THE RENEWABLE ENERGY MARKET AND THE IMPACTS OF THE ENERGY TRANSITION ON FOOD SECURITY

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ABSTRACT

Energy plays a fundamental role in the economic and social development of humanity. Energy demand is largely covered by fossil fuels which are recognized as being the main sources of greenhouse gases responsible for global warming. This phenomenon threatens the ecosystem and disrupts the well-being and smooth functioning of people's daily lives. The transition to renewable energies represents an alternative to confronting problems related to the environment and climate change. Madagascar is among the victims of this climate change and has initiated steps for energy transition and food self-sufficiency. Accelerating the transition to the use of renewable energy sources as well as increasing the population's access to healthy and nutritious food represent huge challenges that Madagascar aims to achieve. The renewable energy market and the impacts of this energy transition on food security were the subject of this research. Its main objectives are to describe the Malagasy energy mix and to study the impacts of this energy transition on households. The approach adopted is hypothetico-deductive, combining bibliographic studies, surveys of 50 households in the Rural Commune of Antehiroka, and data processing and analysis. The results showed a clear domination of renewable energies in the household energy mix characterized by the heavy use of biomass. Availability is the food security component most impacted by the energy transition. Apart from unfavorable climatic conditions, several other factors can also influence food security such as political instability (social unrest) or economic factors (unemployment, rising food prices). Systematic analysis of these factors is key to constructing scenarios that increase visibility of Madagascar's energy and food trajectories.

Keywords: *Renewable energy, Energy transition, Food security, Madagascar*

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1. INTRODUCTION

It is common knowledge that energy is essential for the proper functioning of the daily life of humanity. All human activities require the use of fossil fuels or renewable energy. Their access is therefore essential to economic and social development for a harmonious life and the well-being of humanity. Today, energy demand is mainly covered using fossil fuels. The latter are recognized as being the main sources of greenhouse gases (GHG). The observed increase in GHG concentrations is the main cause of global warming (IPCC, 2007). Indeed, the most important environmental problem related to energy use is climate change (Dincer and Rosen, 1999), and global energy consumption continues to increase. The International Energy Agency (IEA, 2010) forecasts a growth rate in energy demand of 1.4% per year by 2035.

To prevent the catastrophic consequences of climate change, the atmospheric concentration of carbon dioxide (CO_2) must be stabilized. Thus, the challenge that all countries are called upon to take on consists of transitioning to a more secure energy system that emits less CO_2 without hindering economic and social development (IEA, 2008). The transition to renewable energies immediately constitutes an option for solving problems concerning the environment and climate change.

In undertaking its energy transition, Madagascar faces a double challenge: increasing the population's access to electricity, while ensuring the energy transition and gradual shift towards the use of renewable energy sources. The two challenges complement each other, and the energy transition seems to be underway (Rafitoson, 2017). Indeed, the country has abundant renewable resources, the hydroelectric potential has been estimated at around 7.8 GW, and only 2% of this potential is exploited. Agricultural biomass resources represent a sector that produces a lot of plant waste and almost all regions of Madagascar receive more than 2,800 hours of sunshine per year. The maximum potential is among the highest in the world and the minimum potential is on average 3 to 4 times higher than the potential in Western Europe (EDBM, 2018). Despite these great opportunities that exist to make the sector efficient and sustainable, the situation remains critical. The development of the Malagasy electricity sector is significantly behind schedule and the sector's performance is generally poor (Rakotoarivelo, 2022).

Furthermore, like most countries on the planet, Madagascar also suffers and endures the consequences and harmful effects of climate change. This phenomenon increasingly exposes Madagascar to natural disasters, such as cyclones or drought, thus hindering development efforts. For farmers, these changes most often mean concrete losses in agricultural income. By destroying staple crops like rice, this disastrous climate change is seriously compromising the country's food security. This phenomenon worsens the already precarious situation of the Malagasy people, 90% of whom live below the poverty line (Georgelin, 2016). Food security remains the major problem for households while Madagascar has enormous natural resources including a vast expanse of arable land as well as the means and factors of production necessary for its food sovereignty.

These contradictory realities lead to the formulation of the problematic statement "how are the supply and demand for renewable energies, and the effects of the energy transition on the components of food security." The objectives consist of describing the state of the Malagasy energy mix and studying the impacts of the energy transition at the household level.

2. MATERIAL AND METHODS

A survey was conducted among 50 households from 7 Fokontany[1] in the Rural Commune of Antehiroka[2].

2.1 Renewable energies and real household needs

Two steps are required to verify the hypothesis stating that "renewable energies meet the real needs of households": the renewable energies deployment approach and that for covering household needs.

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

[2] *The geographical coordinates of Antehiroka are approximately $18^{0}51'$ South Latitude and $47^{0}29'$ East Longitude*

2.1.1 Deployment in the household energy mix

A descriptive analysis was carried out to represent renewable energies in the household energy mix and the reasons associated with this choice. The evaluation of the Pearson correlation coefficients was then carried out to measure the presence or absence of a relationship between each energy source used while the calculation of the p-value validates the results obtained from these correlations by highlighting their significance.

The variables used to assess the potential of renewable energies in the study area are either a single source: Biomass (B), Wind (E), Gas (G), Hydraulic (H), Solar (S); or the combination of at least two sources: BE, BG, BH, BS, SG, HG, BSG, BHG, BSHG, BSH, BEG.

2.1.2 Coverage of energy needs and renewable energies

The analysis focused on the use of renewable energies by households. It consisted of using a contingency table where household responses relating to the energies used and the use of renewable or non-renewable energies in their energy mix were cross-referenced.

- The chi² test, through the significance of their p-value, checks whether there is a link between the coverage of energy needs and the use or not of renewable energies by the household. The Fisher test confirms the reliability of these results.

- The proportions by column confirm the dimensions of yes/no responses for each of the energies considered relating to the coverage of household energy needs.

- The two qualitative variables used are: the response methods in terms of energy used (B), (E), (G), (H), (S), and the use or not of renewable energies (Use yes; Use no).

2.2 Development of renewable energies and impacts on food security

The hypothesis suggests that "the development of renewable energies impacts at least one dimension of food security." Measuring a household's living conditions consists of studying its level of food security in terms of availability, accessibility, use and stability. The approach undertaken is therefore focused on studying the impact of the energy transition on these four dimensions. Descriptive statistics were used to have all the details on the variables used.

This analysis required the following steps:

- The non-parametric Kruskal-Wallis test on k independent samples to determine if the samples come from the same population or if at least one sample comes from a population different from the others through its p-value. If the p-value is such that we must reject the hypothesis H_0, then at least one sample is different from another.

- The Levene Test to evaluate the equality of variance for a variable calculated for two or more groups. Some common statistical procedures assume that the variances of the populations from which different samples are taken are equal.

- Dunn's method to identify the sample responsible for the rejection of H_0. Multiple pairwise comparisons enabling the identification of the dimension of food security most impacted by the energy used by households.

- The Bonferroni correction, processed automatically by the XLSAT software, to determine whether the comparisons are carried out on different (k) groups of variables.

The variables used are ordinal qualitative and consist of:

- The physical **Availability** of food (D), the level of food production, the levels of provisions, and net trade. The proposed modalities are frequency and dietary diversity (Insufficient=0; Average=1; Acceptable=2)

- Economic and physical **Access** to food (A) based on income, expenditure, market, and price of food. The modalities considered are food expenses (Insufficient=0; Average=1; Acceptable=2)

- Food **Utilization** (U): adequate intake of energy and nutrients, good biological use of foods consumed. The method chosen is food intake (Insufficient=0; Average=1; Acceptable=2)

- **Stability** of the other 3 dimensions over time (S): a regular basis disrupted by unfavorable climatic conditions (droughts, floods), political instability (social unrest), or economic factors (unemployment, increase in food prices). The modality considered is dietary regularity (Insufficient=0; Average=1; Acceptable=2) (Table 3).

3. RESULTS

3.1 The household energy mix

3.1.1 The deployment of renewable energies

The descriptive statistics of the 50 observations provide a higher average to biomass (38%) as part of the energy mix. The fossil follows closely with 32%. The populations are less homogeneous compared to the solar and hydraulic responses (Figure 1). The reasons associated with these choices show a higher average to the lack of information (30%), followed by load shedding relief and non-priority which are tied (28%) and finally low purchasing power (16%) (Figure **2**).

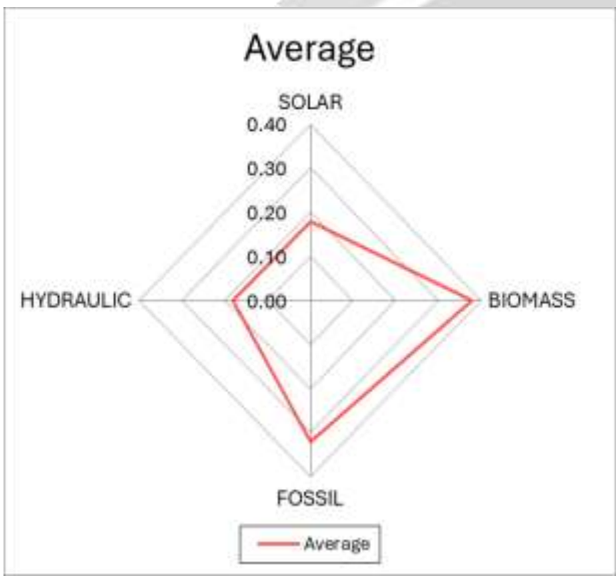

Figure 1: Household energy sources

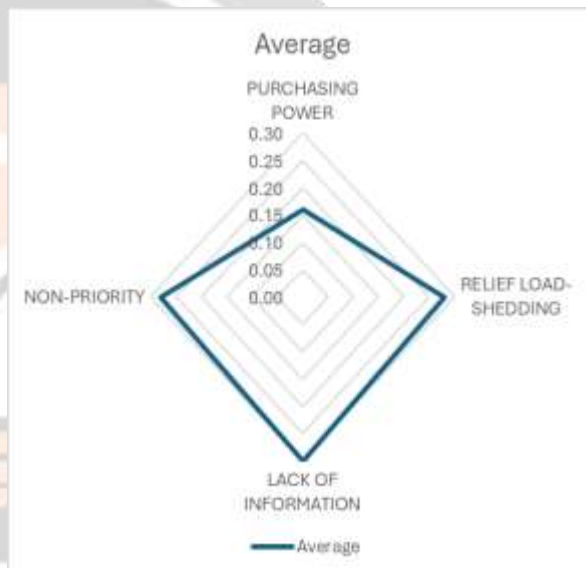

Figure 2: Reasons of the choice

The results of the correlation matrix show that the energy mix consists of biomass, fossil and solar. The reasons are positively correlated with low purchasing power, lack of information and load shedding relief (Table 1).

Table 1: Correlation matrix (Pearson)

VARIABLES	HYDRAULIC	SOLAR	FOSSIL	BIOMASS	LOW PURCHASING POWER	LACK OF INFORMATION	NON-PRIORITY	LOAD SHEDDING RELIEF
HYDRAULIC	**1**	-0.260	-0.210	-0.220	-0.062	0.148	**-0.060**	0.056
SOLAR	-0.260	**1**	**-0.449**	-0.260	-0.004	**-0.333**	0.062	**0.246**
FOSSIL	-0.210	**-0.449**	**1**	**-0.321**	-0.182	**0.206**	0.050	-0.141
BIOMASS	-0.220	-0.260	**-0.321**	**1**	**0.222**	-0.080	-0.060	-0.060
LOW PURCHASING POWER	-0.062	-0.004	-0.182	**0.222**	**1**	**-0.286**	-0.272	-0.272

LACK OF INFORMATION	0.148	**-0.333**	**0.206**	-0.080	**-0.286**	**1**	**-0.408**	**-0.311**
NON-PRIORITY	**-0.060**	0.062	0.050	-0.060	-0.272	**-0.408**	**1**	**-0.389**
LOAD SHEDDING RELIEF	0.056	**0.246**	-0.141	-0.060	-0.272	**-0.311**	**-0.389**	**1**
*Values in **bold** are different from 0 at a significance level alpha=0.05*								

The correlation coefficients vary between -1 and 1; thus,

- The “fossil fuels-lack of information” pair gives a positive correlation (0.206).

- Households use fossil fuels in their energy mix as a simple habit without worrying about the issues and harms of using them (32%).

- Many households continue to integrate biomass into their energy mix to the extent that, in terms of cost, it is considered affordable which perfectly suits their low purchasing power (0.222).

- Solar power is associated with load shedding relief, which also displays a positive correlation (0.246). On the other hand, a negative correlation (-0.060) is recorded between hydraulic and non-priority (Table 1) which shows the reluctance of households to connect to the existing hydraulic network.

Coefficients in bold are significant at the 0.05 significance level ($p < 0.05$). This means that the risk of rejecting the null hypothesis even though it is true is less than 5%. This confirms the previous results. The deployment of renewable energies considers the potential available (Table 2).

Table 2: P-values (Pearson) of the correlation coefficient

VARIABLE	HYDRAULIC	SOLAR	FOSSIL	BIOMASS	LOW PURCHASING POWER	LACK OF INFORMATION	NON-PRIORITY	LOAD SHEDDING RELIEF
HYDRAULIC	**0**	0.069	0.144	0.126	0.666	0.306	0.677	0.701
SOLAR	0.069	**0**	**0.001**	0.069	0.975	**0.018**	0.667	0.085
FOSSIL	0.144	**0.001**	**0**	**0.023**	0.205	0.152	0.732	0.328
BIOMASS	0.126	0.069	**0.023**	**0**	0.122	0.583	0.677	0.677
LOW PURCHASING POWER	0.666	0.975	0.205	0.122	**0**	**0.044**	0.056	0.056
LACK OF INFORMATION	0.306	**0.018**	0.152	0.583	**0.044**	**0**	**0.003**	**0.028**
NON-PRIORITY	0.677	0.667	0.732	0.677	0.056	**0.003**	**0**	**0.005**
LOAD SHEDDING RELIEF	0.701	0.085	0.328	0.677	0.056	**0.028**	**0.005**	**0**

3.1.2 Coverage of energy needs

Households cover their needs mainly using biomass, the biomass-hydraulic combination, and gas. The chi² test whose p-value is < 0.0001 shows that there is a link between the use or not of household energy and the coverage of energy needs. This is confirmed by the Fisher test where the p-value is also < 0.0001 (Table 3).

Table 3: Coverage of energy needs

TEST KHI² : < 0.0001 TEST DE FISHER : < 0.0001				**PROPORTIONS/COLUMN**				
Variables	B	B_H	G	Variables	B	B_H	G	Total
Use_no	<	<	>	Use_no	0.00	0.00	1.00	0.22

Use_yes	>	>	<	Use_yes	**1.00**	**1.00**	0.00	**0.78**
				Total	1	1	1	1

Légende
B : Biomass *B_H : Biomass-Hydraulic* *G : Gas* *Use_no : Utilization no* *Use_yes : Utilization yes*
Highly significant symbols are in red.

Fisher's exact test gives positive and negative significance and only highly significant symbols were considered in this study. The use of biomass and the biomass-hydraulic combination displays strong positive significance, which is not the case for gas. The priority given to the use of biomass and the combination of biomass and hydraulic in covering household energy needs is confirmed by the Proportions/Column table. The results show that those who use renewable energies largely outnumber those who do not (0.78; 0.22), which means that the household energy mix is largely dominated by renewable energies.

3.2 The dimension of food security most impacted by the energy transition

The observations relate to the 50 households in the Rural Commune of Antehiroka. The Levene test displays a p-value equal to 0.001 which shows that at least one of the variances is different from the others. The Kruskal-Wallis test gives a p-value <0.0001 and indicates that the samples come from different populations (Table 4).

Dunn's method classifies the dimensions of food security into two groups A (Stability, Access, and Use) and B (Availability). The availability dimension displays the lowest average of ranks (68,460); it is thus significantly closer to the average of the ranks than the other dimensions. Consequently, it is the most impacted by the energy transition (Table 4).

Table 4: Level of household food insecurity

KRUSKAL-WALLIS TEST: K OBSERVED VALUE: 34,418; K CRITICAL VALUE: 7,815 BILATERAL P-VALUE :<0.0001									
LEVENE'S TEST (AVERAGE/BILATERAL TEST) P=0.001					**MULTIPLE PAIR COMPARISONS ACCORDING TO DUNN'S PROCEDURE (BILATERAL TEST)**				
SAMPLE	LEVEL OF FOOD INSECURITY								
	Min	Max	M	ET	SAMPLE	NUMBER OF HOUSEHOLDS	SR	MR	GROUPS
AVAILABILITY	0.000	1.000	0.660	0.479	STABILITY	50	6,177,000	123,540	A
ACCES	0.000	2.000	1.120	0.627	ACCES	50	5,344,500	106,890	A
UTILIZATION	0.000	2.000	1.080	0.444	UTILIZATION	50	5,155,500	103,110	A
STABILITY	0.000	2.000	1.320	0.551	AVAILABILITY	50	3,423,000	68,460	B

Légende
M : Average ET : Standard deviation SR : Sum of ranks MR : Average of ranks

The Bonferroni correction confirms the previous results. The significant differences in food insecurity (p < 0.0001) are in the availability dimension and the economic and physical access to food. The same is true for the availability dimension and that of food stability (p<0.0001) (Table 5).

Table 5: Results matrix of p-values for false H_0 and margin of error=0.05

	AVAILABILITY	**ACCES**	**UTILIZATION**	**STABILITY**
AVAILABILITY	1	**<0.0001**	**0.000**	**<0.0001**
ACCES	**<0.0001**	1	0.695	0.085

UTILIZATION	**0.000**	0.695	1	0.034
STABILITY	**<0.0001**	0.085	0.034	1
Bonferroni corrected significance level : 0.0083				

4. DISCUSSION

4.1 Energy mix and renewable energies

The gradual transition from carbon-based energies to clean and renewable energies responds to a series of challenges. "Quite a few findings reveal that there is no ideal mix that would be required" (IRENA, 2013). The energy transition is specific to each country, even if the adoption of major global objectives is sought during international climate summits (Avadikyan & Mainguy, 2016).

In Madagascar as in sub-Saharan countries, the energy sector is characterized by the predominance of biomass in final energy consumption (79% of total consumption in 2017) (Ministry of Energy and Hydrocarbons, 2017). It is essentially composed of firewood and charcoal which represent important sources of energy for households. Figure 1 shows the dominance of biomass as an energy source used by households for cooking. Table 3 specifies that households cover their energy needs mainly through the use of biomass and the biomass-hydraulic couple. Louvel & Gromard (2017) confirm that in developing countries, and in Africa particularly, biomass sectors are expanding. In addition, the results in Figures 1 and 2 integrate biomass into energy mix policies; this observation prevails in the majority of African countries which still mainly use traditional biomass to access basic energy (Cantoni & Musso, 2017).

In terms of energy mix, the correlation matrix displays a combination largely dominated by renewable energies. The household energy mix includes biomass, fossil, solar and hydraulic (Table 1). 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 and wind. However, the presence of fossil fuels in the household energy mix, correlated with a lack of information (Table 1), demonstrates the lack of communication and awareness about the dangers and harms of their use. Fossil fuels are part of factors responsible for the production of greenhouse gases, air and water pollution and, above all, the degradation of soil and biodiversity. At the same time, hydraulics negatively correlated with non-priority prove the disinterest of households in connecting electricity because of frequent load shedding and the unsatisfactory service provided by the service provider.

Still, according to Table 3, the energy needs of households are mainly covered by the use of renewable energies. These results confirm hypothesis 1: "Renewable energies meet the real needs of households in the Rural Commune of Antehiroka". Firewood and charcoal satisfy the main energy needs of the greatest number of people. They are available practically everywhere and within the reach of the majority of households. Energy from biomass, widely available in Madagascar, meeting the most essential needs of households, will likely continue to occupy a predominant place in Madagascar's energy mix in the medium term, provided that the sustainability of this resource is ensured, by making its use more efficient or by substituting other energy sources (Georgelin, 2016).

4.2 Impact of the use of renewable energies on food security

Food security is at the center of the concerns of the populations of the target area of the study. It is a complex issue that depends on several factors including food production, distribution, access and consumption. Exogenous factors also influence the achievement of food self-sufficiency, including unfavorable climatic conditions, political instability and natural disasters. Climate variability and extreme weather events cause multiple cumulative effects on food systems. Climate disasters harm agricultural productivity, with significant repercussions across the entire food value chain (FAO, 2016).

The energy transition is one factor among others that can have consequences for food security. According to a study by FAO et al (2022), the energy transition can have positive and negative impacts on food security. Positive impacts include reducing production costs, improving air and water quality, and reducing greenhouse gas emissions. Negative impacts include reduced availability of agricultural land, competition for water resources, reduced availability of food for poor and vulnerable populations, and degradation of soil quality. Furthermore, this study states that the energy transition can be beneficial for food security if well planned and implemented. Renewable energy can help reduce production costs and improve energy efficiency, which can help farmers increase production and reduce post-harvest losses. Renewable energy can also help improve energy access in rural areas, which can help farmers improve their productivity and quality of life. Sutton (2022) adds that the energy transition can help reduce greenhouse gas emissions. Which can help reduce the effects of climate change on agriculture and food security. These findings are consistent with the pairwise comparisons according to Dunn's method (Table 4) which indicate that food availability is most impacted by the energy transition. Hypothesis 2 is thus validated: “The development of renewable energies impacts at least one of the dimensions of food security”.

5. CONCLUSION

The current trend of households reducing the use of fossil fuels in favor of renewable energies is starting to gain momentum. The household energy mix is dominated by biomass, composed mainly of firewood and charcoal. The use of the latter as a final energy source is perfectly suited to the budget of households, the majority of which still have low purchasing power. Wood energy occupies a predominant place in household energy mix. These results confirm Hypothesis 1 “Renewable energies meet the real needs of households in the Rural Commune of Antehiroka”.

However, the gradual shift towards the use of renewable energies can affect the components of food security. It is important to note that the impact of renewable energy on food security depends on many factors, such as the type of renewable energy used, the technology used for energy production, the availability of natural resources and government policies. Climate change also plays a crucial role in this process, endangering the livelihoods and food security of households living in rural areas. Increased climate variability and climate extremes linked to climate change have impacts on all dimensions of food security and nutrition. These findings also validate Hypothesis 2: “The development of renewable energies impacts at least one dimension of food security”.

More in-depth research deserves to be carried out to determine the best energy combination adapted to the local context and to identify the factors blocking the achievement of food security. Systematic analysis of these factors is key to constructing scenarios that increase visibility on Madagascar’s energy and food trajectories.

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