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Household water-energy-food security nexus: Empirical evidence from Hamburg and Melani communities in South Africa

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Abstract

The water-energy-food (WEF) nexus debate has gained traction at various macro scales, with less sway at the micro (household level). Thus, this study sought to investigate the inter-relationships between water, energy and food security at the household level, using the cases of Melani and Hamburg communities in the Eastern Cape Province, South Africa. A cross-sectional survey of 283 randomly selected households was conducted. Structural equation modeling (SEM) was used to analyze the data. The results indicated that most households in both communities were food and energy secure. Regarding water security, the results reveal that both communities were water insecure. Nexus estimate results revealed a positive association between food insecurity and water security, caused by food substitution and possible omission of meals as households try to balance the limited time required for the collection of adequate water from distant sources and cooking meals. A positive nexus between food insecurity and energy poverty was also noted, triggered by low energy and caused by the usage of expensive electric stoves at the expense of cheap additional measures of energy sources. With low energy, households were therefore forced to select food groups that do not require high energy (capable of compromising their dietary diversity) and possibly missed some meals in response to available energy. The study concludes that there are several non-linear synergies and trade-offs in the WEF nexus at household level worth understanding to ensure sustainability in the nexus.

Keywords: Energy security; Food security; Structural equation modeling; Melani; Hamburg; Water-energy-food nexus; Water security

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1. Introduction

The water-energy-food (WEF) nexus is a framework that captures the inter-relations, synergies, and trade-offs between the demand for water, energy, and food, in the context of the emerging constraints of sustainable development in particular regions or systems (Scott et al., 2015). The word “nexus” simply means a bond or form of connection within a group (Mohtar and Lawford, 2016). The World Economic Forum first formulated the nexus approach in 2011 (Leese and Meish, 2015). The aim was to move forward the connected linkages that bind resources and offer straightforward rights for water, energy, and food (Biggs et al., 2015). The World Economic Forum presented the water-energy-food (WEF) nexus framework, based on a security point of view, following the version which took many surfaces with replacement components, which are water resources as a dominant component (Hoff, 2011), water-land-energy (Howells et al., 2013) and food which represented the core component with water-land-energy linkages (Ringler et al., 2013).

Several studies attest that improved water-energy-food security and human well-being can be achieved with a nexus approach (Mabhaudhi et al., 2016; Carter and Gulati 2014; Bizikova et al., 2013; Adnan, 2013; Mohtar and Daher, 2016). The water, energy, and food resources are usually governed in isolation with no communication between the governing institutions, which leads to a lack of integrated planning, management, and efficient allocation of these scarce resources (Mohtar and Daher, 2016). On the other side, sector-based analytical models for decision-making persist, limiting our understanding of the interrelatedness of these essential resources (Adnan, 2013). Siloed approaches tend to be one-sided and favor one resource, usually food security, whereas all three resources should be treated with equal weights as they are all essential for human well-being (Mabhaudhi et al., 2016). Development agencies such as the Food Agricultural Organization (FAO) have developed multi-scale intergrade modeling tools to understand the nexus among water, food, land, and energy (Adnan, 2013). In comparison, Mabhaudhi et al. (2019) used qualitative methods to identify and justify the interactions at the resource management interface. Thus Albrecht et al. (2018) argue that the WEF nexus is valuable for understanding complex systems and decision making to achieve sustainable development. However, a limited number of studies still look at the WEF nexus at the household level. Terrapon-Pfaff et al. (2018) noted that most water-energy-food nexus challenges seem to appear at the household level or community level in rural areas as earlier highlighted by Leck et al. (2015). With that background, the European Commission (2015) suggests that studies should put the future focus on local level challenges to address community problems and achieve resource sustainability.

Recently, Wa’el et al. (2018) stated that, to date, there has been little effort to investigate the implications of the WEF nexus on the household’s food security. Given the interdependence of water, energy, and food at the household level in rural areas, understanding the water, energy and food interlinkages becomes critical for the long-term development and well-being of South African rural communities, particularly at household levels. For the most part, the cost of unintended nexus trade-offs is paid by the most vulnerable rural communities because of their limited means to influence higher decision-making levels and because they frequently lack the capacity to mediate changing nexus dynamics (Terrapon-Pfaff et al., 2018).

Most studies conducted in the Eastern Cape Province have not explored the interlinkages of water, energy and food security in an integrated approach. Empirical evidence only shows the high levels of poverty and food security (Selepe et al., 2015; Musemwa et al., 2015; Rogan and Reynolds, 2018) which has a negative implication for households’ well-being. However, such silo evidence does not highlight the importance of water and energy on food security. The interlinkages of water-energy-food resources and how these resources can be managed efficiently at the household level are under-researched. Moreover, the application of choice-based theories in empirical research can help understand households' decisions when maximizing their water, energy, and food security are limited. On the other side, a comparison of the household size from the two communities within similar regions in South Africa indicates that the average household size in Mzinyathi, KwaZulu Natal is 4.8 (Sinyolo et al., 2014) compared to the four-adult individual in both Melani and Hamburg. While household income is R36,494 in Mzinyathi, most households in the Melani and Hamburg communities earn between R1000 – R1999 (Martins, 2015). Thus, since households in the Melani and Hamburg communities have high household sizes and their income is limited, their ability to meet water, energy, and food security is highly compromised.

Within this context, a more in-depth understanding is needed of how the WEF nexus interlinks at the household level and how the knowledge of the nexus status can be achieved. Not having enough information about the connections between water, energy, and food makes it difficult to achieve sustainable development (Chang et al., 2016). To understand the relationship between the WEF nexus components, great integration of literature is needed (Murphy et al., 2016). The overall objective of this study was to explore the WEF nexus at the household level using cases of the Hamburg and Melani communities in the Eastern Cape Province, South Africa.

2. Literature review

Food security covers several issues which include availability, access, utilization, stability, and nutrition (FAO, 2014; Msaki and Hendriks, 2014; Megbowon and Mushunje, 2018). At a national scale, food security is strictly connected to national market dynamics of production, financial and international forces within the global system, demand, and supply. All in all, at the local level, food security is driven by population growth, availability of land, urbanization, water resources and soil degradation (Carter and Gulati, 2014). Due to factors like population growth, mobility, urbanization, etc., demand for fresh water, clean energy, and food is forecasted to increase in the next decades (Hoff, 2011). These three resources of the water-energy-food nexus are considered very important for human livelihood, poverty reduction and sustainability of households (Biggs et al., 2015; Smajgl et al., 2016). Studies that link water and household food security dominate literature (Butt and Mccarl, 2005; Gulati et al., 2013; Selepe et al., 2015) compared to the energy and food security (Sola et al., 2016; Von Bormann and Gulati, 2016). For the available literature on water and food security, a positive association is supported by most studies (Gulati et al., 2013; Donnenfeled et al., 2018).

These studies argued that food production requires both the quantity and quality of water (Kirby et al., 2003; Abunnour et al., 2016). Thus far, results from previous literature show that with limited water supply, food production will be reduced, leading to food insecure communities (Gulati et al., 2013; Donnenfeld et al., 2018; Wenhold et al., 2007). On the contrary, in semi-urban areas where income is the driver of food security, water security does not influence household food security (Sharafkhani et al., 2011; Zhou et al., 2017). Scholars have stressed that as a result of the decline in farming activities in rural areas, soon water security will not have a significant hold on food security (Simbi and Aliber, 2000; Isaacs et al., 2017). Thus, against this background, more studies are required to look at the influences of water security on food security at household level, more especially in rural areas, given the background that water security and food security both compete for the household income which is a significant factor that affects household food security.

Concerning the connections between energy and food, limited empirical studies are available. The limited available literature generalizes the connection between energy and food (Inglesi-Lotz, 2012; Carter and Gulati, 2014). These studies assume that an increase in energy price also triggers food insecurity (Nigatu et al., 2014; WWF, 2014). Recently, Lenfers et al. (2018) stated that energy security does not influence food security as some energy sources are freely available (e.g., wood). Thus, more studies are required given that most areas in South Africa are now connected to payable electricity which puts a strain on household income.

Most importantly, the water and energy variables do not operate in silos; rather they are connected to food security (Biggs et al., 2015; Pittock et al., 2015; Rasul and Sharma, 2015). On the same point of view, Carter and Gulati (2014) stated that if South Africa continues with the isolation of the water-energy-food nexus resources, a huge risk exists that an increase in the water, energy and food insecurity of the country is bound to occur. These resources can still be maintained at the national level; however, this issue cannot be ignored at the community level (Carter and Gulati, 2014).

Shocking events like food price increases or shortages of water and electricity in several countries have triggered a debate over the interdependence of the three resources (Artioli et al. 2017). More so, the water-energy-food nexus has gained great attention after the food crisis of 2007 and 2008 (Artioli et al., 2017). The study argues that many scholars have studied the WEF nexus resources in silos, compared to those that conducted these studies in relation to the food, energy and water resources in a combined format (Biggs et al., 2015; Prasad et al., 2012).

It has been realized that to sustainably reduce environmental deterioration, policy measures must be planned in conjunction with interconnections of the three resources (Dominic, 2011). At household level, the water, energy, and food sectors should be considered inseparable from household daily activities and needs (Januar, 2018). Of late, debates have emerged with regards to the importance of acknowledging the water-energy-food sectors in a combined approach (Januar, 2018). For instance, at household scale preparing food, for example, requires all three resources of the nexus (Foden et al., 2018).

3. Research methodology

3.1. Conceptual framework: The household water-energy-food nexus approach

The water-energy-food (WEF) nexus is a framework that captures the inter-relations, synergies, and trade-offs between the demand for water, energy, and food, in the context of the emerging constraints of sustainable development in particular regions or systems (Scott et al., 2015). The nexus framework describes how the emerging scarcity of resources is looked at globally (FAO, 2014). The propagation of different conceptualizations in a short time points to a fundamental interest in the nexus approach. Still, a lack of agreement exists on the scope, objectives, understanding of the dimensions, interactions, contextual drivers, and pressures of the water-energy-food nexus resources. For this reason, the WEF nexus approach remains mostly theoretical, with a few exceptions where specific framings have been applied to local case studies (Jalilov et al., 2016; Smajgl et al., 2016; Bromwich, 2015; Marino et al., 2013; Davis, 2014; Foran, 2015; Miller-Robbie et al. 2017). As part of achieving sustainability, the Bonn 2011 nexus conference came up with a conceptual framework to understand the water-energy-food nexus interaction. Therefore, this study sought to understand the intersection of the water-energy-food nexus at the household level, using two rural communities in the Eastern Cape. The following conceptual framework was adopted to help understand the water-energy-food nexus at the household level (Tan et al. 2018; Mirzabaev et al. 2015). Compared to Tan et al. (2018), the following framework is based at the relationship between the three essential resources at the household level. While Guta et al. (2015) focused on energy as the center of the WEF nexus, this study suggests that these resources are equally important for human well-being at the household level. By so doing, the following framework considers that the three resources are equally important and are affected by external and internal factors that may limit their security. Thus, the study modified the conceptual framework at the household level and the socio-economic factors involved in resource management and use.

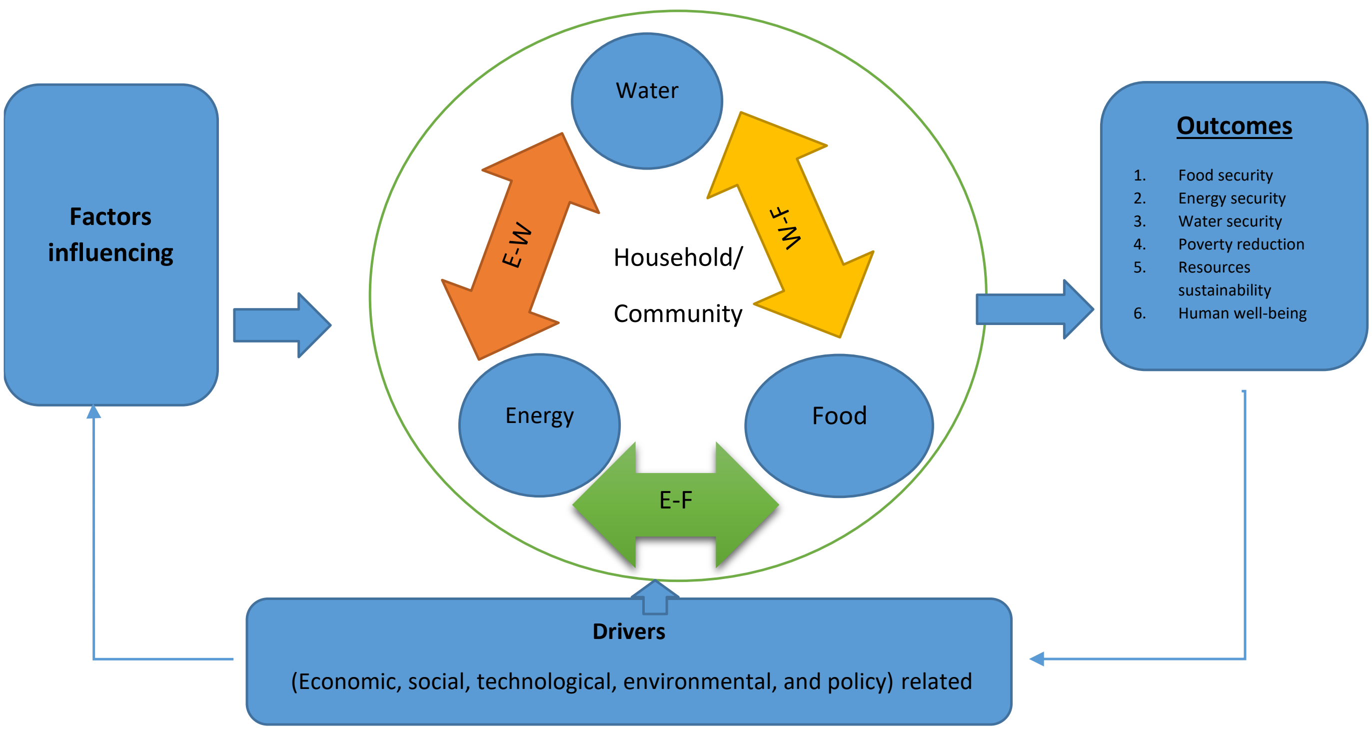

Figure 1. Conceptual framework: Authors' adaptation of the water-energy-food nexus at the household level (Adapted from: Tan et al., 2018; Guta et al., 2015)

3.2. The study area

The study was conducted in the Keiskamma catchment located in the Eastern Cape Province of South Africa. The Keiskamma catchment was selected as the research area because it covers similar coastal and inland regions of the Eastern Cape Province. The study chose two specific study cites in the catchment, namely Melani-inland and Hamburg-coastal communities, as illustrated in Figure 2.

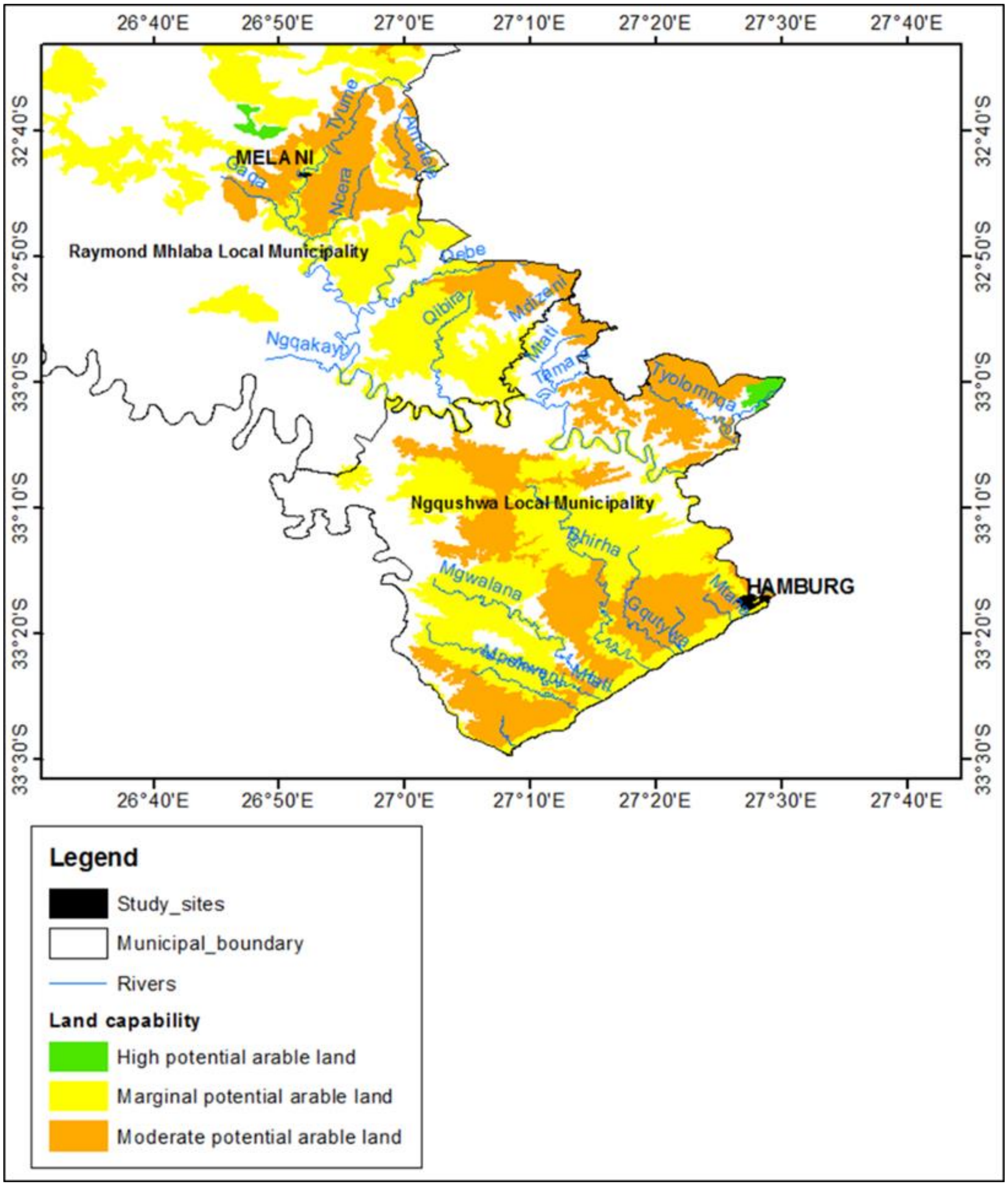

Figure 2: Study area map (Ningi et al., 2020; Ningi, 2020)

These two specific study areas were purposively selected based on the vulnerability of natural resources such as water, energy and food. Hamburg is a small rural area under the Ngqushwa local municipality. Hamburg is located near the Keiskamma Estuary, where the Keiskamma river streams to the Indian Ocean (33° 17′ 26.88″ S, 27° 28′ 30″ E) (Martens, 2015). It is made of communal, private, and state-owned land. The area is connected to the R72 road with a 14km gravel road (Africa, 2012). To consider a different dimension, the study also focused on Melani rural inland community to explore the nexus resource linkages from a different setting to that of the Hamburg-coastal community. Melani is a village located approximately 12 km north of Alice town in the Eastern Cape Province, South Africa. The village is in the Raymond Mhlaba Local Municipality, previously known as Nkonkobe Local Municipality. The village is also situated along the Keiskamma River (32°

43’29” S, 27° 07’35” E). Several scholars have found these communities to be resource insecure (Budaza, 2018; Musemwa et al., 2015). Households around these communities rely on food production for their livelihoods (Martens, 2015). However, natural resources such as water are slowly declining (Africa, 2012), making it hard for food production.

3.3. Sample selection

A cross-sectional research design was used to gather information from 283 randomly selected households in the two study sites. Previous studies have found the catchment to be vulnerable to food resources unavailability in the Eastern Cape Province (Mhangara et al., 2011; Africa, 2012; Ndhleve et al., 2013; DWAF, 2004). The study selected 141 households from Melani and 142 from Hamburg to make up the 283 households (Ningi et al., 2020; Ningi, 2020).

The sample size was derived from the formula below, following Israel, (2013).

$$n = \frac{N}{1+N(e)^2} \quad (1)$$

Where n is the sample size, N is the population size, and e is the level of precision. Thus, applying this formula with the known number of households and a margin of error of 5% is:

$$n = \frac{945}{1+945(0.05)^2} \quad (2)$$

= 283 households

According to Nkonkobe Municipality (2012), Melani community has a population of 500 households, and Hamburg has a total population of 454 households (StatsSA, 2013), which makes a combination of 945 households. Thus, to obtain a 95% confidence with a 5% error level, 283 households would be the lowest accepted number. The unit of analysis is presented in the next section.

3.4. Analytical framework

A set of indices were calculated to get water, energy, and food security at the household level. Firstly, the water poverty index (WPI) was calculated to get households’ water security status in each of the study sites. Secondly, a multidimensional energy poverty index (MEPI) was calculated to formulate households’ energy security status in each of the study sites. Lastly, the household food insecurity access score (HFIAS) was calculated to get the household’s food security status in the two study sites.

3.4.1. Measuring water security

The household water security index is composed of the following variables as illustrated in (Ningi, 2020):

> *“Water availability, Access to safe water, Clean sanitation, and Time taken to collect domestic water”*

The WPI is presented by the following equation: (Sullivan, 2002)

$$WPI = w_a A + w_s S + w_t(100 - T) \quad (3)$$

where A: is the adjusted water availability (AWA) as a percentage. It is calculated based on groundwater and surface water availability related to ecological water requirements and an essential human requirement and all other domestic demands as well as demands from agriculture; S: is household access to safe drinking water and sanitation (%); T: is the index (between 0 and 100) representing the time and effort required to collect water for household use. The final level of the WPI, w_a, w_s and w_t are the weights given to each component of the index so that ($w_a + w_s + w_t = 1$).

Given that A, S, and T are all defined between 0 and 100 and between 1 and 0; to produce a WPI value between 0 and 100, there is need, therefore, to modify the formula as follows:

$$WPI = \frac{1}{3}(w_a A + w_s S + w_t(100 - T)) \quad (4)$$

The linear index was interpreted as follows: if WPI= 100, the household was water secure. Then if WPI= 0, this means the household was water insecure.

3.4.2. Measuring energy security

Secondly, a multidimensional energy poverty index (MEPI) was calculated to formulate households' energy security status in each of the study sites as indicated in (Ningi et al., 2020). The MEPI comprises three broad categories of energy use: lighting, cooking, and additional measures (Sadath and Acharya, 2017). These three categories are given a score of 33.33% each. Thus, depending on whether a particular quality indicates energy secure or energy insecure, each category was assigned a value of 0 or 1, respectively. For instance, lighting, a household not having access to electricity, was coded as 1, while a household with electricity was coded as 0. Under cooking, a household using an electric stove was coded as 0, and a household not having access to the electric stove was coded as 1. Under additional measures, a household using firewood, cow dung, crop residue, and coal for cooking, lighting, and heating purposes were given a value of 0, and households not using these were given a value of 1.

The MEPI was represented by the weight of the individual component multiplied by the assigned value. Then the index is obtained by summing up the values across all components. However, MEPI may be vulnerable to weights assigned to different dimensions. Thus, to test the sensitivity of the proposed index to the weights used, a sensitivity analysis using different weights and the ranking of the dimensions was conducted. Sensitivity was obtained from the rank sum method of assigning weights. The three dimensions of energy poverty, namely cooking, lighting and additional measures were ordered based on the relative importance of the individual measurements. Below is the formula for the weights, which was used.

$$W_{ti} = \frac{K - r_i + 1}{\sum_{j=1}^{K} K - r_i + 1} \quad (5)$$

where, r_i is the rank of i^{th} objective and K is the total number of objectives. The energy poverty dimension ranked first had a weight of 50%, second 33.33%, and third 16.66%. The study used two ordering schemes, with the first being cooking, lighting, and additional measures, and the second was lighting, cooking, and additional measures. If there was more than one indicator in a given dimension, it was equally divided among them. For example, based on the first ordering, cooking has the highest weight of 50%, and it is equally split at 25% between the two sub-dimensions. Lighting has a weight of 33.33%, and additional measures have a weight of 16.66, and these are equally divided among the five sub-dimensions at 3.33% each. The same method was followed in the second ordering. Thus, the linear index is interpreted as the closer the household's poverty index is to 0, the lower the household's energy poverty levels, and the closer the household's poverty index is to 100, the higher the household's energy poverty levels.

3.4.3. Measuring food insecurity

Lastly, a household food insecurity access score (HFIAS) was calculated to determine the food security status of the households in the two study sites. HFIAS is based on the idea that the incident of food insecurity triggers predictable reactions that can be quantified with the survey and summarized on a scale (Coates et al., 2007). The HFIAS was calculated based on the frequency of occurrence of the answers to the household food insecurity access score questions. The study asked the household head or anyone in the household who can answer on behalf of the household head if any of the problems had ever occurred in their household in the previous month. Based on the occurrence of the situation, the household head was asked the frequency of occurrence as follows: rarely, sometimes, or often. The household would then be scaled as follows: 1 (never), 2 (sometimes), and 3 (often). According to Coates et al. (2007), the higher the score, the higher the probability of the household being food insecure. When the response was positive, households were then asked to indicate if the event occurred: rarely (1-2), sometimes (3- 10), or often (more than 10 times) (Coates et al., 2007).

The HFISA was computed as follows:

$$\text{HFIAS Score } (0-27) = Q1a + Q2a + Q3a + Q4a + Q5a + Q6a + Q7a + Q8a + Q9a \quad (6)$$

where, Q is the occurrence question, the expected score range is 0, and the highest is 27. Thus, the higher the score, the higher the possibility is of households being food insecure (Maziya et al., 2017). According to Mango et al. (2014), the HFIAS is the perfect method because it includes all four domains of food security, namely access, anxiety, insufficient quality, and quantity of food supply. The study categorized the HFIAS into four groups as defined below:

a) HFIAS 0-6 food secure
b) HFIAS 7-13 mildly food insecure
c) HFIAS 14-20 moderately food insecure
d) HFIAS 21-27 severely food insecure.

3.4.4. Correlation model

To evaluate the association of water and energy security on households' food security, the study employed a correlation model. Correlation is a bivariate analysis that measures the strength of association between two variables and the relationship (Statistics Solutions, 2019). In terms of the strength of the relationship, the value of the correlation coefficient varies between +1 and -1. A value of ± 1 indicates a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. The sign of the coefficient indicates the relationship; a + sign indicates a positive relationship, and a – sign indicates a negative relationship (StatsS, 2019). In statistics, we measure four types of correlations: Pearson correlation, Kendall rank correlation, Spearman correlation, and the point-biserial correlation (StatsS, 2019). However, the study used the Spearman correlation method to measure the relationship between water, energy and food security.

Spearman rank correlation is a non-parametric test that is used to measure the degree of association between two variables. The Spearman rank correlation test does not carry any assumptions about the distribution of the data. It is the appropriate correlation analysis when the variables are measured on a scale that is at least ordinal (StatsS, 2019). The following formula is used to calculate the Spearman rank correlation:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (7)$$

p = Spearman rank correlation

di = the difference between the ranks of corresponding variables

n = number of observations

3.4.5. Structural equation model (SEM)

A structural equation modeling approach was also used to determine the relationship between water, energy and food security for the households in the study area. Before estimating the structural equations, the data was first used to calculate the WPI, MEPI and the HFIAS to determine the status of water, energy and food security for the respondents in the study areas. After the statuses had been calculated, the SEM was then conducted with the data used for the water, energy and food indices. SEM is useful to analyze the connection between the latent and the variables. The following equation illustrates the SME model (Ngarava et al., 2019):

Structural equation model : $\eta = \eta_\eta + \xi\Gamma + \varsigma$ (8)

The measurement model for : $x : x = \eta\Lambda_x + \delta$ (9)

The measurement model for $y : y = \eta\Lambda_y + \varepsilon$ (10)

where η is an $m \times 1$ random vector of endogenous latent variable; ξ is an $n \times 1$ random vector of exogenous latent variable; B is an $m \times n$ matrix of coefficients of the η variable in the structural model; Γ is an $m \times n$ matrix of coefficients of the ξ variables in the structural model; ς is an $m \times 1$ vector of equation errors (random disturbances) in the structural model; x is a $q \times 1$ vector of predictions or exogenous variables; Λ_x is a $q \times n$ matrix of coefficients of the regression of x on ξ δ is a $q \times 1$ vector of measurement errors in $x; y$ is a $p \times 1$ vector of endogenous variables; Λ_y is a $p \times m$ matrix of coefficients of the regression of y on $\eta;$ ε is a $p \times 1$ vector measurement error in y. The reliability of the SEM was then measured based on the relevant goodness of fit (GFI) as recommended in Jackson et al. (2009). The application includes the ratio of coefficient of determination (CD), the standardized root means square residual (SRMSR), Akaike information criterion

(AIC) and, Bayesian information criterion (BIC). According to Arabnia and Tran (2015), AIC and BIC represent a good fit when the value is lower and SRMSR is lower than 0.08.

4. Results and discussion

4.1. Descriptive statistics

Figure 3 shows that in both communities, females dominated in gender as indicated by 74.6% of females in Hamburg and 66.7% in Melani. Most of the sampled households in Hamburg indicated that their household head had attained secondary education (43%). In comparison, most households in Melani pointed out that their household head had achieved primary education (44.7%). Most households in Hamburg were married (61.3%), while only 45.4% of the sampled households in Melani were married and living in households whose average size is four members. Most of the sampled households in both communities indicated that they mostly depend on social grants as their source of income: Hamburg (76.8%) and Melani (84.4%). In Melani, there was no evidence of depending on agriculture as a source of income while respondents in Hamburg indicated that they use agriculture as a source of income (1.4%). In both communities, the respondents indicated high levels of unemployment as follows: Hamburg (88%) and Melani (90.8%).

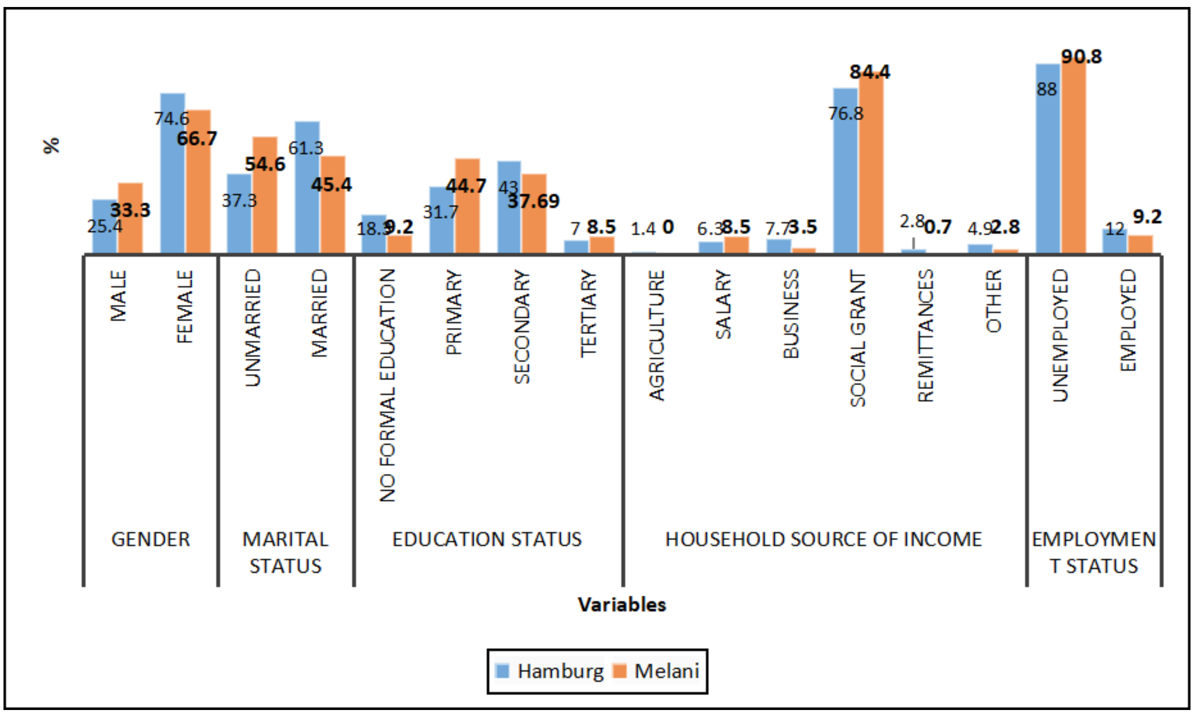

Figure 3. Descriptive statistics of sampled households

Table 1 shows that in both communities, age of household head ranged between 25 to 96 years with the average age of the household head being 59 years. In addition, households' size in Hamburg ranges between one to 13 individuals, while in Melani household size ranged between one and 12 individuals. Both communities had an average of four individuals residing in one household.

Table 1. Descriptive statistics of sampled households

Community	**Hamburg**			**Melani**		
	Min	*Max*	*Mean*	*Min*	*Max*	*Mean*
Age	25	93	59	25	96	59
Household size	1	13	4	1	12	4

4.2. Water security status of households

Figure 4 indicates that households in the Hamburg community are water insecure. This is shown by the low water poverty index (16). For respondents from the Hamburg community, a low water poverty index of 15.7 was revealed, also suggesting water insecurity. Results further reveal that most of the respondents from both communities had access to clean and safe water to drink (Hamburg = 86%: Melani = 74%). Time taken to collect water was moderately low for both communities (Hamburg = 28: Melani = 33). However, water availability was scanter for Hamburg (17) than Melani (24). The results thus imply that high levels of water insecurity in both communities are mainly caused by low water availability and time spent towards water collection.

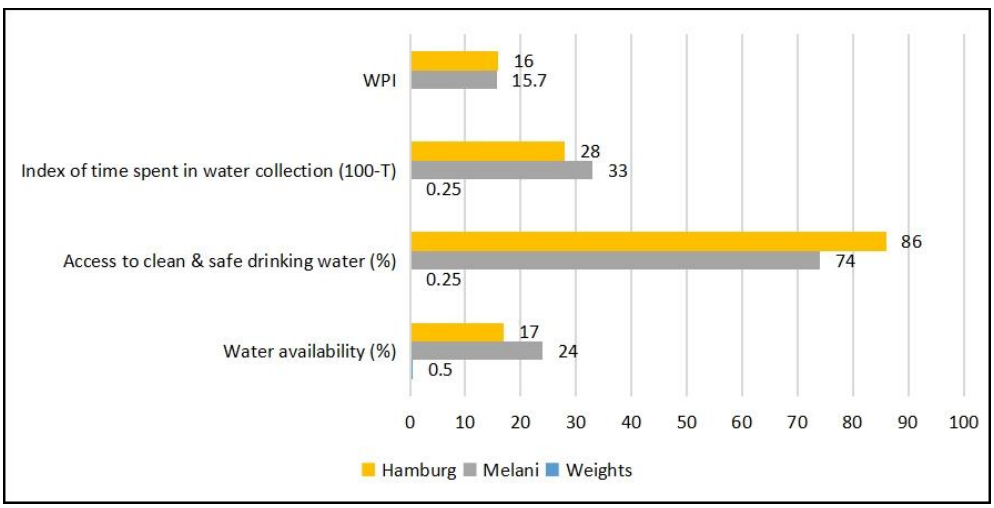

Figure 4. Water poverty index for Melani and Hamburg communities

Both communities have water challenges related to low water availability and the time taken to collect water. However, though water availability and time taken to collect water in both communities are very poor, the limited available water was clean and safe for drinking in both communities (Hamburg: 86% and Melani: 74%), as illustrated in Figure 4. Thus, the water challenges in the two communities are technical and institutional. Assefa et al. (2018) attested that the lack of water infrastructure, institutional capacity, and unreliable power supply are the major causes of household water insecurity in rural areas. Cho and Ogwang

(2010) also asserted that resources like declining water availability per capita, access to bottlenecks, capacity, and use of water are some of the major issues contributing to water insecurity in rural communities.

4.3. Energy security status of households

The results of the energy security status are presented in Figure 5. The findings indicate that in Hamburg, households were generally energy secure. This is revealed by the low MEPI (0.17) and low energy deprivation index (0.25). Furthermore, the high level of energy security is indicated by the large number of households connected to electricity in Hamburg (95.1%). From the total sampled households, 72.5% had access to an electric stove for cooking, with 31.2% having access to additional measures of energy (e.g., wood, paraffin, gas, etc.).

In Melani, households were also energy secure. This is revealed by the low MEPI (0.16) and low energy deprivation index (0.21). Moreover, the high level of energy security is based on the high number of households connected to electricity (98.6%). From the total sampled households, 89.4% had access to an electric stove for cooking, with 40.1% having access to additional measures of energy (e.g., wood, paraffin, gas, etc.). In general, the findings suggest a very high-energy security status for respondents from the two communities, though access to additional measures of energy was very low for both communities. This could be explained by limited access to additional measures which could also suggest that natural resources in these communities are slowly declining (Africa, 2012).

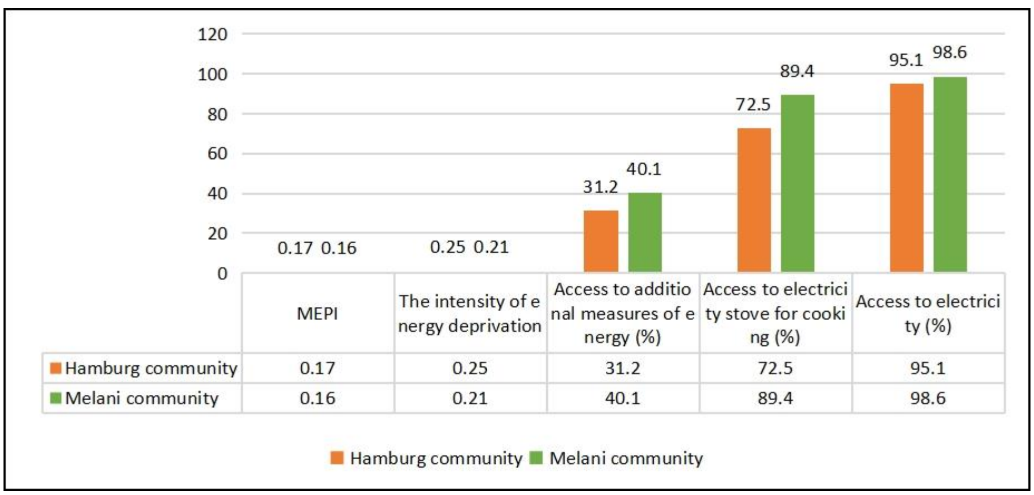

Figure 5. Multidimensional energy poverty index estimates for Melani and Hamburg

4.4. Food security status of households

Table 4 presents the results of the HFIAS formulated in the study area. The results suggest that 39.7% of respondents from the Melani community were food secure, 33.3% mildly food insecure, 21.3% moderately food insecure, and 5.7% severely food insecure. In the Hamburg community, the results indicated that 34.5% of the respondents were food secure, 43.7% mildly food insecure, 18.3% moderately food insecure, and 3.5%

severely food insecure. In general, both communities are food secure, with few people being severely food insecure.

Table 4. Household Food Insecurity Access Scale

Household Food Insecurity Access Scale		
Food security status	**Melani Community**	**Hamburg Community**
	%	%
Food secure	39,7	34,5
Mildly food insecure	33,3	43
Moderately food insecure	21,3	19
Severely food insecure	5,7	3,5

4.5. Water, energy and food security relation

4.5.1. Association of water and energy security on household's food insecurity

Table 5 presents the results of the bivariate correlation analysis. The results reveal a statistically significant (p-value = 0.023) weak positive correlation (coefficient = 0,135) between household water security (WPI) and HFIAS. These results suggest that as household water security increases, there is a weak increase in the household's food insecurity access score.

Table 5. Correlation matrix between water, energy, and food insecurity

			HFIAS	**WPI**	**MEPI**
Spearman's rho	**HFIAS**	Correlation coefficient	1.000	135**	.315**
		Sig. (2-tailed)	.	.023	.000
		N	283	283	283
	WPI	Correlation coefficient	.135*	1.000	.077
		Sig. (2-tailed)	.023	.	.198
		N	283	283	283
	MEPI	Correlation coefficient	.315**	.077	1.000
		Sig. (2-tailed)	.000	.198	.
		N	283	283	283

***. Correlation is significant at the 0.05 level (2-tailed).*

****. Correlation is significant at the 0.01 level (2-tailed)*

Table 5 shows a statistically significant (p-value = 0.000) weak positive correlation (coefficient = 0,315) between household energy poverty (MEPI) and household food insecurity access score. These results suggest that as a household's energy poverty increases this may be associated with a weak increase in the household's food insecurity access score. Given that correlation does not imply causation but rather a systematic relationship prone to several types of bias (wrong way and spurious causation), in the next section a complementary analysis of the confirmed systematic association is given.

4.6. Interlinkages between water, energy and food security

Table 6 and Figure 6 present the results of the structural equation model analysis. The acceptable level of confidence was set at 95% for the parameter estimates. The overall fit of the model was as follows: CD = 1.000, AIC = 4273.535, BIC = 4390.189. The SRMR was above the suggested threshold = 0.110.

Table 6. The relationship between water, energy, and food

Path	Estimate	SE	P-Value
Drinking water < == WPI	1.000	-	--
Water resource availability < ==WPI	0.048	0.085	0.573
Time spent to collect water < == WPI	0.388	0.216	0.072
Food secure < == HFIAS	1.000	--	--
Moderately food insecure < == HFIAS	-1.598	0.054	0.000
Mildly food insecure < == HFIAS	-0.367	0.048	0.000
Severely food insecure < == HFIAS	-0.055	0.026	0.037
Cooking < == MEPI	0.928	0.348	0.008
Lighting < == MEPI	1.000	---	---
Additional measures < == MEPI	-0.531	0.231	0.022
WPI < == HFIAS	0.072	0.037	0.052
WPI < == MEPI	0.015	0.028	0.588
MEPI < == HFIAS	0.029	0.010	0.004

The results suggest that there is a positive relationship between water security and food insecurity in the two communities. The results also indicate a positive relationship between energy poverty and food insecurity. The next section discusses the estimated associations.

4.6.1. Drivers of water poverty index

Time taken to collect water in the communities had the highest loading on water insecurity. The loading factors among latent variables were found to be statistically significant at 10%. The results indicate that time taken to collect water had a positive impact on the household's water security (parameter estimate equal to 0.388). The results are in line with Tussupova (2016), who demonstrated that time taken to collect water (as the latent) had a significant influence on the water security status of households in rural communities. Furthermore, rural households tend to use public water sources and walk long distances and spend much time collecting water to increase their water security status (Tussupova, 2016).

4.6.2. Water-food security nexus

Figure 6 and Table 6 present the trade-offs and synergies between water security and food insecurity. The results indicate that the relationship between water and food insecurity combined has the following synergy effect: For every 1% increase in time taken to collect water, water security increases by 0.39%. Similar results were observed in Lewis (2016) who claimed that households spend most of their time collecting water to improve their water security due to water unreliability in rural areas. As a result, households who invest their time collecting water are most likely to be water-secure (Tussupova, 2016). Unfortunately, the results further reveal that for every 1% increase in water security, food insecurity increases by 0.07%. These findings reinforce the earlier detected positive correlation. The observed trade-off suggests that, as households try to address water security by allocating more time towards the collection of water, this may compromise time for the actual preparation of their food to eat. To accommodate time lost, households may select food groups and food choices that do not require a lot of time to prepare, and thus negatively affecting food quality and sometimes increasing the frequency of uptake per day or omitting meals.

4.6.3. Drivers of energy security

For energy security, using an electric stove for cooking and accessing additional energy measures had the highest loading on energy security (MEPI). The loading factors among latent variables were statistically significant at 5% for cooking with an electric stove. The results indicate that using an electric stove for cooking positively affects the household's MEPI (parameter estimate equal to 0.928). In addition, households with additional measures of energy sources were statistically significant at 5 %. The results indicate that having access to additional energy measures (such as wood, gas, paraffin, etc.) negatively affects the household’s MEPI (parameter estimate equal to 0.531). The results are in-line with Uhunamure et al. (2017), who claimed that households in rural areas tend to depend on additional measures such as wood to improve their energy security mainly because it is freely available. An electric stove (purchase, use and maintenance costs) puts financial pressure on households’ budgets, negatively affecting budget allocations for purchased energy sources (electricity) and thus leading to energy insecurity.

4.6.4. Energy-food security nexus

Figure 6 and Table 6 present the trade-offs and synergies between energy security and food insecurity. The results indicate that the relationship between energy security and food insecurity combined has the following trade-off effects: For every 1% increase in the usage of an electric stove to cook, the MEPI increases by 0.93%, while a 1% increase in additional measures of energy sources, the MEPI decreases by 0.53%. Results also reveal that, for every 1% increase in the MEPI, food insecurity increases by 0.03%. These findings reinforce the earlier detected positive correlation between energy poverty and household food insecurity. The observed trade-offs suggest that, as households' energy poverty increases (MEPI), which is triggered by using electric stoves, their food insecurity (HFIAS) also increases. Electric stoves place financial pressure on rural households' budgets (purchase, usage and maintenance costs). In response, these households are forced to reduce budgets for purchased electricity and other household necessities that require cash (food groups and types). Reduction in purchased electricity increases their energy poverty (MEPI), forcing rural households to consider selective cooking targeting food groups and food choices that require less energy (capable of compromising food quality). In some cases, these households may also skip meals in an effort to save energy which further affects their food security. Having access to additional energy measures (such as wood, gas, paraffin, etc.) reduces the energy poverty (MEPI) of rural households. This may reduce pressure on rural households' budgets which enables them to purchase adequate electricity to cook food groups and types of their choice, purchase adequate food and avoid missing meals.

Figure 6. The interrelationship between water, energy, and food security in Melani and Hamburg communities

5. Conclusion

Water, energy and food at the household level play a crucial role in the livelihoods of rural people. Therefore, addressing one resource at the expense of the other will not lead to sustainable resource management. The three resources need to be considered simultaneously at all levels to achieve resource sustainability. Against this background, this paper concludes that water security is one of the major issues from the study areas due to the long distances traveled by households to collect water. While most of the respondents were energy secure, low access to additional measures of energy sources could negatively affect their energy security given the potential of additional measures of energy sources to reduce energy poverty (MEPI). Reliance on electric stoves also increases energy poverty as meager rural households' budgets are shared among several competing necessities. Thus far, the paper concludes that trying to address water security in the context of the study area (investing more time in collecting water from distant sources) promotes household food insecurity (HFIAS) through loss of time for food preparation, which may trigger the selection of unwanted food groups and types and omission of meals in response to time constraints. Also, energy poverty triggered using electric stoves promotes food insecurity through selective cooking, targeting food groups and food choices that require less energy (capable of compromising food quality). Lastly, improving energy security through access to additional energy measures (such as wood, gas, paraffin, etc.) may have an income and food substitution effect capable of reducing food insecurity, through relaxed pressure on household budgets.

5.1. Policy insights

Based on the results, the observed water-energy-food security nexus suggests that in a society trying to address water security by investing more time in the collection of water from distant sources may promote household food insecurity, because the two (time for water collection and time for food preparation) compete for the household's limited time. To balance the limited time, food selection and possible omission of meals are some of the trade-off's households will be faced with. Thus far, addressing water security in such communities without addressing water sources that are near residents of households may fail to address the expected water-food security improvement. Improving water sources near residents of households may be a policy option for these communities with positive household water and food security net effects. A relapse in energy security, on the other hand, may trigger household food insecurity through compromised food selection choices and change in cooking habits to accommodate low energy levels. Efforts to address energy-food security improvements in such low-income communities should therefore focus on other additional energy sources that are not expensive to avoid the income substitution effect. Thus far, the water-energy-food security nexus at the household level is not obvious and direct, but rather complicated, depending on several socio-economic and location-based geopolitical factors worth understanding.

5.2. Areas of future research

Several area-specific studies are required to understand different dynamics across geo-political areas with regards to the water-energy-food security nexus at household level. And also, on how the connection of the water-energy-food nexus might influence households' livelihoods.

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