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# Multi-dimensional energy poverty patterns around industrial crop projects in Ghana: Enhancing the energy poverty alleviation potential of rural development strategies

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ABSTRACT

Several countries across sub-Saharan Africa have promoted industrial crops to boost rural development, including rural energy poverty alleviation. However, little evidence exists about the intersection of rural development and energy poverty in industrial crop settings. We undertake a household survey to explore multidimensional energy poverty patterns around three operational industrial crop projects in Ghana (oil palm, jatropha, sugarcane). We conduct 850 surveys with households with different involvement in these projects (e.g. plantation workers, smallholders), as well as household not involved (i.e. control groups). Overall, distinct patterns emerge between sites and groups, reflecting the different area, project and household characteristics. Jatropha and oil palm plantation workers register lower energy poverty levels than their respective control groups, while oil palm and sugarcane smallholders register either the same (or higher) energy poverty. This is largely because income from engagement in industrial crop activities can reduce energy poverty for some groups, but only where modern energy options are readily available. In reality, other factors can be equally important, including other livelihood activities (e.g. sugarcane/palm oil processing) and the gender of household head. Such distinct patterns and local dynamics must be understood when aiming to achieve positive energy poverty alleviation outcomes through industrial crop expansion.

## 1. Introduction

Extreme poverty, lack of access to modern energy, and excessive reliance to (and use of) biomass for household needs such as cooking are tightly linked across sub-Saharan Africa (SSA) (International Energy Agency, 2014, 2018). Several scholars have perceived the lack of access to modern energy such as electricity and liquefied petroleum gas (LPG), as both a driver and a consequence of poverty (Kimemia et al., 2014; Nussbaumer et al., 2012; Obeng et al., 2008; Olang et al., 2018; Sovacool, 2012). In fact the expected outcomes of energy policies and poverty alleviation strategies are often strongly intertwined across many SSA contexts (International Energy Agency, 2014). At the same time the international development community has recognized that ensuring access to modern energy and energy security are major global sustainability challenges through the adoption of the Sustainable Development Goal 7 (SDG7) (Mccollum et al., 2017). Most countries in SSA are far from realizing sustainable energy for all, with little progress towards meeting SDG7, especially in rural agrarian contexts (World Bank, 2015). However, it should be pointed that there is a lot of heterogeneity in progress across countries, with for example significant progress in rural electrification in Ghana (from 15% in 1990 to 67% in 2017) (IEA, IRENA, UNSD, WB, 2019).

Many scholars and international agencies have pointed to the high incidence of energy poverty across SSA, and the toll it takes on sustainable development (Nussbaumer et al., 2012; Olang et al., 2018; World Bank, 2015). Energy poverty manifests at the household level when households are not able to realize their capabilities due to insufficient access to affordable, reliable and safe energy services (Sadath and Acharya, 2017; Day et al., 2016; González-Eguino, 2015; Nussbaumer et al., 2012) (see Section 2.4). It is estimated that over half a billion

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people in SSA are energy poor (International Energy Agency, 2014), largely due to poor economic productivity and socioeconomic development (Adaramola et al., 2017). Households in SSA, and particularly West Africa, could be trapped in a vicious cycle of energy poverty and income poverty unless necessary steps are taken to address some of the chronic challenges of the energy sector (International Energy Agency, 2014). These include, among others, the low levels of modern energy supply, poor distribution networks, financial/infrastructure constraints, and political barriers (Adaramola et al., 2017; Bazilian et al., 2014; Mensah et al., 2014).

Energy poverty is increasingly conceptualised as a multidimensional phenomenon (Nussbaumer et al., 2012; Pelz et al., 2018). Tools such as the multidimensional energy poverty index (MEPI) are now used to assess energy poverty at the national and the regional scale (Sadath and Acharya, 2017; Nussbaumer et al., 2012; Pelz et al., 2018). Such studies often use readily available secondary data from national statistics to understand population-wide energy poverty patterns (Edoumiekumo et al., 2010; Mbewe, 2018; Nussbaumer et al., 2012; Zedini and Belhadj, 2015). Some scholars have employed multi-dimensional energy poverty metrics to understand the effects of different interventions or household energy choices (e.g. Olang et al., 2018). It has been suggested that such metrics can be used to track progress toward the SDGs, especially in poor rural areas (Pelz et al., 2018).

The improvement of households' economic status such as, for example, increases in income/consumption and engagement in stable employment, could influence the switch from traditional fuels (e.g. fuelwood, charcoal) to modern energy sources (e.g. electricity, LPG) (Baptista, 2017; Hiemstra-Van Der Horst and Hovorka, 2008; Rahut et al., 2017; Van Der Kroon et al., 2013). This transition can manifest in the total replacement or partial complementation of traditional fuels with modern energy choices (Anver et al., 2017; Khandker et al., 2012; Mudombi et al., 2018a; Van Der Kroon et al., 2013). In this respect, socioeconomic transitions can be a major driver of energy poverty alleviation, with different interventions that target broader socioeconomic development possibly having ripple positive effects on energy poverty alleviation (Acharya and Sadath, 2019).

Industrial crop production has been one of the major avenues for boosting socioeconomic development and employment generation in poor agrarian settings of SSA (Acheampong and Campion, 2014; Balat et al., 2009; Gasparatos et al., 2015; German et al., 2011; Hill, 2012; Schoneveld et al., 2011b). For the purpose of this study, industrial crops refer to crops not used for food (e.g. cotton, tobacco) or crops that have non-food uses but are also integral components of the food industry without being staple crops (e.g. oil palm, sugarcane) (Wiggins et al., 2015). Several studies have argued that the involvement of local communities in industrial crop value chains as smallholder producers or plantation workers can provide new sources of income and employment opportunities, thus improving and diversifying rural livelihoods (Ahmed et al., 2019a; Mudombi et al., 2018b; Van Eijck et al., 2014; von Maltitz et al., 2014). Furthermore, industrial crops have been perceived as a development option that can diversify and modernise agrarian economies that face increasing pressures, including from climate change (Belloumi, 2014; Thurlow et al., 2016). When it comes to energy poverty, it has been hypothesised that the positive livelihood outcomes of engagement in industrial crop production, combined with the wider community development effects of ancillary infrastructure (e.g. improved market access through roads, rural electrification), can catalyse the adoption of modern energy options (Ehrensperger et al., 2015). However, while some anecdotal evidence exists (Leite et al., 2016; Mudombi et al., 2018b), few studies have attempted to explore empirically and systematically such phenomena in SSA.

Ghana is one of the few countries in SSA that have "aggressively" attempted to both reduce energy poverty (Energy Commission, 2006) and promote industrial crops as a means of rural development and poverty alleviation (Ahmed et al., 2017). Major milestones in the efforts to decrease energy poverty, include the Strategic National Energy Plan (SNEP) of 2006, the Renewable Energy Act of 2010, the solar energy initiative of 2017 and a series of rural electrification projects since the 1980s (Energy Commission, 2010, 2006; Gyamfi et al., 2015; Sakah et al., 2017). Many studies have explored the institutional barriers (Arthur et al., 2011; Gyamfi et al., 2015; Mohammed et al., 2013; Sakah et al., 2017) and the health/poverty outcomes of energy transitions and household energy choices in the context of these policies (Asumadu-Sarkodie and Owusu, 2017; Mensah and Adu, 2015; Sackeyfio, 2018). However, even though multi-dimensional energy poverty has been declining in the country following such initiatives, its incidence and intensity remains especially high in rural contexts and some social groups (Crentsil et al., 2019).

At the same time there has been a rather coordinated effort during the past decades to promote industrial crop production in Ghana as a means of boosting rural development (Ahmed et al., 2017). Some crops such as cocoa and oil palm have been traditional pillars of the national economy (Ministry of Food and Agriculture, 2011; Osei-Amponsah et al., 2014). More recently bioenergy crops such as jatropha were widely promoted between 2005 and 2011, but largely failed (Ahmed et al., 2019b; 2017; Schoneveld, 2014). Currently there is a recent surge in the interest for sugarcane production with some key policies being enacted (Ministry of Trade and Industry, 2016). The promotion of such industrial crops has been seen as an avenue to modernise and diversify Interestingly some of the most heavily promoted industrial crops (and especially jatropha) were essentially promoted through the same energy policies seeking to reduce energy poverty, albeit in a rather uncoordinated manner (Ahmed et al., 2019b). There has been an extensive literature of how involvement in industrial crop value chains in Ghana as plantation workers or smallholders can affect household income (Acheampong and Campion, 2014; Ahmed et al., 2019a), poverty (Ahmed et al., 2019a; Schoneveld et al., 2011a) and food security (e.g. Dam Lam et al., 2017). However, there is a total lack of literature on how involvement in such value chains might influence household energy choices and rural energy poverty, as well as the mechanisms through which this might happen.

The aim of this study is to investigate the interface of rural development and rural energy poverty in Ghana. In particular, we seek to explore whether rural development strategies based on industrial crop production could have ripple rural energy poverty alleviation benefits in the areas of industrial crop production. In this respect we do not explore the energy poverty alleviation outcomes of actual energy policies (see Section 2.1), but the possible energy poverty alleviation co-benefits of rural development interventions based on industrial crop production. This type of information is critical for countries such as Ghana that seek to reduce the consistently high rates of rural energy poverty (a major energy policy objective, Section 2.1), but at the same diversify and boost agrarian economies (Ahmed et al., 2017).

To achieve this, we assess the multidimensional energy poverty characteristics (Nussbaumer et al., 2012) of different groups involved in industrial crop production (e.g. planation workers, smallholders) and groups not involved (i.e. control groups). We focus on three operational projects that have undertaken sugarcane, jatropha and oil palm production through different modes of production (i.e. large-scale, smallholder-based) in different parts of Ghana. This analysis moves further from previous studies in the specific sites and other industrial crop contexts that have focused on objective and subjective wellbeing (Ahmed et al., 2019a), by discussing how engagement in industrial crop value chains might intersect with energy poverty. Furthermore it adds more nuanced information to the recent surge of national-level multi-dimensional poverty studies in Ghana (Adusah-Poku and Takeuchi, 2019; Crentsil et al., 2019) and other parts of the world (Anver et al., 2017). In this sense, it is a response to the call for establishing stronger empirical evidence about energy poverty baselines and alleviation progress to track progress toward SDG7 (Pelz et al., 2018).

Section 2 outlines the methodology, including the rural energy policy context (Section 2.1), study sites (Section 2.2), and the data collection and analysis methods (Section 2.3-2.4). Section 3 reports the main patterns of multi-dimensional poverty in the study sites. Section 4 synthesizes patterns between sites (Section 4.1) and identifies some of the key policy implications, caveats, and methodological reflections (Section 4.2).

## 2. Methodology

### 2.1. Rural energy policy context in Ghana

Ghana has been undergoing a rapid energy transition in the past decades (Crentsil et al., 2019). Final energy consumption has increased by 81% between 2005 and 2015, largely through the growing electricity consumption (62% increase between 2005 and 2015) (Ministry of Energy, 2019). This sharp increase in electricity consumption was propelled by the long-term government effort of achieving 100% electrification by 2020 (Energy Commission, 2016; Ministry of Energy, 2019). A key element of this effort has been to increase the share of renewable energy sources, boosting installed capacity from 42 to 1353.6 MW by 2030 (Ministry of Energy, 2019; Obeng-Darko, 2019).

This transition has been catalyzed by different policy initiatives including the National Electrification Scheme (1989), National Renewable Energy Strategy (2003), Strategic National Energy Plan (2006), National Energy Policy (2010), Energy Sector Strategy and Development Plan (2010), Bioenergy Policy (2010), Renewable Energy Act (2011 Act 832), Sustainable Energy for All Action Plan (2012), and Mini-grid Electrification Policy (2016) (Kemausuor et al., 2011; Obeng-Darko, 2019). The Ministry of Energy has been the main government agency responsible for energy policy formulation, coordination, and implementation. However, different government agencies are mandated to manage specific aspects of the energy sector. For example, power generation and distribution are managed by the Volta River Authority (VRA), Independent Power Producers (IPP), Ghana Grid Company Limited (GRIDCo), Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo).

However, despite this impressive progress the fact remains that most of the energy access benefits in Ghana have materialized in urban contexts. Indeed, there is a stark different in energy poverty levels between urban and rural areas (Adusah-Poku and Takeuchi, 2019; Crentsil et al., 2019). This is linked to many interrelated factors such as the disjointed rural electrification policies (see below), the high reliance of the household sector on traditional biomass fuels such as fuelwood and charcoal (Adusah-Poku and Takeuchi, 2019), and the lack of infrastructure that curtails accessibility to modern energy sources (Asante et al., 2018).

Indeed rural energy provision has been one of the major perennial energy policy challenges facing the Ghanaian government. The first-ever effort toward rural energy development started with the National Electrification Scheme (NES) in 1989, which promoted rural electrification for poverty reduction (Gyamfi et al., 2018; Sakah et al., 2017). During that time, electricity was made accessible through grid extension (mainly from hydro) even though many rural households relied on traditional biomass for cooking and lighting (Obeng-Darko, 2019). Due to the low success of this endeavor the government later realized that grid extension alone could not achieve the ambitious targets without promoting grid integration of other renewables and off-grid energy infrastructure (Boamah and Rothfuβ, 2018). In 1992, policies promoted decentralised rural electrification through biogas but the programme faced major challenges relating to sustainable feedstock supply to digesters (Obeng-Darko, 2019). These included, among others, the transportation, socio-cultural factors relating to the use of digested faecal material for household agricultural activities, and low revenue from the plants (Obeng-Darko, 2019).

At the same time the reliance of rural households on traditional biomass energy has been particularly high, constitutes one of the most controversial and contradictory aspects of the energy policies outlined above. On the one hand successive governments have expressed their intention of reducing household dependency on traditional biomass energy to curb negative environmental and health impacts (Obeng--Darko, 2019). On the other hand, however, the National Energy Policy (2010) seeks to sustain woody biomass production as a way of reducing rural poverty (Energy Commission, 2010). This is because a large fraction of the rural population either depends on income from fuelwood and charcoal production regardless of wealth (Brobbey et al., 2019b) or cannot easily afford or access other energy options (Asante et al., 2018).

Actually, biomass energy development in rural areas was not an immediate government priority in the rural energy policies outlined above, as it was not considered a renewable energy source (Obeng--Darko, 2019). Drawing from the previous lessons, the Ghana Renewable Energy Master Plan was developed in 2019 re-affirms the aim of providing decentralised renewable energy-based options for rural communities in the country, with biomass energy playing a prominent role (Ministry of Energy, 2019). This mainly focuses on the promotion of improved cookstoves (adoption of 3 million units by 2030) and sustainable fuel production (development of 428,000 ha of woodlots to produce 1 Mt of briquettes/pellets) (Ministry of Energy, 2019). This reorientation in sustainable feedstock production makes agricultural residues a valuable aspect of rural energy development.

It is in this context of high rural energy poverty and switching energy policy priorities that it is important to understand the interface between industrial crop production and energy poverty. On the one hand engagement in industrial crop projects can provide income (Ahmed et al., 2019a; Mudombi et al., 2018b) that can be invested in improved energy services. At the same time industrial crop projects (especially large plantations) can become broader drivers of development improving rural infrastructure or offering directly energy services.

### 2.2. Study sites

We identify patterns of multi-dimensional energy poverty at the household level around three sites of industrial crop production: a smallholder sugarcane production site (Dabala), a large jatropha plantation (Yeji), and a large oil palm plantation surrounded by smallholders (Kwae) (Table 1, Fig. 1). We capture the multi-dimensional energy profiles of households involved in different capacities in industrial crop production (Section 2.2).

The three study sites represent (a) different industrial crops that are commonly used as biofuel feedstock (i.e. sugarcane, jatropha, oil palm), (b) modes of production (i.e. large plantations, smallholder-based production, hybrid systems) (c) locations in diverse agro-ecological zones (i.e. savanna, semi-deciduous forest, rain forest), with different pre-existing deprivations in access to modern energy and poverty incidence rates. Such multi-site and multi-crop approaches has been identified as particularly useful to understand the household-level socioeconomic outcomes of industrial crop production in SSA (Ahmed et al., 2019a; Gasparatos et al., 2018a; Mudombi et al., 2018b).

The sugarcane site is located in Dabala (South Tongu district) within the semi-deciduous forest ecological zone of Ghana (Fig. 1). Sugarcane is produced exclusively from smallholders, which they sell subsequently to local ethanol producers. Approximately 1,415 households, from the estimated 3,236 households in the wider area derive their main livelihoods from sugarcane production (Ghana Statistical Service, 2014a). The district has a poverty incidence rate of 25.4% in terms of the fraction of households earning less than GH'1,314.0 (US$ 240) per adult equivalent per annum, making it one of the average performing districts in Ghana (Ghana Statistical Service, 2015). The local community is connected to the national electricity grid, but electricity access varies among households (see Section 3.1). Traditional biomass plays a major role for household use (Ghana Statistical Service, 2014a).

The jatropha site is located in Yeji (Pru district) in the savanna zone of Ghana. The site contains a large plantation owned and operated by Smart Oil Ghana for the production of biofuel feedstock, which is then

**Table 1**
Key characteristics of the three study sites.

| | Dabala (sugarcane) | Yeji (jatropha) | Kwae (oil palm) |
|---|---|---|---|
| GPS coordinates | 5°59′7.76″N 0°40′29.76″E | 8°13′34.46″N 0°39′12.93″W | 6°14′40.82″N 0°58′12.43″W |
| District | South Tongu | Pru | Kwaebibirem |
| Industrial crop company | – | Smart Oil | GOPDC |
| Year of industrial crop production | Not certain | 2006 | 1975 |
| Land ownership | Individual family farms | Corporate plantation | Corporate plantation surrounded by individual family farms |
| Mode of industrial crop production | Smallholders | Plantation | Hybrid (Core GOPDC plantation is surrounded by outgrowers and independent growers) |
| Agro-ecological zone | Semi-deciduous forest | Savanna | Rainforest |
| Agricultural water use | Rainfed, with irrigation during the dry season | Rainfed | Rainfed |
| Land acquired (ha) | 4,124 | 6,750 | 14,000 |
| Area cultivated (ha) | 2,450 | 720 | 8,200 |
| Annual rainfall (mm) | 900-1,400 | 1,088–1,197 | 1,400–1,800 |
| Poverty rates (%) | 25.4 | 43.1 | 16.6 |
| Number of poor persons in district | 21,957 | 54,818 | 18,457 |

Source: Compiled based on (Ghana Statistical Service, 2015a; McPherson et al., 2016)

exported to Burkina Faso and Italy. Smart Oil has a land concession of 6,750 ha, developed after the consolidation of land from communities in Kadue, Agentriwa and Kwaese. There is no smallholder-based jatropha production in the area, but Smart Oil employs dozens of local community members from Kadue, Kobre, Kwaese, Agentriwa, and Kojo Boffour. The Pru district has a poverty incidence rate of 43.1%, which is one of the poorest in Ghana (Ghana Statistical Service, 2015), with only some of the study communities connected to the national grid.

The oil palm site is located in Kwae in the rainforest zone. The site contains a large oil palm plantation with a processing mill operated by the Ghana Oil Palm Development Corporation (GOPDC). Hundreds of out-growers directly supported by GOPDC and other independent smallholders operate in the area. GOPDC has a renewable energy generation capacity of 2.5 MW for its oil palm estate. The poverty incidence rate is 16.6%, one of the lower in the country (Ghana Statistical Service, 2015).

Ahmed et al. (2019a) assessed the characteristics, and the objective and subjective wellbeing of households with different involvement in industrial crop value chains in the three sites, as summarised below. In Dabala (sugarcane) and Kwae (oil palm), most of the surveyed households are male-headed, while in Yeji (jatropha) most permanent and seasonal plantation workers households are female-headed (Tables 2 and 3). There is a consistent pattern of low formal education attainment for most groups across all study sites (Table 2), with the main exception being the GOPDC oil palm plantation workers in Kwae (Table 2). This is because basic education attainment is a requirement for some job categories such as mill workers.

In terms of household size, all groups in Yeji (i.e. savanna zone) have the largest household sizes, followed by Dabala and Kwae (Table 2). Similarly, study groups in Yeji have more children, followed by households in Dabala and Kwae. The GOPDC plantation workers have the smallest household sizes. consisting of only one or two adults, as 60% of these households have migrated to Kwae from other parts of the country. In Dabala and Yeji, there are no significant differences for mean household size between the study groups (Table 3).

GOPDC plantation workers in Kwae report the lowest levels of total land ownership and cultivated land, as most are migrants and do not have land titles in the area (see above). On the contrary, oil palm outgrowers and independent smallholders in Kwae report significantly larger land sizes and cultivated land areas (Tables 2 and 3), compared to both the GOPDC plantation workers and the control group. Household in Dabala have no significant difference in terms of total land ownership and cultivated area (Tables 2 and 3). In Yeji, the permanent and seasonal jatropha workers cultivate on average less land and have more uncultivated land compared to the control groups (Tables 2 and 3). This can be partly due to their limited financial capacity and lower household labour availability to cultivate land, as they invest significant labour to work for the company (especially full time workers) (Ahmed et al., 2019a). Interestingly, seasonal workers have both the lowest land ownership and income levels (see below), which suggests that only the poorest and least endowed households in the community are inclined to engage in season plantation employment (Ahmed et al., 2019a).

Oil palm outgrowers and independent growers in Kwae have significantly higher mean income than the control group and GOPDC workers (Tables 2 and 3). Furthermore, the control group also has a mean household income of almost 40% higher than plantation workers. However, this income disparity is much lower in terms of income per household member, considering that GOPDC workers have smaller household sizes. Sugarcane smallholders in Dabala have a significantly higher mean income (both in absolute and per capita terms) and total expenditure compared to their respective control group (Tables 2 and 3), while the control group in Yeji has both higher mean income and expenditure compared to permanent and seasonal jatropha workers (Tables 2 and 3). The above suggest that in each site involvement in industrial crop production as smallholders or outgrowers is associated with higher mean income, compared to the respective control groups (see also Ahmed et al., 2019a). On the contrary, involvement in plantation employment (i.e. workers) is associated with lower (or at best the same) mean income compared to the respective control groups (Ahmed et al., 2019a).

Finally, in Kwae GOPDC workers spend the most on energy services followed by independent smallholders, with mean differences being statistically significant between all group pairs (Tables 2 and 3). Permanent and seasonal jatropha plantation workers also spend on average more on energy than their respective control group, with the differences, however, not being statistically significant (Tables 2 and 3). On the contrary control groups in Dabala spend significantly more on energy than sugarcane producers (Tables 2 and 3).

### 2.3. Data collection

Based on an extensive literature review by Karanja and Gasparatos (2019) we identified that energy choices in SSA depend on different factors including the type of livelihoods (e.g. Owen et al., 2013), income (e.g. Mengistu et al., 2015), education (e.g. Kituyi and Kirubi, 2003), gender (e.g. Foote et al., 2013), household composition (e.g. Fuso Nerini et al., 2017), and existence of energy infrastructure (e.g. grid, fuel markets) (Mudombi et al., 2018a). On the other hand, multi-dimensional energy poverty depends on the availability of different fuel options and asset ownership (see Section 2.4).

We capture these variables through a household survey to groups with different involvement in industrial crop production such as plantation workers, smallholders/outgrowers. For comparative purposes we also surveyed community members residing within the study site areas whose primary source of livelihood is farming but are not involved in industrial crop value chains (control groups). The sampling and survey approach followed the main methodological steps proposed by

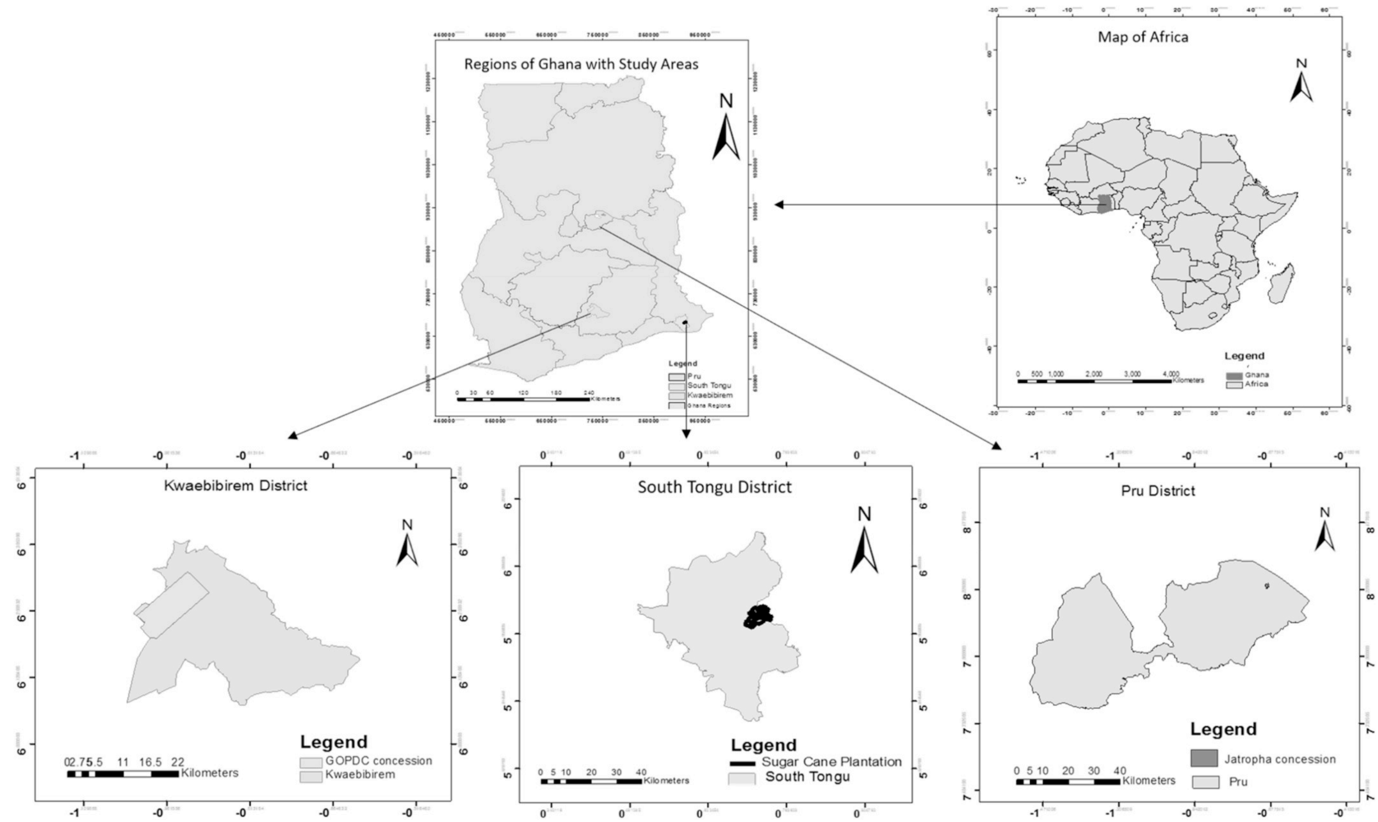


**Fig. 1.** Location of the three study sites.

Gasparatos et al. (2018a), and is explained in more detail below and Table 4.

In Dabala, we divided the community into four zones based on the major roads within the community. In each of the four zones, we selected 25–27 households of sugarcane growers and control groups through transect walks (see Table 4).

In Kwae we followed a sampling protocol to ensure representativeness within each group (Table 4). GOPDC plantation workers were randomly sampled from assembly points either after finishing or before starting their shifts (Table 2). There were unique assembly points for workers coming from each of the four local communities around the plantation (i.e. Kwae, Anwean, Asuom, Otumi). In total we distributed 105 questionnaires to plantation workers, targeting between 25 and 27 workers from each of the four major communities. Subsequently we selected an approximately equal number of outgrowers, independent smallholders and control groups in these communities through snowball sampling (Table 4). Mapping of the sampled households shows that in each community, workers, outgrowers, independent smallholders and control households intersect. They are relatively equally distributed within the respective communities and not segregated.

In Yeji we followed a more targeted sampling approach. As Yeji is a major city, plantation workers come both from urban and rural areas, so they tend to have different livelihood sources. We avoided sampling respondents from both urban and rural areas as this could make it very difficult to achieve a proper comparison with the other sites that are predominately rural. For this reason, we surveyed only workers and control groups from the rural communities of Kadue, Kobre, Agentriwa and Kojo Boffour. Workers from these areas were selected randomly at the warehouse and company office as they come to record their names after the end of their daily shifts. Based on the origin of these workers we selected control groups in each community through snowball sampling (Table 4).

To avoid sampling household with dual involvement in industrial crop production (e.g. households that grow industrial crops but at the same time their members are employed at a plantation), we asked direct questions at the beginning of the interview. After ensuring that there is no dual involvement we progressed with the main questionnaire. If dual involvement was found, then the enumerators were trained to skip this household and move to the next one. In all study sites, questionnaires with serious data omissions were eliminated.

The household survey consisted of open-ended and close-ended questions on basic household characteristics, livelihoods, agricultural activities, and energy procurement and use, among others (see also Ahmed et al., 2019a). Data was collected during three fieldwork campaigns: Dabala (February–March 2016), Kwae (December 2016–January 2017), Yeji (August–September 2017). Household surveys were analysed following the procedures outlined in Section 2.4, using SPSS version 25.

### 2.4. Data analysis

The main analysis presented in this paper revolves around the estimation of the energy poverty of groups with different involvement in industrial crop production. The underlying assumption is that groups with different involvements have different household characteristics and experience different socioeconomic outcomes (e.g. income, access to services), which collectively affect energy poverty. We use the MEPI as a proxy for energy poverty (Nussbaumer et al., 2012), which have been inspired by other multidimensional poverty measures (Alkire and Foster, 2011), which were in turn inspired by Amartya Sen's capability approach (Sen, 1999; Sadath and Acharya, 2017).

The methodology measures the incidence and intensity of poverty across five dimensions of energy deprivation, namely cooking, lighting, household appliances, entertainment/education appliances, and telecommunication (Table 5). The methodology is calculated in two steps. The first step focuses on the identification of deprived households based

**Table 2**
Study areas, targeted groups, and sample sizes.

| Study site (Feedstock) | Group | Code | Sampling strategy | Communities | Sample per Community | Final sample |
|---|---|---|---|---|---|---|
| Kwae (Oil Palm) | Plantation permanent workers for GOPDC | Worker | Workers congregate at assembly points from each community in work groups such as mill workers, harvesters, security, nursery workers and plantation workers. From each worker group, we randomly selected five respondents from each community as they disembark from the buses. | Kwae | 25 | 100 |
| | | | | Anwean | 25 | |
| | | | | Asuom | 25 | |
| | | | | Otumi | 25 | |
| | Oil palm outgrowers for GOPDC | Outrgower | We divided each community into 4 zones, using the main roads. The first out-grower was identified randomly through a transect walk from the edge of the community towards the centre. Subsequently we identified the next outgower for the next out-grower every 3–4 houses. About 5–6 respondents were selected in each zone following this approach. A similar approach was used to identify independent smallholders and control groups. | Kwae | 25 | 100 |
| | | | | Anwean | 25 | |
| | | | | Asuom | 25 | |
| | | | | Otumi | 25 | |
| | Oil palm independent smallholders | Independent Grower | | Kwae | 25 | 100 |
| | | | | Anwean | 25 | |
| | | | | Asuom | 25 | |
| | | | | Otumi | 25 | |
| | Food crop farmers within oil palm area (control) | Control | | Kwae | 25 | 100 |
| | | | | Anwean | 25 | |
| | | | | Asuom | 25 | |
| | | | | Otumi | 25 | |
| Dabala (Sugarcane) | Sugarcane smallholders | Smallholder | The first sugarcane-growing household in each zone was identified randomly through a transect walk starting at the edge of the community. Subsequently we selected 25–27 sugarcane smallholder households in each zone through a transect walk towards the centre of the community. To allow for randomization we selected respondents every 3–4 households following this transect. A similar approach was used to identify control group respondents. | Dabala | 100 | 100 |
| | Food crop farmers within sugarcane area (control group) | Control | | Dabala | 100 | 100 |
| Yeji (Jatropha) | Permanent plantation workers for Smart Oil | Permanent Worker | We randomly selected permanent and seasonal workers from the identified communities at the company warehouse and main office as they come randomly to the warehouse and company office to record their daily presence at work. We excluded workers from Yeji main city to avoid a sample that would include a combination of respondents from urban and rural areas. | Kadue | 25 | 100 |
| | | | | Kobre | 25 | |
| | | | | Agentriwa | 25 | |
| | | | | Kojo Boffour | 25 | |
| | Seasonal plantation workers for Smart Oil | Seasonal Worker | | Kadue | 14 | 50 |
| | | | | Kobre | 12 | |
| | | | | Agentriwa | 12 | |
| | | | | Kojo Boffour | 12 | |
| | Food crop farmers within jatropha area (control group) | Control | Snowballing was used to select the control group. The first non-worker was randomly selected through a transect walk starting at the edge of the community. We then asked each subsequent respondent for the nearest non-worker neighbour. | Kadue | 20 | 100 |
| | | | | Kobre | 30 | |
| | | | | Agentriwa | 20 | |
| | | | | Kojo Boffour | 30 | |
| **Total** | | | | | **850** | **850** |

Source: Ahmed et al. (2019a)

**Table 3**
Multi-dimensional energy poverty dimensions, variables, cut-offs and relative weights (in parenthesis).

| Dimension | Indicator (weight) | Variable | Deprivation cut-off (Poor if …. ) |
|---|---|---|---|
| Cooking | Modern cooking fuel (0.2) | Type of cooking fuel | use any fuel beside electricity, LPG, kerosene, natural gas, or biogas |
| | Indoor pollution (0.2) | Food cooked on stove or open fire (no hood/ chimney) if using any fuel beside electricity, LPG, natural gas, or biogas | true |
| Lighting | Electricity access (0.2) | Has access to electricity | false |
| Services provided by means of household appliances | Household appliance ownership (0.13) | Has a fridge | false |
| Entertainment/ Education | Entertainment/ education appliance ownership (0.13) | Has a radio OR television | false |
| Communication | Telecommunication Means (0.13) | Has a phone landline OR a mobile phone | false |

Source: adopted from (Nussbaumer et al., 2012)

on the individual cut-off points as shown in Table 5. The second step focused on the aggregation the energy deprivations of different households across the five domains outlined above. A group is considered energy poor if the total combined deprivation score is higher than defined thresholds as outlined in Table 5 (Nussbaumer et al., 2012).

More formally, the MEPI assumes that energy poverty for a population with $n$ households $(i = 1, \ldots, n)$ and $d$ dimensions of deprivation (attributes) of energy poverty $(j = 1, \ldots, d)$ can be expressed in an achievement matrix as $Y = [y_{ij}]$ representing the $n \times d$ for $i$ household across $j$ variables (Nussbaumer et al., 2012). The methodology allow for uneven variation in the weighting of indicators. A weighting vector $w$ is composed based on elements of $w_j$ which corresponds with the weight applied to variable $j$ (Nussbaumer et al., 2012) and the summations is expressed as follows:

$$\sum_{j=0}^{d} w_{j=1} \tag{1}$$

where:

$d$ = Total deprivation count in $j$ variables
$w$ = Weight
$j$ = Deprivation variables

With the weights, a household is deprived if the total weights across any of the indicators are zero. The summation of all the weights across the five dimensions gives a total deprivation for a particular household. To compute MEPI, it involves calculation of poverty incidence and intensity. The poverty head-count (H) is expressed as follows:

$$H = q/n \tag{2}$$

where:

$q$ = The number of people identified as poor
$n$ = The total number of people in the sample.

The intensity is expressed as:

$$A = \sum_{i=1}^{n} \frac{C_i(k)}{q} \tag{3}$$

where:

$q$ = The number of people identified as poor
$n$ = The total number of people in the sample
$C_i$ = The sum of weighted deprivation
$k$ = deprivation cut-off

The MEPI is an expression of both incidence and intensity of energy poverty (Alkire et al., 2015a; Alkire and Santos, 2011, 2014) as follows.

$$MEPI = H \times A \tag{4}$$

where:

H = The incidence of poverty representing the proportion of households that are energy poor
A = The intensity of deprivation.

$C_i(k)$ is a deprivation score or the average deprivation score obtained as an additive function of the weighted indicators. To understand the relationship between energy poverty and other demographic variables of households, we categorised the censored deprivation $C_i(k)$ of the energy poor into three levels acute ($C_i(k) > 0.7$), moderate ($C_i(k)$ $0.3 \leq 0.7$), and low ($C_i(k) < 0.3$).

For MEPI, it is important to assess if the difference between groups is statistically significant. We used the standard errors in the construction of the hypothesis test (Alkire and Santos, 2011) and this assists in obtaining the statistic of interest (Alkire et al., 2015b; Biewen, 2002). Bootstrap resampling was used for statistical inference on poverty between groups (Biewen, 2002).

As the MEPI methodology allows for variation in weights (Nussbaumer et al., 2012), we performed restricted dominance analysis by varying the weights of the indicators as shown in Table 6. The new MEPI rankings are compared with the original MEPI by doing a Spearman rank correlation (Alkire et al., 2015b; Mudombi et al., 2018b).

**Table 4**
Alternative scenarios and variations in the weight of multi-dimensional energy poverty indicators.

| Variable | Original Scenario | Alternative Scenario 1 | Alternative Scenario 2 | Alternative Scenario 3 |
|---|---|---|---|---|
| Modern cooking fuels | 0.2 | 0.16 | 0.3 | 0.25 |
| Indoor air pollution | 0.2 | 0.16 | 0.3 | 0.25 |
| Has electricity | 0.2 | 0.16 | 0.1 | 0.2 |
| Owns a Fridge | 0.13 | 0.16 | 0.1 | 0.1 |
| Owns a Radio/TV | 0.13 | 0.16 | 0.1 | 0.1 |
| Owns a mobile phone | 0.13 | 0.16 | 0.1 | 0.1 |
| Weight distribution | 40% for cooking and 60% to the others | Equal weighting | 60% for cooking fuels and 40% to others | 50% for cooking fuels and 50% to the others |

**Table 5**
Demographic and socioeconomic characteristics of study groups.

| Case Study (Feedstock) | Group | Male Header Household (%) | Household Head educated (%) | Household Composition | | | Land (ha) | | | Mean annual income per household (GH') | Mean Annual Income per capita (GH') | Annual Expenditure per capita (GH') | Annual Energy Expenditure Per capita (GH') |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total size | Adults | Children | Total | Cropland | Unused | | | | |
| Kwae (Oil Palm) | Worker | 63 | 83 | 2.5 ± 1.0 | 2.1 ± 0.5 | 0.4 ± 0.7 | 0.6 ± 1.3 | 0.5 ± 1 | 0.1 ± 0.5 | 5834.5 ± 2501.1 | 2585.1 ± 1263.8 | 1366.2 ± 759.0 | 172.1 ± 50.2 |
| | Outgrower | 73 | 52 | 4.4 ± 1.8 | 3.1 ± .14 | 1.3 ± 1.2 | 7.2 ± 3.9 | 4.1 ± 2.4 | 3.1 ± 2.3 | 12915.2 ± 6051.0 | 3331.6 ± 1982.8 | 1683.2 ± 821.1 | 120.3 ± 97.2 |
| | Ind. Grower | 73 | 47 | 4.4 ± 1.8 | 2.9 ± 1.2 | 1.5 ± 1.2 | 7.1 ± 3.7 | 3.5 ± 2.7 | 3.6 ± 1.8 | 13429.9 ± 7071.1 | 3474.6 ± 2151.8 | 1433.1 ± 411.6 | 142.2 ± 80.1 |
| | Control | 74 | 53 | 4.2 ± 2.0 | 2.8 ± .14 | 1.4 ± 1.4 | 4.9 ± 4.5 | 1.9 ± 0.9 | 3.0 ± 2.5 | 9092.5 ± 4424.2 | 2714.5 ± 2056.4 | 1248.7 ± 462.9 | 153 ± 79.2 |
| Dabala (Sugarcane) | Smallholder | 74 | 40 | 5.1 ± 1.5 | 3.2 ± 1.1 | 1.9 ± .1.4 | 3.2 ± 2.6 | 2.0 ± 1.7 | 1.2 ± 0.7 | 10648.1 ± 6488.1 | 2347.4 ± 1900 | 770.2 ± 327.2 | 71.9 ± 51.2 |
| | Control | 63 | 48 | 5.0 ± 1.9 | 3.3 ± 1.2 | 1.7 ± 1.2 | 2.9 ± 2.4 | 2.2 ± 1.6 | 0.7 ± 1.3 | 6386.3 ± 3253.9 | 1415.9 ± 870 | 693.4 ± 318.6 | 80.2 ± 44.7 |
| Yeji (Jatropha) | Permanent workers | 44 | 27 | 5.7 ± 3.0 | 2.5 ± 1.2 | 3.2 ± 2.2 | 3.6 ± 1.6 | 1.4 ± 0.9 | 2.2 ± 1.3 | 5086.8 ± 1759.9 | 1142.0 ± 930.7 | 561.6 ± 336.6 | 59.4 ± 30.1 |
| | Seasonal Worker | 34 | 38 | 5.8 ± 2.9 | 2.3 ± 1.2 | 3.5 ± 2.2 | 2.5 ± 1.7 | 2.0 ± 1.4 | 0.5 ± 0.5 | 4275.4 ± 1790.2 | 1043.8 ± 979.5 | 576.3 ± 144.0 | 59.1 ± 37.4 |
| | Control | 60 | 37 | 6.3 ± 2.8 | 2.4 ± 1.0 | 3.9 ± 2.3 | 3.5 ± 3.1 | 3.1 ± 3.1 | 0.4 ± 0.4 | 5907.3 ± 3018.9 | 1254.9 ± 1357.0 | 726.7 ± 611.0 | 54.3 ± 23.4 |

Finally, we should note that various factors could affect energy poverty at the local level. In this paper we are particularly interested whether involvement in industrial crop production can indeed affect energy poverty. For this reason we make all comparisons between groups in each site, rather than groups between sites. This is because many of the factors possibly affecting outcomes of industrial crop production and energy poverty are largely similar within each site (e.g. land tenure rules, energy infrastructure, and agro-ecological conditions dictating biomass availability and industrial crop type/yields).

However, establishing pure causality is a very contentious in this type of studies, both due to the lack of baseline data prior as well as the fact that the calculation of MEPI does not allow the use of common tools to establish causality such as Propensity Score Marching. To overcome these points we use already tested protocols (e.g. Gasparatos et al., 2018a) that we have been applied in many different studies in such contexts in SSA (Ahmed et al., 2019a; Balde et al., 2019; Mudombi et al., 2018b). We also use very careful language to avoid misleading the reader. This is why we have carefully selected the word "patterns between groups" rather than "impacts". We offer a deeper discussion of limitations in Section 4.2.

## 3. Results

### *3.1. Aggregate multi-dimensional energy poverty index (MEPI)*

Table 7 and Fig. 2 highlight the MEPI levels between study groups and sites. In Kwae (oil palm), GOPDC workers are characterised by low energy poverty (MEPI$\leq$0.3), while all other groups by moderate energy poverty (0.3 $\leq$ MEPI$\leq$ 0.7) (Table 7, Fig. 2). In fact there is a significant difference between the MEPI levels of GOPDC workers and the other groups, despite having the lowest levels of income and consumption (Table 2). A possible explanation could be that workers benefit from access to electricity (see Section 3.3) by virtue of accommodation offered by the company as well as extension of grid to communities. This might also explain the rather higher energy expenditures compared to other study groups in Kwae (Table 3).

In Dabala (sugarcane), both study groups can be characterised as moderately energy poor (Table 7, Fig. 2). In fact, there are no significant differences in MEPI levels between the sugarcane smallholders and the control group, despite the significant differences in income and expenditure (Section 3.1). Furthermore, both groups rely on fuelwood readily available in the wider Dabala area, with energy-related expenditure related constituting less than 1% of the total expenditures for both groups. There is practically no difference in mean energy expenditure between sugarcane growers (GH' 71.9) and the control group (GH' 80.2). In a way differences in income and consumption levels do not seem to translate to higher energy security or investment in energy services.

In Yeji (jatropha), permanent workers can be characterised as moderately energy poor, while seasonal workers and control group as acutely energy poor (Table 7, Fig. 2). On the other hand, permanent workers have significantly lower MEPI compared to the other groups, suggesting their lower energy poverty. Conversely, there is no significant difference between the MEPI levels of seasonal workers and the control group. However, despite permanent workers having lower income when compared to the control group, they spend more on energy in absolute terms. In fact energy expenditure constitutes 2.4% of the total household expenditure for permanent workers, while 1.5% for the control group.

To test the robustness of the MEPI, we change the weights of the different indicators as outlined in Table 6, resulting in three alternative MEPIs (Table 8). Results for Dabala (sugarcane) and Kwae (oil palm) are generally robust to the weight variations, as the ordering of the groups does not change (Table 8, see also Figs. S1–S3 in Supplementary Electronic Material). However, in Yeji (jatropha), results might be less robust considering the changes in group order for Alternative MEPI 1 (Table 9).

**Table 6**
Statistical differences in the demographic and socioeconomic characteristics between study groups.

| Case Study | Groups | Household Head | | Household Members | | | Household Land (ha) | | | Mean annual income per household (GH') | Mean Annual Income per capita (GH') | Annual Expenditure per capita (GH') | Annual Energy Expenditure Per capita (GH') |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Age | Education | Total | Adult | Children | Total | Cropland | Unused | | | | |
| Kwae (Oil Palm) | Worker Vs Outgrower | 0.864 | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.002*** | 0.000*** | 0.000*** |
| | Worker vs Ind. grower | 0.001*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** |
| | Worker vs Control | 0.337 | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.016** | 0.000*** | 0.593 | 0.074* | 0.000*** |
| | Outgrower vs Ind. Grower | 0.001*** | 0.481 | 0.931 | 0.734 | 0.205 | 0.314 | 0.022** | 0.428 | 0.759 | 0.626 | 0.076* | 0.013** |
| | Outgrower vs Control | 0.412 | 0.888 | 0. .218 | 0.263 | 0.737 | 0.000*** | 0.000*** | 0.259 | 0.000*** | 0.032** | 0.000*** | 0.000*** |
| | Ind. Grower vs Control | 0.013** | 0.397 | 0.150 | 0.495 | 0.095 | 0.000*** | 0.000*** | 0.057* | 0.000*** | 0.011** | 0.000*** | 0.000*** |
| Dabala (Sugarcane) | Smallholder vs Control | 0.228 | 0.256 | 0.551 | 0.794 | 0.791 | 0.118 | 0.274 | 0.028** | 0.000*** | 0.000*** | 0.000*** | 0.086* |
| Yeji (Jatropha) | Permanent Worker vs Seasonal Worker | 0.312 | 0.170 | 0.765 | 0.139 | 0.370 | 0.000*** | 0.001*** | 0.000*** | 0.000*** | 0.573 | 0.163 | 0.431 |
| | Permanent Worker vs Control | 0.535 | 0. .131 | 0.068 | 0.995 | 0.025** | 0.007** | 0.000*** | 0.000*** | 0.283 | 0.494 | 0.012** | 0.313 |
| | Seasonal Worker vs Control | 0.014 | 0.905 | 0.235 | 0.150 | 0.365 | 0.021** | 0.008* | 0.347 | 0.000*** | 0.346 | 0.001*** | 0.283 |

Note: Statistical difference was calculated using the Mann Whitney *U* test for the comparison of mean ranks, as data is not normally distributed. Significance levels between groups is denoted as: *** at 1% level of significance, ** 5% level of significance, * 10% level of significance.

**Table 7**
MEPI levels and the 99% confidence intervals (upper and lower bounds) for the study groups.

| Site | Group | MEPI | Standard error | 99% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower bound | Upper bound |
| **Kwae (oil palm)** | Workers | 0.182 (low) | 0.027 | 0.118 | 0.252 |
| | Outgrowers | 0.456 (moderate) | 0.012 | 0.423 | 0.487 |
| | Independent Growers | 0.446 (moderate) | 0.016 | 0.403 | 0.490 |
| | Control | 0.345 (moderate) | 0.025 | 0.277 | 0.408 |
| **Dabala (sugarcane)** | Smallholders | 0.572 (moderate) | 0.017 | 0.525 | 0.618 |
| | Control | 0.551 (moderate) | 0.018 | 0.505 | 0.595 |
| **Yeji (jatropha)** | Permanent workers | 0.650 (moderate) | 0.014 | 0.614 | 0.686 |
| | Seasonal workers | 0.730 (acute) | 0.012 | 0.694 | 0.758 |
| | Control | 0.720 (acute) | 0.012 | 0.696 | 0.752 |

Note: Acute energy poverty (MEPI > 0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

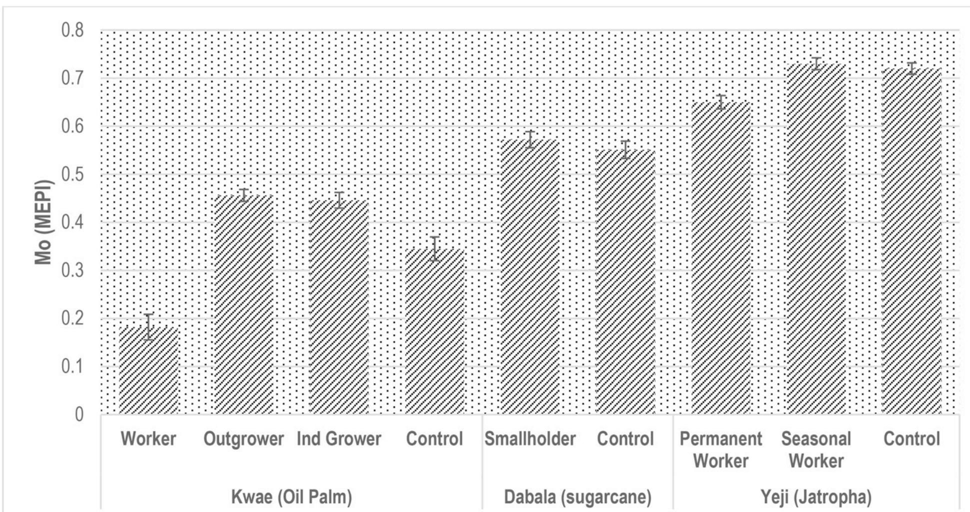


**Fig. 2.** MEPI levels and standard errors for each group.
Note: Lower Mo (MEPI), indicate lower energy poverty. Acute energy poverty (MEPI>0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

**Table 8**
Weight variation effects on MEPI levels.

| Case Study (Feedstock) | Group | Original MEPI | Alternative MEPI 1 | Alternative MEPI 2 | Alternative MEPI 3 |
|---|---|---|---|---|---|
| **Kwae (oil palm)** | Workers | 0.182 (low) | 0.130 (low) | 0.213 (low) | 0.203 (low) |
| | Outgrowers | 0.456 (moderate) | 0.192 (low) | 0.628 (moderate) | 0.540 (moderate) |
| | Independent growers | 0.446 (moderate) | 0.274 (low) | 0.605 (moderate) | 0.524 (moderate) |
| | Control | 0.345 (moderate) | 0.193 (low) | 0.460 (moderate) | 0.402 (moderate) |
| **Dabala (sugarcane)** | Smallholders | 0.572 (moderate) | 0.454 (moderate) | 0.704 (moderate) | 0.644 (moderate) |
| | Control | 0.551 (moderate) | 0.426 (moderate) | 0.681 (moderate) | 0.625 (moderate) |
| **Yeji (jatropha)** | Permanent Workers | 0.650 (moderate) | 0.837 (acute) | 0.765 (acute) | 0.714 (acute) |
| | Seasonal Workers | 0.730 (acute) | 0.650 (moderate) | 0.806 (acute) | 0.792 (acute) |
| | Control | 0.720 (acute) | 0.649 (moderate) | 0.812 (acute) | 0.779 (acute) |

Note: Acute energy poverty (MEPI> 0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

### 3.2. Deprivation against individual MEPI indicators

According to Table 9, most groups are deprived in terms of cooking fuel and lighting. This largely reflects the high reliance on traditional biomass fuels for cooking (e.g. fuelwood, charcoal) and the generally limited access to electricity for most groups.

In Kwae (oil palm), there is a marked difference in the levels of many indicators of deprivation between plantation workers and other study groups (Table 9). Plantation workers are less deprived in terms of cooking fuel and indoor air pollution, but more deprived in terms of household and entertainment appliance ownership. Among the other study groups, the most marked difference is the large observed deprivation for cooking fuel and indoor air pollution between those involved in oil palm production (as out-growers and independent smallholders), and the control group.

In Dabala (sugarcane), both sugarcane growers and the control group have relatively similar levels of deprivation for all individual indicators apart from household appliance ownership, with sugarcane smallholders being more deprived compared to the control group (Table 9). There is particularly high deprivation for both groups for cooking energy and indoor pollution due to the overreliance on traditional fuel such as fuelwood and charcoal.

In Yeji (jatropha), there is 100% deprivation for cooking fuel and indoor pollution for both worker groups and the control group. Permanent jatropha workers are by far the least deprived group in terms of electricity access. Surprisingly seasonal workers are not deprived in

**Table 9**
Deprivation against each of the MEPI indicators, expressed as a fraction (%) of the total population in each group.

| Case Study (Feedstock) | Group | Modern cooking fuel (%) | Indoor pollution (%) | Electricity access (%) | Household appliance Ownership (%) | Entertainment appliance ownership (%) | Telecommunication Means (%) |
|---|---|---|---|---|---|---|---|
| **Kwae (Oil Palm)** | Worker | 31 | 31 | 19 | 85 | 16 | 4 |
| | Outgrower | 97 | 97 | 9 | 31 | 3 | 3 |
| | Ind. Grower | 91 | 91 | 12 | 52 | 0 | 0 |
| | Control | 69 | 69 | 21 | 50 | 0 | 0 |
| **Dabala (sugarcane)** | Smallholder | 97 | 97 | 37 | 77 | 6 | 6 |
| | Control | 95 | 95 | 39 | 64 | 8 | 6 |
| **Yeji (Jatropha)** | Permanent Worker | 100 | 100 | 49 | 91 | 0 | 25 |
| | Seasonal Worker | 100 | 100 | 86 | 100 | 0 | 0 |
| | Control | 100 | 100 | 67 | 98 | 0 | 47 |

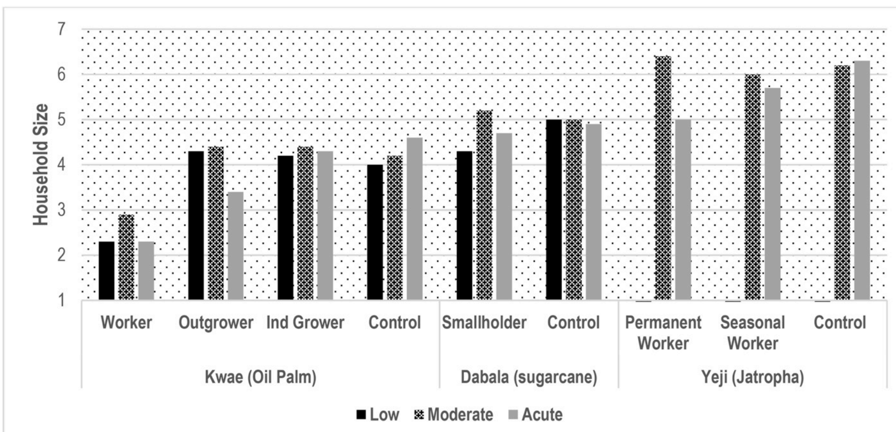


**Fig. 3.** Relation between MEPI and household size.
Note: Acute energy poverty (MEPI>0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

terms of telecommunication, compared to permanent workers (25% deprivation) and the control group (47% deprivation).

### 3.3. Social differentiation in MEPI levels

Below we identify patterns between MEPI categories and some of the main household characteristics outlined in Section 3.1, such as household size, gender of household head, land ownership, income, total expenditure and energy expenditure. Figs. 3–5 identify the mean of each of these characteristics for the sub-sample of the group falling in each of the three MEPI categories (i.e. acute, moderate, low).

When comparing MEPI levels and household size (Fig. 3), we find that larger household sizes are not necessarily associated with higher energy poverty (i.e. increase of MEPI). The only marginal exceptions are the control groups in Kwae and Yeji. In fact for most groups, larger households tend to have moderate MEPI. In this sense household size does not seem to influence substantially energy poverty in our study sites.

Regardless the gender of the household head, most study groups tend to be moderately energy poor in Kwae (oil palm) and Dabala (sugarcane) (Fig. 4). The main exceptions are the oil palm workers in Kwae (low) and the groups in Yeji (acute). However when looking closer, some patterns diverge for female- (Fig. 4a) and male-headed households (Fig. 4b). In particular the proportion of the male-headed households in lower and moderate MEPI categories increase for oil palm workers and control in Kwae, while it reduces for sugarcane smallholders in Dabala and all study groups in Yeji (Fig. 4). This suggests that gender of household head can indeed play a role in MEPI levels.

Household income, expenditures and land ownership are three indicators directly related to the household livelihoods and endowments in the agrarian contexts of our study. With few differences, the patterns between MEPI levels are consistent between these variables in each site (Fig. 5). For example in Kwae richer and better-endowed households seem to have consistently lower and moderate energy poverty. For land ownership there is a clear pattern of declining energy poverty between all groups as cultivated land increases, suggesting that better endowed households having lower energy poverty. The patterns are quite consistent between households that depend on own agricultural production for their livelihoods (i.e. outgrowers, independent growers, control), which are in turn different to those of oil palm plantation workers (Fig. 5). On the other hand in Dabala (sugarcane) and Yeji (jatropha) increasing wealth and endowment do not necessarily translate into lower energy poverty. Most households in these sites exhibit moderate and acute energy poverty despite increasing levels of wealth and land endowment in some groups (Fig. 5).

## 4. Discussion

### 4.1. Multi-dimensional energy poverty patterns accross sites

In the oil palm site (Kwae), the GOPDC plantation workers registered significantly lower MEPI compared to all other study groups (Table 7). This is largely driven by their much lower deprivation score for cooking energy and indoor air pollution, compared to all other groups (Table 9). However, the significantly higher mean income of oil palm outgrowers and independent growers (Ahmed et al., 2019a), does not translate in higher MEPI scores (and as an extent to lower multi-dimensional poverty) compared to plantation workers and the control group (Fig. 2). In particular, these two groups have by far the largest deprivation in terms of cooking fuel and indoor air pollution in Kwae

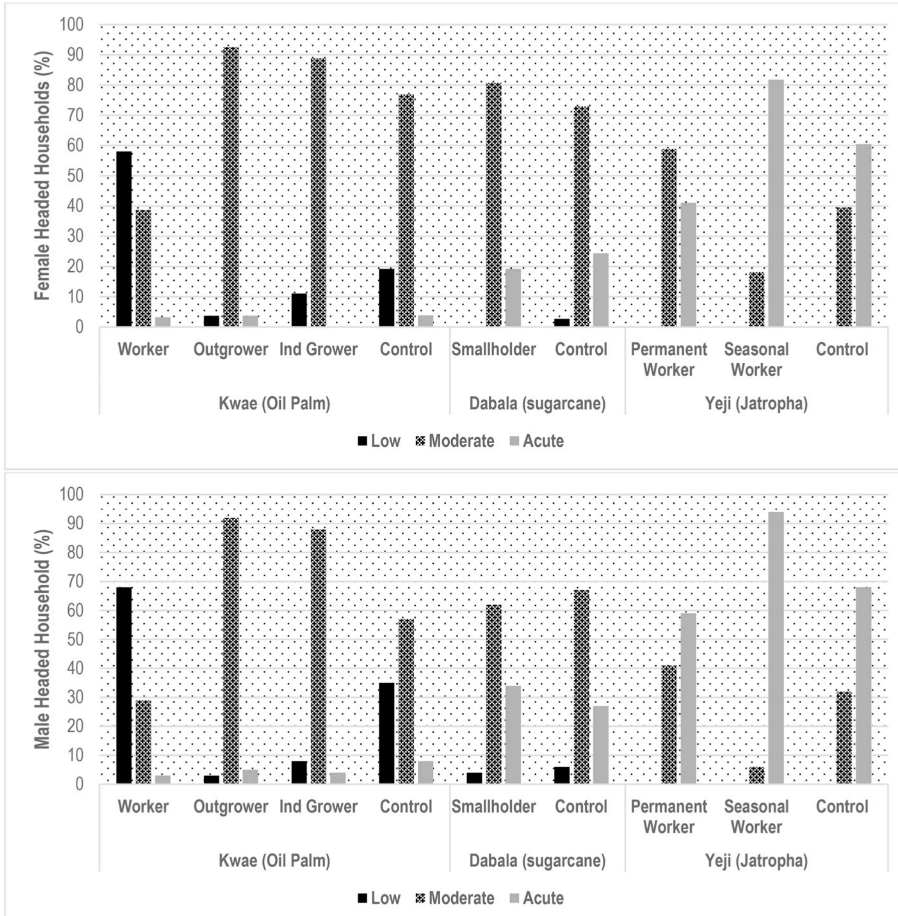


**Fig. 4.** Relation between gender of household head and MEPI for female- (4a) and male-headed households (4b).
Note: Acute energy poverty (MEPI>0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

(Table 9).

The energy poverty patterns for GOPDC plantation workers possibly reflect their lower mean income and distinct household composition (Section 2.2) (see also Ahmed et al., 2019a). Most plantation worker households comprise of just one or two persons, and are mostly migrants (60%) and male-headed (Section 2.2). This suggests a lower household labour availability, compared to other households in the area. Considering that fuelwood collection is a time-intensive task mostly performed by females in Ghana (Anang et al., 2011), many plantation workers might have opted to invest in quick cooking options that do not rely on fuelwood or charcoal (and its high time costs). This is corroborated by the fact that workers have substantially higher mean energy expenditures compared to other groups (Section 2.2). However, their significantly lower incomes and distinct household characteristics might have also curtailed their ability or interest to invest in other household appliances such as fridges (85% deprivation in household appliances) and TVs (16% deprivation in entertainment appliances), despite their rather similar access to electricity compared to other groups (Table 9).

Patterns for oil palm outgrowers and independent growers might be explained by their large dependence on fuelwood for oil palm processing. Visits to many such households during data collection revealed that these groups also tend to engage in small-scale palm oil processing, which is an extremely energy demanding activity (Osei-Amponsah et al., 2012). These households conveniently tend to use the surplus fuelwood for cooking, possibly reducing their incentives to invest in better energy options, as also indicated by their relatively lower energy-related expenditures (Section 2.2).

In the sugarcane site (Dabala), the control group has lower MEPI levels than the sugarcane smallholders, though the difference is not significant (Fig. 2). Similar to oil palm producers, many of the sugarcane smallholders in Dabala use large amounts of fuelwood for small-scale sugarcane processing to alcohol. This reliance on fuelwood for their livelihood might simply make it more convenient for these households to continue using traditional biomass fuels for cooking, rather than investing in modern cooking options. Infrastructure constraints might also contribute to this overall lack of investment in cleaner cooking options. For example, at the time of the survey there was no LPG retail station in Dabala, with the few households (<3%) reporting LPG use for cooking usually procuring it from the district capital (Sogakope).

In the jatropha site (Yeji), the permanent plantation workers have significantly lower MEPI than their respective control group. This is largely due to their much lower deprivation for electricity (Table 9), which largely reflects the distribution of their accommodation. Interestingly, despite the very low access to electricity (86% deprivation) and income (Section 2.2, also Ahmed et al., 2019a) of seasonal workers, they do not seem to experience deprivation with regard to entertainment and communication appliances. As suggested during the interviews and site visits, this is because the dry cell batteries mostly used for radios and mobile phones are recharged by vendors for a small fee either in Yeji, or within their own community. Uniformly, all groups in Yeji face total deprivation for cooking fuel and indoor air quality (Table 9). The relatively high household sizes for all groups in Yeji (highest among sites, Section 2.2) imply a larger household capacity for fuelwood collection. This is also reflected from the almost similar levels of energy expenditure between groups (Section 2.2). Interestingly, Yeji is the only site where female-headed households report consistently lower energy

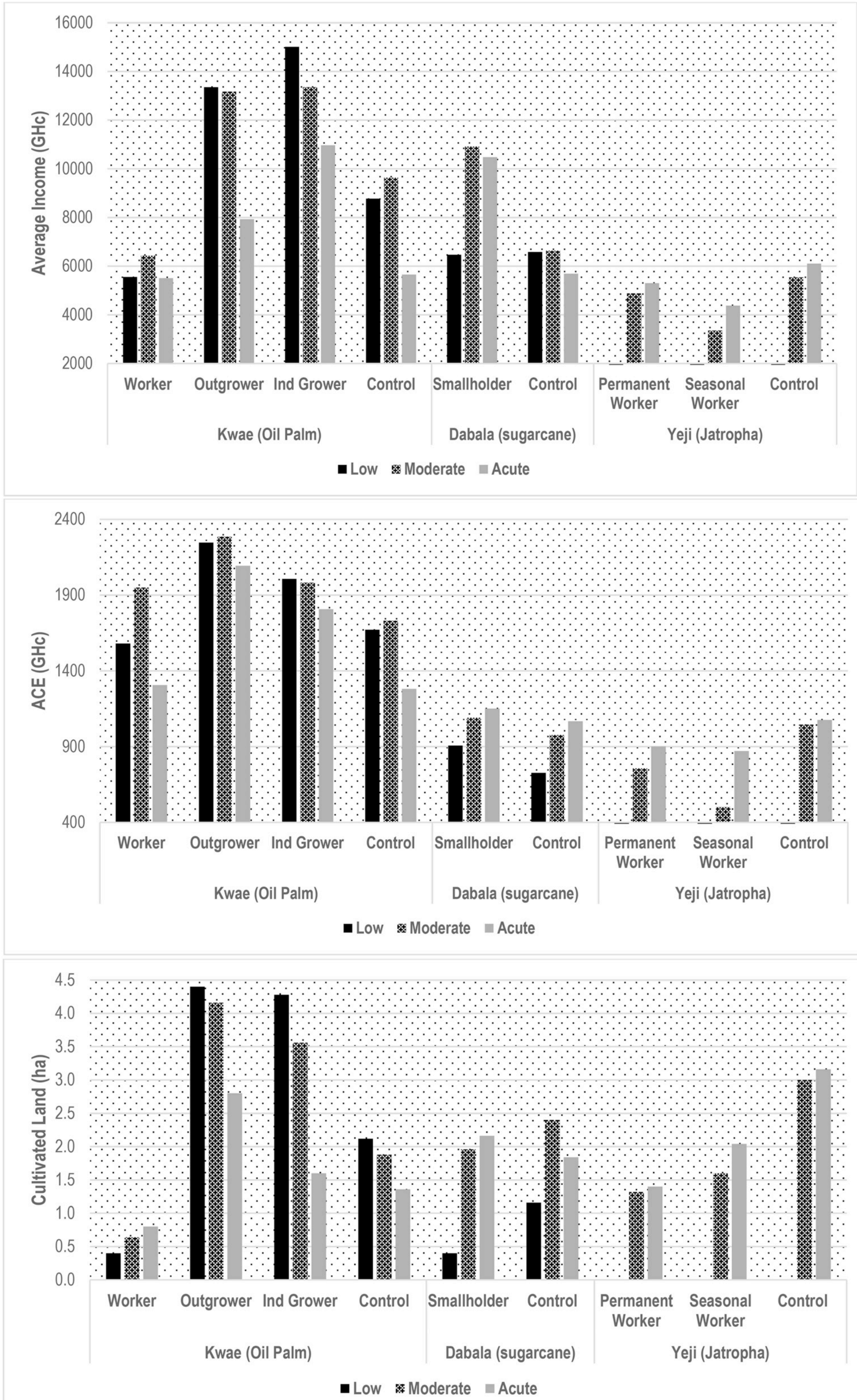


**Fig. 5.** Relation between MEPI and household income (5a), expenditures (5b) and cultivated land (5c).
Note: Acute energy poverty (MEPI>0.7), Moderate energy poverty (0.3 ≤ MEPI≤0.7), Low energy poverty (MEPI<0.3).

poverty levels than male-headed households (Fig. 4). In the savanna dryland (including Yeji) fuelwood and charcoal are the most common sources of energy and important of livelihood activities especially for women (Brobbey et al., 2019a).

The above suggest that several factors uniquely combine to shape the energy poverty patterns observed in each site. However, it is possible to identify some general patterns. For example, when comparing energy poverty patterns across different agro-ecological zones, groups in the rainforest zone (Kwae) are consistently less energy poor compared to every group in the semi-deciduous forest zone (Dabala), which are in turn less energy poor than every group in the savanna zone (Yeji) (Fig. 2, Table 7). Furthermore, all groups in Kwae and Dabala report MEPI levels that are below the 2012 national MEPI level for Ghana (0.62), while all groups in Yeji report higher levels (Nussbaumer et al., 2012). This reflects well the existing literature that suggests the comparatively higher multi-dimensional energy poverty in the savanna zone compared to other agro-ecological zones in Ghana (Crentsil et al., 2019; Adusah-Poku and Takeuchi, 2019). Conversely the mean income, total expenditure and energy expenditure all decrease consistently from the forest zone (Kwae), to the semi-deciduous forest zone (Dabala) and the savanna zone (Yeji) (Ahmed et al., 2019a). These patterns generally reflect other studies and national statistics that have pointed the wet-dry gradient for income, poverty, education, household sizes and multi-dimensional energy poverty in Ghana (Ghana Statistical Service, 2015, 2014b; Crentsil et al., 2019; Adusah-Poku and Takeuchi, 2019).

Apart from the general socioeconomic patterns within Ghana, our results reflect also well some of the actual characteristics of the study sites. Kwae is overall more developed as an area, with higher access to (and adoption of) electricity between groups (Table 9). In this area improved energy options do exist, and for some groups the income from involvement in industrial crop activities indeed seems to enable the adoption of improved energy services, and escape energy poverty (see above). In other sites there is simply not a direct translation of industrial crop incomes to lower energy poverty, largely due to the general lack of energy options (see above). This finding is consistent with an emerging literature which indicates that higher income levels increase households' capabilities and improve energy choices only when such options are available (Day et al., 2016; Nussbaumer et al., 2012; Sadath and Acharya, 2017). For example financial and non-financial barriers have reportedly undermined households' energy choices in different SSA countries such as Ghana, Senegal, Tanzania and Zambia (Haselip et al., 2015, 2014).

Gender disparities can be a major factor contributing to energy poverty (Sovacool, 2012). Female-headed households increasingly participate directly to income-earning activities in Ghana to supplement household income from agriculture (Ahmed et al., 2016). However according to Crentsil et al. (2019), female-headed households in Ghana have a higher probability of being multi-dimensionally energy poor. As different mechanisms mediate the links between gender, livelihoods and energy poverty (Karanja and Gasparatos, 2019), it is not easy to identify causal pathways. In our study, patterns depend substantially between sites: (a) female-headed households involved in industrial crop activities have lower MEPI than their male-headed counterparts and control groups (in Yeji), and (b) female-headed households involved in industrial crop activities have higher MEPI than control groups and male-headed households (in Kwae and Dabala). In the first case female-headed households constitute 56% of the permanent jatropha workers, and are better off than control households and male-headed households, which sharply contrasts the discourse over the feminization of poverty (Chant, 1997; Listo, 2018; Sovacool, 2012). On the contrary, the patterns in the oil pam and sugarcane areas reflects, to some extent, existing debates that gender inequalities shape energy poverty (Kohlin et al., 2011). While we cannot understand through our results why these distinct patterns emerge, this gender imbalance in MEPI levels offers more nuanced information that can complement larger-scale studies (e.g. Crestil et al., 2019).

When generalising our findings we need to be sensitive of the fact that they are obtained through unique case studies, embedded in specific socioeconomic and environmental contexts. However, a consistent narrative that seems to come out from most sites is that income gains from industrial crop production do not translate automatically in energy poverty alleviation. Even though this extra income can be an important mechanism that could in theory contribute manifold to energy poverty alleviation, other mechanisms such as the local availability (or lack of thereof) of improved energy options and engagement in other livelihood options that require fuelwood (e.g. sugarcane or palm oil processing) that might equally prevent energy poverty alleviation. These mechanisms might create path dependence and disincentivise households to invest their added income in improved energy options. To overcome this there would be a need for added interventions mediated by different actors (Section 5).

### 4.2. *Limitations and direction for future research*

A key limitation of this study is the inability to establish a causal relationship between involvement in industrial crop production and MEPI levels. First, we do not have baseline data about the different indicators before the commencement of industrial crop production. Second, due to the MEPI calculation procedure (i.e. MEPI characterises an entire study group rather than individual households), it is not possible to use statistical techniques such as Propensity Score Matching (PSM) to infer causality (see Ahmed et al., 2019a; Balde et al., 2019). Even though this does not affect the validity of the results, as we are interested in energy poverty *patterns* for different groups rather than the actual *impacts* of engagement in industrial crop production, establishing causality would have increased the explanatory power of the study.

When it comes to the MEPI methodology, even though it is a powerful aggregate metric for identifying energy poverty patterns, it has important shortcomings. First, some indicators might be irrelevant in certain local contexts due to prevailing cultural practices. For example it can be argued that in some SSA contexts where perishable food is not extensively consumed, the ownership of a fridge might not be more of a necessity compared to cooling appliances (e.g. ceiling/standing fan, air condition). Indeed, cooling service is an important omission within the MEPI methodology especially in SSA, as outbreaks of weather-related diseases are very common due to the lack of cooling in many households (Codjoe and Nabie, 2014; Dovie et al., 2017). Future research could consider cooling as a new MEPI dimension, e.g. by adding cooling appliance ownership as an indicator.

Second, the MEPI methodology lacks indicators that capture the stability of energy access (Olang et al., 2018), which can be an important element of household energy security (Pelz et al., 2018). This is particularly relevant in the context of our study, as some of the indicators and deprivation scores depend on the benefits accruing from engagement in industrial crop production. However, such benefits are not always safe as they can be lost due to the loss of employment or relocation see similar points made for the Multidimensional Poverty Index: (Mudombi et al., 2018b). Therefore, for some types of industrial crop engagements there is a high inherent risk of instability of access. Alternatively, while households relying extensively on fuelwood might have low MEPIs, they might not experience access instability due to high fuelwood abundance. Similarly, the ownership of a radio or a mobile phone does not necessarily imply access to reliable energy or lower energy poverty. For example, in some of our study areas many households use dry cell batteries and/or diesel/petrol-powered generators to recharge phones or use their radios. Without understanding the stability of energy access, recommendations and policy interventions based on MEPI could be short-sighted. Future MEPI studies can consider stability effects, e.g. the frequencies, distance, cost and time in accessing different energy sources.

Another important aspect of our study is the many interlinkages and feedbacks of industrial crop promotion and expansion in the food-energy-water nexus. All of the studied crops in this paper are practically biofuel feedstocks, even though only jatropha in Yeji is currently promoted for energy purposes. Many studies have identified the many feedback mechanisms of biofuel crop production in the food-energy-water nexus (Rulli et al., 2016), especially in SSA contexts (Moioli et al., 2018).

Regarding food-energy linkages, industrial/biofuel crop production can compete with land for food crops, and as such reduce food availability and thus food security (Gasparatos et al., 2018b). However this is only one of the many interacting mechanisms (Wiggins et al., 2015). For example, the income generated through involvement in industrial crop production can increase the adoption of modern energy options, especially where modern energy options are available (i.e., agriculture feedback to energy) (see also Karanja et al., 2019). Furthermore, there is potential in some areas to locally generate renewable energy through crop residues such as sugarcane bagasse, jatropha shells, and oil palm waste (i.e., agriculture feedback to energy) (Stafford et al., 2019; IRENA, 2017). Such mechanisms could in theory reduce rural energy poverty, and possibly increase household income availability, as fuelwood purchase constitutes a high recurring household expenditure (especially in areas of fuelwood scarcity), while its collection is a major burden on time availability for women for other income-generating and household care activities (e.g. food preparation, child feeding) (Karanja et al., 2019). It has been shown that income availability and women empowerment can have major positive outcomes for different food security pillars in the context of industrial crop production in SSA (Wiggins et al., 2015).

Even though energy-water linkages are less notable in our study, they can be important in some area. For example, in Dabala, some of the income generated from sugarcane sales is used to purchase diesel for water pumps (i.e., energy feedback to agriculture). Especially during the dry season, rivers within the wetlands are used for the small-scale irrigation of sugarcane and food crops (particularly okra and vegetable cultivated by women). Water availability during these periods can increase the yields of food crops and sugarcane, having positive effects for income generation and food security as has been shown in different sugarcane areas across SSA (Herrmann et al., 2018; Terry and Ogg, 2017).

The above suggest the existence of feedback loops in all sites, where energy availability affects agricultural outcomes. In this light, it would be necessary to adopt nexus approaches to maximize the wellbeing outcomes of industrial crop production and other related investments in SSA on food security, poverty alleviation, energy poverty alleviation (de Strasser, 2017; Ringler et al., 2013). This further suggests the need for policy coherence between energy planning and strategies on water and food security (de Strasser, 2017; Ringler et al., 2013). However, there are still significant knowledge gaps about the nature of the feedback mechanisms and the necessary institutional responses both in the specific sites, and other SSA contexts.

## 5. Conclusion and policy implications

This study investigated energy poverty patterns for groups with different involvement in industrial crop production, as a means of identifying the possible rural energy poverty alleviation co-benefits of rural development strategies based on industrial crop production. In particular we elicited the multidimensional energy poverty patterns around industrial crop projects in Ghana using the MEPI framework, comparing MEPI levels between groups with different types of engagement in industrial crop production (e.g. workers, smallholders) and control groups. In this respect, this study is a response to the call for establishing a strong empirical evidence about baseline conditions and progress in rural areas of SSA (Pelz et al., 2018), in order to track progress towards energy poverty alleviation at the local level, assist decentralised planning of energy and mainstreaming energy in existing local development planning processes (Hiremath et al., 2010, 2007).

One of the main findings is that energy poverty patterns vary around industrial crop projects. While several factors converge to collectively affect the overall MEPI levels (e.g. gender, income, local context), it is particularly striking that the higher mean incomes of many industrial crop groups do not automatically translate into household energy investments to reduce energy poverty. Investment in better energy services tends to occur only for some groups (interestingly the income-constrained plantation workers) and only in areas that such options are widely available (i.e. Kwae). Furthermore there are multiple possible feedback loops where energy availability affects agricultural outcomes.

This suggests that rural development strategies based on industrial crops can in theory have some possible rural energy poverty alleviation co-benefits (e.g. through better income and employment prospects). However, this does not happen automatically in every local context despite the strong links between wealth and multi-dimensional energy poverty in Ghana (Crentsil et al., 2019). In such contexts, while it is worthwhile in its own right to enhance the incomes of those involved in industrial crop activities (and the broader community), it might not alleviate rural energy poverty. To ensure energy poverty alleviation benefits from rural development interventions (if deemed socially and politically desirable) it is important to (a) ensure the wide availability of modern energy options; (b) capitalise on the unique characteristics of individual local contexts and industrial crop intervention. These two aspects are quite interrelated as discussed below, and could potentially enhance positive interlinkages from industrial crop investments in the water-food-energy nexus.

Ensuring the wider availability of modern energy options would be an important step, considering the strong linkage between reliance on traditional biomass fuels and multi-dimensional energy poverty in Ghana (Adusah-Poku and Takeuchi, 2019). However, this would require coordinated policy action across different levels of government and between different stakeholder groups as has been discussed in many SSA contexts (e.g. Karanja and Gasparatos, 2019). Related to this paper would be the need to build stronger linkages between rural development, energy planning policies and practices, something that is currently lacking in Ghana (Section 1, 2.1), and possibly in other parts of SSA. Decentralised measures such as bioenergy supply through the use of agricultural residue from industrial crops could be important initiatives for energy poverty, and would bode well with existing energy policy directions in the country (Section 2.1). This would require strategic changes in aligning policies and practices to see the actual linkages between rural development and energy poverty alleviation. Rural development approaches must move beyond the mind-set of single agricultural investments, to re-think of integrated investments as parts of wider regional development (i.e. agriculture-energy nexus). Similarly, energy planning approaches could conceptualise integrated investments as possible agents of catalysing de-centralised rural energy transitions.

Furthermore, it would be important to capitalise opportunistically on the possibilities emerging from the unique characteristics of rural development interventions and the targeted local communities. A particularly pertinent finding is that most study groups are almost completely deprived in terms of cooking fuel and indoor air pollution, which reflects closely findings from other sugarcane and jatropha production sites in southern Africa (Mudombi et al., 2018b). Even groups with high incomes are unwilling to invest in modern energy options due to the role that fuelwood plays for their broader livelihoods (e.g. for sugarcane/oil palm processing). In such contexts it might be worthwhile to incentivise small-scale industrial crop processors to adopt processing techniques that are more efficient and rely less (or not at all) on biomass (e.g. see example from the Ghanaian shea industry) (Jasaw et al., 2015). Such interventions could enhance productivity (and thus household income) and break the cycle of fuelwood dependency (Section 2.1, 4.1).

In other contexts it might be more worthwhile to incentivise industrial crop companies to provide directly modern energy options for profit or not for profit. For example, industrial crop companies, relying on extensive infrastructure (e.g. sugarcane, oil palm) can receive incentives to generate on- or off-grid electricity through the use of agricultural residues (e.g. bagasse, oil palm residue) (Kemausuor et al., 2018; Ramamurthi et al., 2016). Among others this would require the proper valorisation of all crop elements, which might increase industrial crop prices, thus having a positive livelihood effect to smallholders. In other contexts, industrial crop companies (especially sugarcane companies) could provide fuel/stoves at low cost as part of their Corporate

Social Responsibility Strategy (CSR). Again both of these options bode well with the existing energy policy directions in Ghana that focus on the integration of renewable energy in decentralised grids and provision of clean cookstoves in rural communities (Section 2.1).

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2019.111123.

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