and Influential variables	Energy-lighting - Candle, Jirama	EE-BJ	1.15	2.46
	Energy-cooking - Coal, firewood, electricity	EC-CBE	2.20	2.20
	Energy-lighting - Candle, Jirama Renewable energy	EE-BJER	2.14	2.14
	Profession - unemployed, independent	P-2	1.85	1.85
Influential variables	Knowledge of EnR - Yes	CER-1	1.55	1.55
	Environnemental impact – Polluting energy	IER-EnPL	1.53	1.53
	Marital status- Single	CM-0	1.52	1.52
	Energy used - Solar, gas	EU-Sol G	1.38	1.38
	Profession – Civil servant, independent	P-3	1.36	1.36
	Utilization of EnR - Yes	UER-1	1.28	1.28

Legends
L: sum of absolute values of variables in rows of the correlation matrix
P: sum of absolute values of variables in columns of the correlation matrix
X: quotient of L over P
Y: product of L and P
EE-BJ: Energy-lighting Candle, Jirama; EC-CBE: Energy-cooking Coal, Firewood, Electricity; EE-BJER: Energy-lighting Candle, Jirama, Renewable Energies, P-2: Profession unemployed, entrepreneurs, craftsmen; CER-1: Knowledge of Renewable Energy Yes; IER-EnPL: ER Environmental Impact; CM: Marital Status; P-3: Profession; EU-SOL G: Energy Used Solar Gas; UER-1: Renewable Energy Use Yes

Space 1 in green on the table lists four dominant factors including Energy-Lighting - Candle and Jirama (EE-BJ); Energy-Cooking – Charcoal, Firewood and Electricity (EC-CBE); Energy-Lighting – Candle, Jirama, Renewable Energy (EE-BJER); and Occupation – Unemployed, Self-Employed (P-2). Five most influential factors are ranked in space 2 in yellow on the table, including Knowledge in Renewable Energy (CER-1); Environmental Impact – Polluting Energy (IER-EnPL); Marital status – single (CM-0); the energy used – solar, gas (EU-Sol G); Use of Renewable Energy (UER-1).

Considering the degree of influence, the candle and Jirama lighting energies have an active effect on the system. In addition to these variables, there are variables with high degrees of influence and importance: energy-cooking, coal, firewood and electricity, and renewable energies, which can immediately stimulate the energy system of households in the study area.

3.2.3 Temporal evolution of the energy mix

The projection variables represent the evolution of the energy combinations used by households. Using the Markov chain, **Error! Reference source not found.** provides a global view of these evolutions. The x-axis is represented by the successive ten years of simulation. The relevant variables are indicated on the y-axis.

The simulation is spread over a period of 10 years. It seems that huge changes will take place around the sixth year for all classes both in terms of the level of energy-lighting and energy-cooking use.

The use of Candle and Jirama lighting energy seems to permanently decrease for classes 1 and 3; on the other hand, classes 2 and 4 will gradually increase to reach the maximum at the end of the period. Regarding energy-cooking coal, firewood and electricity, an increase in their use seems to occur for classes 2 and 3 until the 6th year and will decline thereafter to stabilize from the 8th year. However, those for class 4 seems to regularly increase for the whole period.

It is important to note that the number of heads of household who are unemployed or self-employed will decrease throughout the 10 years for Class 2. It appears that 75% of households will see a continued increase in renewable energy use for the next 6 years.

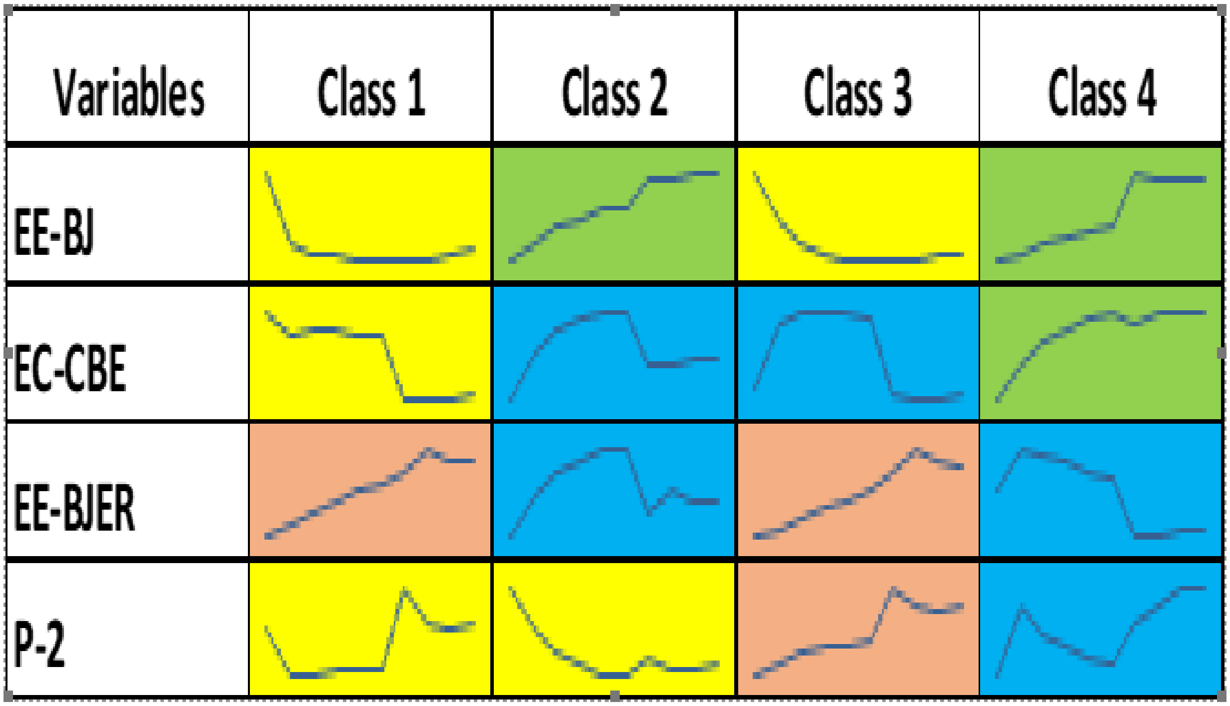

Figure 8: Overview of the evolution of variables by class

Legends

EE-BJ: Energy-lighting Candle, Jirama; EC-CBE: Energy-cooking Coal, Firewood, Electricity; EE-BJER: Energy-lighting Candle, Jirama Energies Renewables; P-2: Profession unemployed, entrepreneurs, craftsmen

4. DISCUSSION

4.1 Mix energetic and renewable energy

The energy sector in Madagascar has a profile typical of the least developed countries. Biomass remains the dominant source of energy, especially wood used for heating and cooking. Households use mainly renewable energy. They vary from one household to another and are essentially composed of a mixture of charcoal, firewood and electricity for cooking and candles, Jirama and solar for lighting (Figure 6). These results coincide with those found by Gatete et *al*., (2016) where regional strategies in Africa advocate the diversification of the energy mix with renewable energy sources such as solar, wind. These renewable energies are seen as alternatives to face the problem of climate change observed in recent years.

Renewable energy for power generation is a group of technologies that is rapidly emerging economically in many countries, after several decades of research and innovation (Rakotoarivelo, 2022). They have several advantages over traditional technologies, particularly in the environmental dimension. In addition, it is important to note that Jirama, the national water and electricity company, is one of the energy sources used by households. This company is facing serious governance, financial and operational difficulties, preventing it from responding to the demands and requirements of users. The increase in the rate of access to electricity now depends on the development of new means of production, in order to meet demand and offer energy at a lower cost (Rojey, 2008). To this end, renewable energies, especially hydroelectric and solar power, are a great opportunity to develop. The development of the electricity sector is the main energy challenge in Madagascar (Georgelin, 2016).

4.2 Impact of the energetic transition on food security

The results of the analysis of variances showed that energy-lighting is one of the significant variables in the study area (Table 3). This finding is confirmed by the results of the process of identifying the relevant variables of the lot, necessary exercises before the prospective analysis. Indeed, according to the information provided in Table 6 and Table 5, all dimensions of the food security variable are impacted by the energy transition. This means that the energy transition and food security are two closely linked areas. In Madagascar, the energy transition is helping to improve food security by increasing the efficiency of food production and reducing production costs. The use of renewable energy sources such as solar energy helps farmers irrigate their crops and increase production. In addition, the energy transition is helping to reduce deforestation, which is a major problem in Madagascar, by providing alternative energy sources for cooking and heating. There are also potential synergies between the energy transition and food security. The use of renewable energy generation technologies helps improve agricultural productivity by providing energy for irrigation, food processing, and the transportation of agricultural products. In addition, renewable energy production also contributes to improved food security by reducing dependence on imported fossil fuels, which reduces food price volatility. However, it is essential to mention that the energy transition can also have negative effects on food security if not managed properly. Energy production from food crops can lead to competition between food production and energy production, which can lead to higher food prices and decreased food production. Hypothesis 1 "Knowledge of the characteristics of the energy used by households contributes to understanding their needs" is validated.

4.3 Factors resulting food insecurity

In general, diets in developing countries are monotonous, non-diversified, poor, and insufficient to provide the energy and micronutrients needed to meet people's daily nutritional needs (Bouis et *al*., 2012). In Madagascar, the food insecurity of the population is above all explained by a problem of economic access linked to the poverty of households and therefore the weakness of their purchasing power. The obsolescence and lack of maintenance of the transport network, as well as weak markets, further complicate households' physical access to food. The level of food insecurity in Malagasy households depends on several factors such as poverty, employment, the number of dependents and the level of education of the head of household (PAM, 2014).

The prospective analysis carried out as part of this study predicts a change in the trajectory of the household energy mix towards the sixth year and a permanent increase in the number of individuals active in the system (**Error! Reference source not found.**). This is the result of many factors affecting the lifestyle of each household. According to the (FAO ONU, 2021) most undernourished people and stunted children live in countries affected by multiple factors. External factors (conflicts and climate shocks) and internal factors (low productivity and inefficient food supply chains) to food systems are driving up the cost of nutritious food across the food system, which, coupled with low incomes, makes healthy diets more financially unattainable. Climate variability and extreme weather events also have multiple cumulative effects on food systems. They not only affect agricultural productivity, but also affect food imports, as countries try to compensate for domestic production losses. Climate-related disasters can have significant impacts on the entire food value chain, also resulting in losses in addition to the food waste typically committed by developed countries.

4.4 Strategies for better food security

Improving the food and nutrition security of the population is based on the one hand, on a better consideration of agriculture in multidimensional strategies related to the fight against malnutrition and, on the other hand, on strengthening the integration of nutritional issues into development projects (Mouton et *al*., 2014). This presupposes the involvement of all actors involved in food chains and the mobilization of all available resources, both material and financial, to ensure the availability of food on time, in quantity and quality. Miller and Welch (Miller and Welch, 2013) reinforce this idea by stating that diet diversification aims to control and prevent micronutrient malnutrition by improving the quality and diversity of diets in order to gradually improve the dietary balance and overall nutritional status of the entire population at all times. But it has also been reported that the economic inaccessibility of healthy diets is due to other factors that affect people's incomes and the cost of nutritious food at all levels of food systems. Poverty and inequality are critical underlying structural factors that amplify the negative effects of key drivers, impacting all levels of food systems and environments, to the point of undermining the affordability of healthy diets and food security and nutrition outcomes. Beyond their direct effects on food systems, key global factors and underlying structural causes undermine food security and nutrition due to their interrelated and circular effects on other systems, including environmental and health systems. Hypothesis 2 is also verified: The prospective analysis of the energy mix in place helps to define the strategies to be implemented for better food security.

5. CONCLUSION

Renewable energies and food security are complex and very important topics that drive the daily lives of people. The purpose of this study is to determine the likely potential links that may exist between these two concepts. The methodological approach adopted is hypothetico-deductive combining bibliographic analysis, socio-demographic study and statistical analyses of the data collected through a survey conducted among fifty households in the Rural Commune of Antehiroka. The two objectives set in terms of assessing the impact of the energy transition and the evolution of the energy mix on food security have been achieved. The first hypothesis, which states that "knowledge of the characteristics of the energy used by households contributes to understanding their needs" is verified. The statistics identified the discriminating variables characterizing the four classes in the study area. These characteristics affect the different combinations of energy used by households, highlighting their relevance to achieving the components of food security. The second hypothesis is also verified. This hypothesis states that "the prospective analysis of the energy mix in place helps to define the strategies to be implemented for better food security". The prospective analysis was used as a tool to predict changes in the energy mix used by households over time. All dimensions of food security are impacted by the energy transition. On the other hand, endogenous and exogenous factors can jeopardize this tendency. Therefore, in all circumstances, it is important to anticipate the risks of food insecurity and to improve the resilience of agricultural systems and households against economic adversity and climate change to ensure the availability of and access to safe, nutritious, and affordable food. A coherent set of policies, investments and laws focused primarily on food productivity is needed to get out of this ambient poverty. And with a view to capitalizing on what has been achieved and the prospects for sustainability, in-depth studies on the structures and modes of operation of the various actors involved in the energy and food sectors deserve to be conducted. The results will help decision-makers in public policy and stimulate research for the country's development.

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