# *Nexus between solar-PV adoption and wild food sustainability: case of income from honey, fruits, traditional-beer, and vegetables in rural Zambia*

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# Nexus between solar-PV adoption and wild food sustainability: Case of income from honey, fruits, traditional-beer, and vegetables in rural Zambia

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ABSTRACT

Rural Zambia faces critical energy access challenges, with electrification rates below 15 % and over 12 million people lacking electricity. The reliance on hydroelectric power, exacerbated by climate-induced droughts, has led to severe energy shortages and up to 21-hour daily load-shedding. This research addresses the dual challenge of energy poverty and unsustainable edible non-timber forest product (ENTFP) practices in rural Zambia. Despite the potential of solar photovoltaic (PV) systems to mitigate energy poverty and enhance livelihoods, adoption remains limited. Simultaneously, wild foods - such as wild honey, fruits, traditional beer, and leafy vegetables - are not only consumed in rural areas, but also crucial income sources. However, they face unsustainable harvesting practices, threatening rural food security, biodiversity and long-term viability. This study investigated the relationship between ENTFP - derived income and solar PV adoption. It explored financing mechanisms tied to ENTFPs, evaluated their benefits and limitations, and examined their environmental and social impacts. The study utilized the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), integrating theories such as Technology Acceptance Model, Diffusion of Innovations, and Social Learning Theory. Data were collected through 40 in-depth interviews, 7 focus group discussions, and stakeholder consultations across three rural districts in Zambia. NVIVO 14 was employed for thematic coding and analysis, ensuring representation of diverse stakeholder perspectives. Income from ENTFPs supports solar PV adoption by providing critical financial resources. Some ENTFPs like wild honey sometimes yield even higher revenues than agriculture, enabling energy investments. However, commercialization poses food security and sustainability risks, such as habitat degradation and resource depletion. Social impacts include empowerment through improved energy access but also risks of community conflict over resource competition. Solar PV systems contribute to reduced deforestation and $CO_2$ emissions, aligning with environmental conservation goals, but require balanced management of ENTFP practices to ensure ecological health. The study recommends the need for robust policies promoting sustainable ENTFP harvesting and solar PV integration. Community-driven strategies, coupled with educational initiatives on sustainable practices, can promote resilience and energy equity. Expanding alternative income sources can mitigate overdependence on ENTFPs, ensuring balanced economic, social, and environmental outcomes.

## Introduction

Zambia faces a significant energy access challenge, with rural electrification rates below 15 %, leaving over 12 million people without electricity (Kapole et al., 2023; MOE - Zambia, 2024; Timmermann & Smith-Hall, 2019). The country heavily relies on hydroelectric power from the Zambia Electricity Supply Corporation (ZESCO) Limited, which accounts for over 85 % of its energy mix, making it highly vulnerable to climate-induced droughts (Energy Regulation Board, 2024; MOE - Zambia, 2024). Recent droughts have led to severe power shortages, causing extended load-shedding of up to 21 h per day in grid-connected areas (ZESCO, 2024). In response, ZESCO has restricted residential electricity to three hours per day on a rotating basis (NDN, 2024), emphasizing the urgent need for alternative energy solutions.

As of 2024, Zambia's installed generation capacity reached 3871.32 MW, up from 3811.32 MW in 2023, with solar power contributing to this growth (Energy Regulation Board, 2024). However, the country still faces a power deficit of approximately 1360 MW, with available

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generation at only 1040 MW. Even with 410 MW of imported electricity, Zambia experiences a shortfall of 950 MW, resulting in persistent load shedding (MOE - Zambia, 2024; ZESCO, 2024). To address energy insecurity, the government has implemented initiatives such as tax exemptions on solar equipment, the Rural Electrification Authority (REA), and the Off-Grid Taskforce to expand rural electrification (Energy Regulation Board, 2024).

Renewable technologies, particularly solar photovoltaic (PV) systems, offer a viable solution to mitigate energy shortages and improve livelihoods in rural Zambia (Pitshou et al., 2023; Yekini et al., 2024). Solar PV enhances rural economies by providing reliable electricity, boosting agricultural productivity, and fostering local enterprises (Ngonda et al., 2023). Access to electricity enables essential activities such as lighting, mobile phone charging, and small appliance use, contributing to household development (Chidembo et al., 2022). However, high initial costs and expensive mini-grid tariffs limit widespread adoption, particularly among low-income households (Bhattacharyya & Palit, 2021; Mulenga et al., 2023; Stritzke & Jain, 2021).

In rural Zambia, where grid electricity remains scarce, solar PV adoption is increasingly financed through agriculture and wild food harvesting—including honey, fruits, traditional beer, and vegetables. These income streams serve as economic enablers of decentralized energy solutions, supporting sustainable livelihoods and enhancing energy access.

### *Background*

In Zambia's rural regions, the integration of solar PV systems with income from non-timber forest products (NTFPs) offers a promising approach to enhancing energy access. All (100 %) rural households in Zambia gather fruits, 86 % harvest leafy vegetables, 86 % gather mushrooms, 82 % collect insects, 75 % harvest bushmeat, 73 % collect tubers, and 14 % catch fish (Steel et al., 2022). However, the informal nature of the non-timber forest products (NTFP) trade limits its economic potential and encourages unsustainable harvesting practices, threatening biodiversity (Anyango et al., 2018; Zulu et al., 2019). NTFPs - including wild honey, wild fruits, traditional beer, and wild leafy vegetables -constitute essential livelihoods for approximately 60 % of rural households (Derebe & Alemu, 2023; Kalinda & Bwalya, 2014). Wild fruits and leafy vegetables provide critical nutrition and income, while traditional beer and wild honey offer significant market potential. The estimated collection of wild foods alone exceeds 380 million litres annually, showcasing the extensive utilization of forest resources (Mulenga et al., 2012; Steel et al., 2022). NTFP-based revenues can contribute up to 32–35 % of rural household incomes, offering financial means for self-financing solar PV investments (Mulenga et al., 2011). Seasonal NTFP revenues can help bridge economic gaps, facilitating access to renewable energy (Shackleton et al., 2024; Timko et al., 2010).

Access to formal credit remains limited for many rural households, making NTFP monetization a crucial source of funds for solar PV adoption (Amadu & Miller, 2024). Leveraging local resources aligns with sustainable development goals by fostering economic resilience and minimizing environmental degradation (Amadu & Miller, 2024). However, unsustainable harvesting poses risks of resource depletion and ecological harm (Anyango et al., 2018; Mulenga et al., 2011). A balanced strategy integrating sustainable NTFP management with renewable energy deployment is vital for maintaining ecological and economic health (Derebe et al., 2023).

### *Study justification and significance*

The convergence of self-financed solar PV adoption and income generation from ENTFPs represents a pivotal opportunity to combat rural energy poverty and drive sustainable development in Zambia. Central and Lusaka Provinces illustrate this synergy, where ENTFPs like wild honey, wild fruits, traditional beer, and leafy vegetables are critical for rural livelihoods, particularly during agricultural downturns (Mclain & Lawry, 2015; Mulenga et al., 2012). Sustainable NTFP harvesting is essential to preserve biodiversity, curb deforestation, and enhance community resilience (Mulenga et al., 2011; Shackleton & Shackleton, 2014).

Integrating solar PV systems within rural economic structures provides dual benefits, reducing dependence on biomass and kerosene while lowering $CO_2$ emissions and mitigating deforestation (Wassie & Adaramola, 2021). NTFP-derived income streams can support self-financing models, empowering rural households to transition to renewable energy (Shackleton & Shackleton, 2014). This research explores how combining solar PV adoption with sustainable NTFP management can improve energy access, bolster rural economies, and promote environmental conservation, fostering resilience and long-term sustainability.

### *Research problem*

The adoption of solar photovoltaic (PV) systems among rural households in Zambia remains poorly understood, despite their potential to mitigate energy poverty. Moreover, the environmental and social implications of income-generating activities linked to edible non-timber forest products (ENTFPs) in these communities require further exploration. This highlights the need for a critical assessment of the interplay between NTFP-derived income, solar PV adoption, and their associated benefits and limitations.

### *Research objectives*

This study aims to examine the relationship between income from edible ENTFPs and the adoption of solar PV systems among rural Zambian households. Specifically, it will assess financing mechanisms tied to ENTFPs, evaluate their effectiveness, and explore the environmental and societal impacts of ENTFP-related income-generating activities within these communities.

### *Research questions*

What financing mechanisms linked to ENTFPs facilitate solar PV adoption in rural Zambia? What are their benefits and limitations? How do ENTFP-based activities affect the environment and society?

## Literature review

This literature review examines the socio-environmental effects of income-generating activities linked to edible Non-Timber Forest Products (ENTFPs) in rural Zambia, with emphasis on self-financed solar photovoltaic (PV) systems. The review provides insights into how ENTFPs, including wild honey, traditional beer, wild fruits, leafy vegetables, nuts, and tubers, intersect with solar energy adoption, influencing local livelihoods and ecological sustainability.

### *Wild honey*

Wild honey and beekeeping are essential livelihood sources in rural sub-Saharan Africa, including Zambia, where organic honey and beeswax production offer significant economic benefits, notably in Mwinilunga (Lowore, 2020). Approximately 4 % of Zambian households engage in honey production alongside other NTFPs like fuelwood and medicinal plants (Kalinda & Bwalya, 2014). Beekeeping diversifies income and enhances resilience against environmental challenges such as droughts, increasing household revenue by up to 11 % (Abro et al., 2022). However, wild honey harvesting presents ecological risks. Unsustainable practices, such as using fire to extract honey, contribute to deforestation and biodiversity loss (Ricketts & Shackleton, 2020). Moreover, overexploitation of wild bees threatens pollination systems

crucial for ecosystem health (Addi & Bareke, 2014; Mickels-Kokwe, 2006). Addressing these risks requires sustainable management to preserve both ecological integrity and economic viability (Mulenga et al., 2011; Vanbergen et al., 2014).

*Traditional beer*

Traditional beer production remains an important livelihood in rural Zambia, contributing to income and cultural practices, especially in regions with high consumption rates (Paltzer et al., 2021). Dominated historically by women, beer brewing offers economic empowerment but also presents complex socioeconomic and environmental challenges (Rogerson, 2019). Increased commercialization has led to social issues, including alcohol dependency and related health problems such as HIV/AIDS and domestic violence (Naamara & Muhwezi, 2014; Rich et al., 2015). The use of agricultural grains for brewing may exacerbate food insecurity, as it diverts resources from essential food production (Paltzer et al., 2021). Environmental degradation from traditional brewing, including deforestation and water pollution, also poses significant concerns (Gumbo et al., 2013). In Zambia, sustainable practices must balance economic gains from beer production with community health and environmental conservation (Norrgren et al., 2000).

*Wild nuts*

Wild nuts and other NTFPs are critical for rural livelihoods in Zambia, providing income and nutrition, particularly for women and children (Kalinda & Bwalya, 2014; Steel et al., 2022). However, commercialization poses sustainability risks, such as deforestation and overharvesting (Murye & Pelser, 2018). Initiatives like Wild Fruits of Africa seek to enhance rural livelihoods, but unsustainable practices threaten ecosystem health and exacerbate poverty (Christian & Kasumi, 2015). Seasonal income from wild nuts, while beneficial, underscores the need for sustainable harvesting to preserve long-term economic and ecological viability (Zulu et al., 2019).

*Wild leafy vegetables*

Wild leafy vegetables contribute significantly to the nutrition and incomes of rural Zambian households, particularly among women (Cyril et al., 2024; Qwabe & Pittawaty, 2023). These nutrient-rich foods enhance food security in resource-poor areas (Mercy et al., 2017). In Zambia, wild leafy vegetables form a substantial part of local economies, with millions of litres of wild foods harvested annually (Arumugam et al., 2020; Steel et al., 2022). Despite their importance, commercialization brings environmental challenges, such as habitat loss and unsustainable harvesting (Murye & Pelser, 2018). The lack of formal cultivation practices exacerbates resource depletion, highlighting the need for integrated approaches that balance economic benefits and environmental sustainability (Arumugam et al., 2020).

*Wild fruits*

Wild fruits, including species like Uapaca kirkiana and Parinari curatellifolia, are integral to the food security and livelihoods of rural Zambian households (Kalaba et al., 2009). Their high nutritional value makes them vital during food-scarce periods (Akinnifesi et al., 2004; Bvenura & Sivakumar, 2017). Beyond consumption, commercialization of wild fruits is a critical income source, with about 80 % of rural households depending on these products (Ickowitz et al., 2021). However, sustainability challenges arise from overharvesting, which threatens biodiversity and ecosystem stability (Hudson et al., 2020). Declining populations of key species such as Dioscorea hirtiflora highlight the need for effective regulatory frameworks to promote sustainable use and mitigate environmental degradation (Anyango et al., 2018).

*Wild tubers*

Wild tubers, including Dioscorea hirtiflora, play a crucial role in the livelihoods of rural Zambians, contributing to food security and income generation (Zulu et al., 2019). Their collection forms a significant part of rural income strategies across Africa (Derebe et al., 2023). However, overharvesting poses risks to biodiversity and threatens the sustainability of wild tuber resources (Murye & Pelser, 2018). In Zambia, declining populations of key species highlight the need for sustainable management to ensure the viability of this critical income source (Zulu et al., 2019).

*Solar PV-based agri-processing and value addition in rural Zambia*

The integration of solar photovoltaic (PV) technology in agri-processing presents a significant opportunity for enhancing rural livelihoods in Zambia. While the high initial costs and limited power output of solar PV remain challenges (Otiti & Soboyejo, 2006; Tong et al., 2015), innovative applications, such as solar-powered irrigation pumps and crop dryers, have demonstrated potential for increasing agricultural productivity and value addition (Tariq et al., 2021). Solar cabinet dryers with forced circulation have been employed to dehydrate local produce, creating employment and reducing post-harvest losses (Tyagi et al., 2024). In Zambia, mechanized cassava processing has been linked to poverty reduction, highlighting the transformative impact of energy access on rural economies (Abass et al., 2017). However, scaling such interventions requires targeted government support and financing mechanisms to ensure affordability and adoption (Middelberg, 2017).

*Productive use of solar PV in rural Zambia*

Beyond agri-processing, solar PV technology plays a crucial role in rural electrification and economic development. In Zambia, micro-hybrid biomass-solar PV power plants have been proposed as a sustainable solution, providing electricity for lighting, refrigeration, and small businesses (Makai & Daniel Chowdhury, 2017; Makai & Popoola, 2024). The integration of solar PV in farm operations has been shown to enhance productivity, reduce reliance on wood fuel, and improve living standards (Chambalile et al., 2024). However, widespread adoption is hindered by high costs, inadequate infrastructure, and limited technical capacity, necessitating targeted policies and financial incentives (Ajayi et al., 2024; Durga et al., 2024).

## Theoretical framework to inform the study

The current study sets out and utilizes the new Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) to help explain the degree to which self-financed solar PV systems in rural areas of Africa impacts the affect rural society and the environmental (see Fig. 1) RUDSHAM integrates three main theoretical frameworks to understand the factors influencing the adoption of renewable energy technologies in rural areas. It combines the Technology Acceptance Model (TAM), Diffusion of Innovations Theory (DOI), and Theory of Planned Behavior (TPB) to focus on internal factors affecting adoption willingness. TAM highlights performance expectancy, effort expectancy, social influence, and facilitating conditions as key drivers of technology adoption (Ajzen, 1991; Davis, 1989; Rogers, 2003; Venkatesh & Davis, 2000). Diffusion of Innovations Theory explains the stages and factors influencing the spread of new technologies over time (Rogers, 2003). TPB suggests that behavioral intentions are shaped by attitudes, subjective norms, and perceived behavioral control (Ajzen, 1991). Additionally, RUDSHAM incorporates Social Learning Theory, which emphasizes the role of observation and imitation in shaping attitudes and adoption decisions (Bandura, 1977). Social dynamics, such as peer effects and active communication within social networks, significantly influence individuals' decisions to adopt renewable energy technologies.

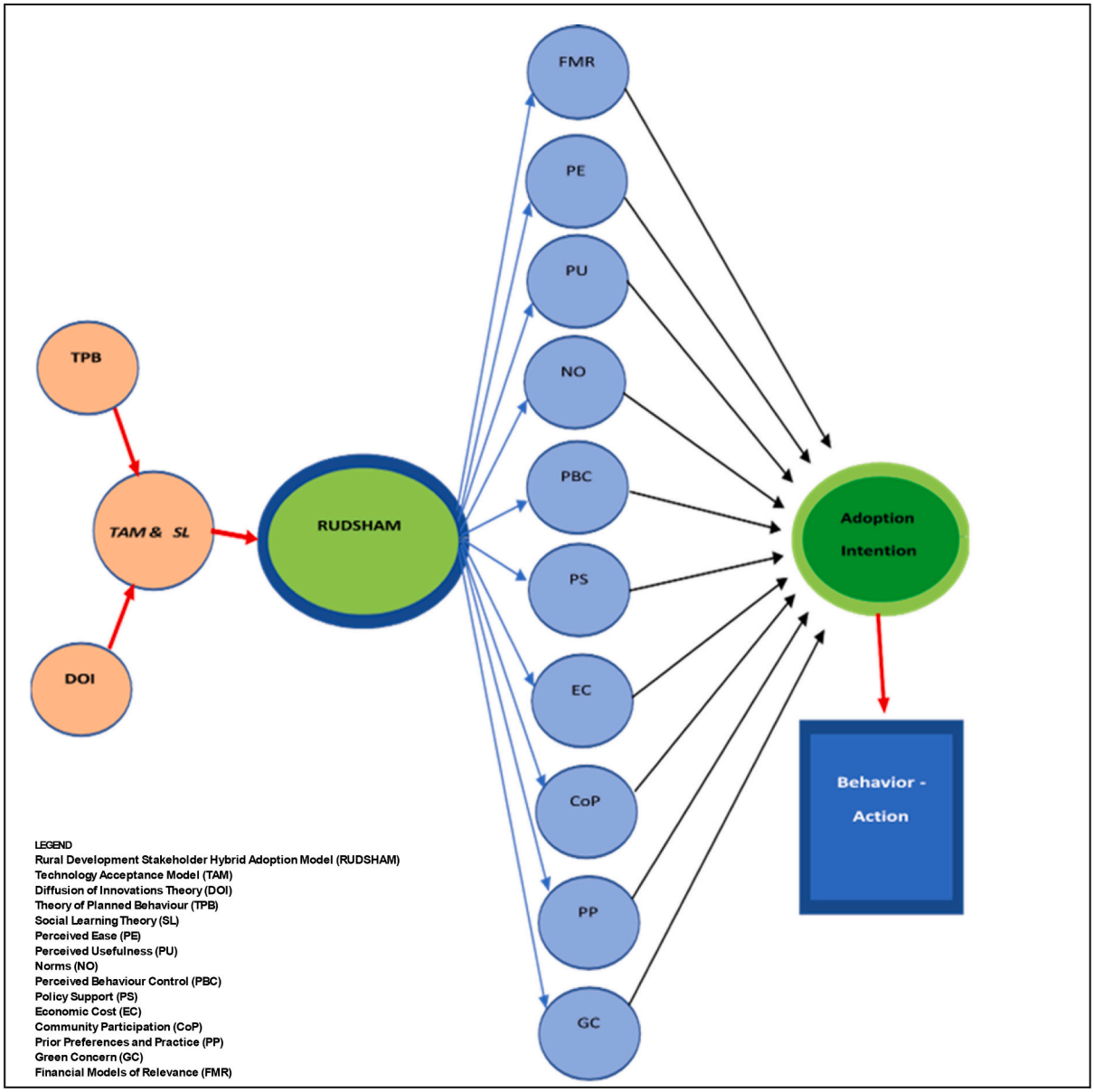


**Fig. 1.** RUDSHAM Hybrid Adoption Model.

By combining internal factors from TAM, DOI, and TPB with external influences from Social Learning Theory and peer effects, RUDSHAM offers a comprehensive understanding of the multifaceted factors driving renewable energy adoption in rural developing areas. This holistic approach recognizes the complex interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviors. The framework provides valuable insights for policymakers, researchers, and practitioners aiming to promote sustainable energy transitions. RUDSHAM's alignment with a mixed-methods research approach, including in-depth interviews, focus groups and observations, ensures a thorough examination of solar PV adoption in rural Zambia. This integration of theoretical and methodological rigor offers a robust foundation for investigating the complex factors impacting solar PV adoption, facilitating the development of effective strategies for sustainable energy development.

The Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) is suitable for analysing the environmental and social impacts of self-financed solar PV systems in rural Zambian rural households. By integrating perceived ease, usefulness, social norms, and behavior control, RUDSHAM captures key factors influencing adoption. Policy support, economic cost, and community participation contextualize the socio-economic environment, while green concern and financial models highlight sustainability and financing challenges. The model's comprehensive approach aligns with assessing energy access, sustainability, and rural livelihoods, offering a valuable theoretical lens to understand household decision-making in the context of solar PV systems adoption. For details on the description of how each attribute of the RUDSHAM framework assisted, refer to appendix B.

## Research methodology

### *Research strategy and data collection methods*

The research was conducted over 6 months (October 2022 to March 2023) across 3 remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), and Chongwe Rural (Lusaka Province) (See Fig. 2). These locations were strategically chosen for their relative isolation and lack of access to the national power grid. A 4-week


**Fig. 2.** Map of Zambia. Map sources: UN 2022. Map of the world.

pre-testing pilot study was conducted with 5 participants in Luano village (Chingola Rural, Copperbelt Province) to ensure the validity and reliability of the research instruments. One research assistant, fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), facilitated data collection. The primary investigator is also fluent in English and has a working knowledge of Bemba, Nyanja and Lamba.

The data collection involved in-depth interviews, ranging in duration from 30 min to 60 min, with 40 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymakers. Additionally, 7 focus group discussions (FGDs), each comprising 8 participants from the selected rural areas (3 from Kapiri, 2 from Mkushi and 2 from Chongwe), were conducted to capture a range of opinions and views from the communities. To address gender sensitivity and dominance issues in FGDs, sessions were facilitated by village headmen or councillors, taking advantage of their trusted positions within the community. Mixed and separate discussions ensured diverse perspectives from both men and women, with participants receiving refreshments and tokens of appreciation.

Recorded interviews and photographs, taken with consent, were securely stored on the University's OneDrive cloud account with restricted access to ensure data security. Data analysis involved coding interview transcripts, using colour codes and NVIVO 14, into specific themes and extracting relevant direct quotations to supplement structured interview data. A pilot study interview was conducted resulting in minor adjustments to the protocol based on the pilot results. This multifaceted qualitative approach, including in-depth interviews, FGDs, photovoice, and observations, ensured the validity and reliability of findings by representing various stakeholder viewpoints.

Ethical approval from the University of Reading Ethics Committee (UK) was obtained in 2022, and informed consent protocols were strictly adhered to, ensuring the study's compliance with ethical standards. By integrating the RUDSHAM framework with rigorous research methods, this study provides valuable insights for policymakers, researchers, and practitioners focused on promoting sustainable energy transitions in Zambia and other developing countries.

## Research findings

### *Income sources in rural Zambia: empirical evidence via RUDSHAM model*

The Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), through interviews and focus group discussions (FGDs), has identified a range of income-generating activities prevalent in rural Zambia. These activities form the backbone of subsistence and local economies but also have varied environmental and social implications. RUDSHAM framework plays a crucial role in supporting the findings of this paper by providing a multidimensional analytical lens to assess solar PV adoption's impact on rural livelihoods in Zambia. The study reveals that income generated from wild honey, traditional beer, wild fruits, and vegetables contributes significantly to household sustainability, often influencing solar PV affordability. For example, Perceived Usefulness (PU) aligns with findings that solar PV enhances livelihoods by enabling investments in productive activities such as honey sales (a2.3) and beer brewing (b2.3). Economic Cost (EC) contextualizes how limited financial resources impact solar PV adoption, as rural households rely on

seasonal income from wild foods to pay for solar lighting systems (c2.1, d2.5). Norms (NO) highlight the interplay between cultural acceptance and economic behavior, such as the ethical dilemmas in honey collection (a3.3) and the unregulated beer industry (b3.4). Additionally, Green Concern (GC) addresses environmental sustainability challenges, such as deforestation linked to honey harvesting (a2.5, a3.2) and the over-exploitation of munkoyo roots (d3.3). Financial Models of Relevance (FMR) further illuminate the need for innovative financing solutions, given that income from wild food trade helps cover solar loan repayments (c2.2, d2.7). Thus, RUDSHAM provides a structured framework for understanding the complex socioeconomic and environmental factors shaping solar PV adoption in rural Zambia.

*Demographic profile*

The study captured a diverse demographic composition of respondents. In terms of age distribution, 35 % were between 19 and 35 years, followed by 34 % aged 46 to 55 years, 19 % aged 36 to 45 years, 9 % aged 56 years and above, and 3 % below 18 years. Gender representation was evenly split, with 50 % male and 50 % female. Monthly income levels varied, with 35 % earning between K5,001 and K10,000, 29 % earning K10,001 to K20,000, 28 % earning below K5,000, and only 8 % earning above K20,000. The majority (78 %) were married, while 18 % were single and 4 % widowed. Education levels were generally low: 64 % had a junior certificate or below, 33 % reported no formal education, and only 3 % held a high school certificate. These demographic insights provide a crucial foundation for understanding the socioeconomic context influencing solar PV adoption in rural Zambia. Solar energy items owned by respondents included primarily solar torches (90 %), solar chargers (80 %), Solar Home Systems (70 %), and a few solar water pumps (5 %).

(a) **Wild honey**

The direct quotations illustrate the economic and cultural importance of wild honey, highlighting both its benefits and challenges. Honey is highly valued for its culinary and medicinal uses, providing a reliable income for many rural households *(a2.2, a2.3, a3.1)*. However, its collection often involves harmful practices such as cutting or burning trees, contributing to deforestation and occasional forest fires *(a1.1, a2.5, a3.2)*. Despite its profitability, honey collection is risky due to bee stings, smoke inhalation, and encounters with wildlife *(a2.4, a3.1)*. High demand has also led to practices like artificial hives and adulteration, reflecting both ingenuity and ethical concerns *(a3.3)*.

***(a1) Illustrative Direct Quotations from Commercial Farmers' Interviews***

*(a1.1) "…That's why people indiscriminately cut trees, even for simple things like honey or ifishimu (Mopani worms) …"*

*(CF Interview 16)*

*(a1.2) "Look at this big tree that has just been cut down…There was something in that tree he wanted, either the Mopani worms or the honey …"*

*(CF Interview 10)*

*(a1.3) "If I take you through this forest, you'll see some beautiful trees that have been cut down…"*

*(CF Interview 11)*

***(a2) Illustrative Direct Quotations from Rural Farmers' Interviews***

*(a2.1) "I collect 'Ubuchi' (Honey) from different places like trees, anthills, or underground burrows…I use smoke to collect the honey from beehives. The problem these days is that there are very few trees."*

*(Chongwe interview 12)*

*(a2.2) "The good thing about honey is that it is easy to store, doesn't go bad, and people love honey - they are willing to buy it as a food sweetener or for medicinal use…"*

*(Luano interview 4)*

*(a2.3) "…a 2.5ltr sells for $15 (K300), and natural honey is always on high demand…it sustained me and helped me buy a good bicycle, household items and even pay back the solar lighting loan…"*

*(Mkushi interview 3)*

*(a2.4) "Honey is not easy to collect… apart from bee stings, there is also smoke inhalation and possible encounter with the snakes..."*

*(Kapiri interview 18)*

*(a2.5) "When the beehive is in a tree… , I start a fire around or in the tree…If the beehive is in a difficult position…, I may cut off the branch or…the tree…"*

*(Kapiri interview 13)*

*(a2.6) "When I find a beehive, …I collect the honey as quickly as possible because if I leave it, someone else might come and take the honey..."*

*(Mkushi interview 8)*

***(a3) Illustrative Direct Quotations from Rural Farmers' FGDs***

*(a3.1) "We can boast of eating pure natural honey… Some people make lots of money from honey, evidenced by their smart phones, iron sheet roofs and bigger solar lighting system loans, but…people sometimes get badly stung and risk their lives."*

*(Mkushi FGD 2)*

*(a3.2) "Sometimes the honey collectors… cut down trees to access the honey. We have seen big trees that end up completely burnt or destroyed in the process… In other cases, they accidentally start forest fires…"*

*(Kapiri FGD 1)*

*(a3.3) "Due to high demand for honey from all over, some households are making artificial beehives. Sadly, other honey traders resort to add other sweet fluids to increase the volume of honey…"*

*(Chongwe FGD 2)*

(b) **Traditional beer**

The direct quotations highlight the dual role of traditional beer in rural communities as both a source of income and a social challenge. While beer brewing, often led by women, supports livelihoods by funding education and household needs *(b2.3, b3.4)*, its unregulated production poses health risks, including illness from unsafe additives *(b3.1, b3.2)*. Excessive consumption drives social issues like violence, criminality, and family breakdowns *(b1.1, b2.1, b3.3)*. The affordability and widespread availability of traditional beer make it culturally significant but also contribute to its overuse and associated health and societal risks *(b3.1, b3.4)*.

***(b1) Illustrative Direct Quotations from Commercial Farmers' Interviews***

*(b1.1) "Beer drinking is a problem in this area, especially for men who don't have jobs... they end up engaging in illegal activities like stealing to raise alcohol money."*

*(CF Interview 16)*

*(b1.2) "I am always careful when driving because if you're not, you might hit a drunk person… Even some women…putting themselves in danger of being sexually harassed..."*

*(CF Interview 11)*

***(b2) Illustrative Direct Quotations from Rural Farmers' Interviews***

*(b2.1) "My husband and I divorced because all he did was drink, womanise, and beat me, especially when he was drunk…"*

*(Kapiri Interview 3)*

*(b2.2) "…some of the men, when drunk, engage in unruly behavior, insult others, become violent, and engage in criminal activities…"*

*(Mkushi interview 4)*

*(b2.3) "Traditional beer (mostly brewed by women), and it has helped many of them to educate their children, have a decent life …., pay for solar lighting for the homes…"*

*(Chongwe Interview 2)*

***(b3) Illustrative Direct Quotations from Rural Farmers' FGDs***

*(b3.1) "Traditional beer is good because it's affordable and helps people relax… However,..because it's unregulated, some brewers end up making fatal brewing mistakes."*

*(Mkushi FGD 2)*

*(b3.2) "You consume traditional beer at your own risk,… many who take it have red/pinkish lips, stomach problems, and poor health… Sometimes, to meet demand, brewers add illegal chemical catalysts…"*

*(Kapiri FGD 1)*

*(b3.3) "Many men in this village are drunkards, and some, out of carelessness and sleeping with prostitutes, have contracted deadly diseases like HIV and STIs…, many children have been orphaned…"*

*(Chongwe FGD 1)*

*(b3.4) "We are aware…the production/sale of kachasu are illegal due to its risks and the unregulated… production. However, it remains popular… due to its affordability and availability"*

*(Chongwe FGD 3)*

(c) **Wild fruits**

Wild fruits play a critical role in rural livelihoods, serving as a source of nutrition, energy, and income. They are consumed, preserved, and sold to urban markets, often aiding households in covering essential expenses like solar lighting loans *(c2.1, c3.2, c3.5)*. However, unsustainable practices, including cutting trees for access or charcoal production, threaten species like Masuku, highlighting the need for conservation *(c2.3, c3.6)*. The cultural significance of these fruits is evident in their diverse uses, such as syrup production from Impundu *(c3.3)*, while equitable access by locals is supported by some commercial farmers *(c1.1, c1.2)*.

***(c1) Illustrative Direct Quotations from Commercial Farmers' Interviews***

*(c1.1) "I allow workers and some villagers to collect wild fruits from my farm,… in a sustainable manner… I understand the importance of living in harmony with the 'owners' of the land."*

*(CF Interview 6)*

*(c1.2) "Since we don't consume all the wild fruits, it's only fair that we allow the locals to collect the fruits which they can eat and sell…"*

*(CF Interview 14)*

***(c2) Illustrative Direct Quotations from Rural Farmers' Interviews***

*(c2.1) "I … sell wild fruits to urban people… It's hard work, but in season, it brings in extra income… to assist in paying back daily/weekly solar lighting system loans."*

*(Kapiri Interview 7)*

*(c2.2) "…From Masuku sales, I make between $4 (K100) and $20 (K500) per day during the harvest season, and this income goes a long way in helping with household expenses… solar chargers, solar lighting, …"*

*(Mkushi interview 1)*

*(c2.3) "Masuku tree numbers are dwindling because some people use them for charcoal burning,… and …cut down… during agricultural land clearing…"*

*(Chongwe Interview 2)*

***(c3) Illustrative Direct Quotations from Rural Farmers' FGDs***

*(c3.1) "Wild fruits are a source of strength as they provide the energy we need."*

*(Chongwe FGD 1)*

*(c3.2) "Wild fruits are liked not just here but by urban people too…. That's why they are sold in every major market in the urban areas"*

*(Chongwe FGD 2)*

*(c3.3) "Many families pick (Impundu fruits) and process them into a sweet syrup, which is used as a sweetener for porridge. This syrup can be preserved for over a year."*

*(Kapiri FGD 1)*

*(c3.4) "Edible wild fruits include Masuku (Uapaca kirkiana), Impundu (Parinari curatellifolia), Intugulu (Afromomum africanum), Ifisongole (Strychnos cocculoides), Kawawasha (Tamarindus indica), Imfungo (Anisophyllea boehmii) etc."*

*(Chongwe FGD 2)*

*(c3.5) "…We consume some, preserve some and sell some to raise some money for salt and sugar."*

*(Kapiri FGD 2)*

*(c3.6) "Masuku trees drop their fruit when ripe, but Imfungo trees don't, so people cut down the branches of big Imfungo trees to access the ripe fruits. However, Masuku trees are quite brittle… so some people have fallen and gotten injured."*

*(Mkushi FGD 1)*

(d) **Wild vegetables and munkoyo**

Wild vegetables and munkoyo serve as essential dietary staples and sources of income for rural households, though their economic returns are modest *(d2.5, d3.1)*. Traditional vegetables such as bondwe and sope are rich in cultural significance and often used as affordable alternatives to western crops, which are more expensive and sometimes preferred in urban areas *(d2.1, d2.2, d2.6)*. Munkoyo, a popular traditional drink, is harvested extensively, yet overharvesting and deforestation threaten its sustainability *(d3.3, d3.5)*. While beneficial, these resources face challenges including limited profits, environmental degradation, and cultural shifts toward commercialised alternatives *(d3.2, d3.5)*.

***(d1) Illustrative Direct Quotations from Commercial Farmers' Interviews***

*(d1.1) "There are many local wild vegetables available, as well as the leaves of sweet potatoes, pumpkins, cassava, and even beans…sometimes they use pounded peanuts in place of cooking oil. I have tried some of these traditional vegetables, and some are quite nice…"*

*(CF Interview 16)*

*(d1.1) "I am familiar with the traditional drink, Munkoyo, and have occasionally enjoyed it. Trade Kings Ltd. has made significant profits by commercializing Maheu..."*

*(CF Interview 4)*

***(d2) Illustrative Direct Quotations from Rural Farmers' Interviews***

*(d2.1) "Apart from eating kalembula (sweet potato leaves), chibwabwa (pumpkin leaves), katapa (cassava leaves), or chimpapila (bean leaves), I collect wild veggies such as bondwe (Amaranthus), sope (sesamum angustifolium), and the okra-like pupwe (Zanthoxylum chalybeum), as well as kanunka (Bidens pilosa or Melanthera albinerva), which are used*

*as relishes… Sesamum angustifolium, apart from being a relish, has medicinal properties…"*

*(Chongwe Interview 3)*

*(d2.2) "…Sadly, some people in urban areas tend to shun and look down upon wild veggies, preferring western vegetables instead…"*

*(Mkushi Interview 4)*

*(d2.3) "Most veggies don't have good profit… Because there are so many farms in the area, we have to travel far to collect the wild veggies."*

*(Mkushi Interview 1)*

*(d2.4) "I wish I could be ordering chikanda (wild orchid), which is more profitable than these wild veggies that I sell because of poverty. My children have to survive and enjoy even the smallest solar lighting package."*

*(Chongwe Interview 1)*

*(d2.5) "I am left with no option but to… survive by collecting and selling wild veggies… I have children to feed…, solar lighting loans to settle…"*

*(Kapiri Interview 17)*

*(d2.6) "…we still eat wild vegetables, but we also like chinese cabbage, rape (kale), spinach, and cabbage, which have overtaken our traditional veggies because they're grown on farms, although they are expensive."*

*(Kapiri Interview 22)*

*(d2.7) "I sell munkoyo (Rhynchosia venulosa roots) here at home and supply the roots to markets in urban areas... The income might not be much, but it helps to buy some relish…, and sometimes to assist in paying back my solar lighting loan."*

*(Kapiri interview 17)*

***(d3) Illustrative Direct Quotations from Rural Farmers' FGDs***

*(d3.1) "I sell wild veggies, but honestly, the income is not much. You need to sell huge volumes just to make a little something…"*

*(Chongwe, FGD 1)*

*(d3.2) "I sell wild veggies… though it doesn't bring in much, it helps me survive… Things are becoming more expensive, rains are becoming rare, fertilizer is spoiling the soil, forests have been turned into farms, fertilizer is expensive,… fertilizer subsidies have been cut…"*

*(Kapiri FGD 2)*

*(d3.3) "We dig to get the roots of the munkoyo shrub, which ultimately dies…"*

*(Kapiri FGD 2)*

*(d3.4) "We are careful to dig pure munkoyo roots and ensure that they are not contaminated with other poisonous roots…"*

*(Chongwe FGD 2)*

*(d3.5) "Due to excessive harvesting of munkoyo roots, loss of forest, and land clearing for agriculture, the munkoyo shrubs have reduced in number…"*

*(Kapiri FGD 2)*

*(d3.6) "…we do not buy munkoyo just from any place. We choose carefully… because some people are unhygienic, and others use magic charms to attract customers and get them spiritually addicted to their drink…"*

*(Mkushi FGD 1)*

## Discussion and interpretations of findings

The RUDSHAM framework enriches the discussion by contextualizing solar PV adoption in rural Zambia's socio-economic and environmental landscape. For example, Perceived Ease (PE) and Perceived Usefulness (PU) highlight solar PV's role in supporting honey production, wild fruit processing, and traditional beer brewing. Norms (NO) and Perceived Behavior Control (PBC) reveal social acceptance and financial flexibility, influencing adoption rates. Economic Cost (EC) and Green Concern (GC) emphasize affordability challenges and environmental sustainability, particularly in wild food harvesting. These attributes collectively inform interpretations on balancing income generation with conservation, emphasizing solar PV's potential for sustainable rural livelihoods. This study, guided by the RUDSHAM framework, reveals a clear relationship between income levels derived from edible NTFPs, sustainability and the adoption of solar PV systems in rural Zambia. Additionally, empirical evidence suggests that individuals with higher incomes, particularly those engaged in ENTFP trade are more likely to afford and invest in advanced solar PV systems.

### *Wild honey*

The empirical evidence gathered from commercial and rural farmers in Zambia highlights the significant role that wild honey harvesting plays in income generation, while also drawing attention to the associated environmental and social challenges. Honey collection, a key non-timber forest product (NTFP), provides nutritional support and crucial financial benefits for a good number of rural households, particularly in remote regions with limited economic opportunities (Mkushi FGD 2). As observed in the interviews, the sale of 2.5 l of wild honey for $15 (K300) has enabled farmers to purchase essential items, such as bicycles and household goods, and even repay solar lighting loans (Mkushi Interview 3). This aligns with research indicating that wild honey hunting and beekeeping are vital to household incomes in Sub-Saharan Africa, supporting livelihoods and food security (Kalinda & Bwalya, 2014; Lowore, 2020). Additionally, empirical findings highlight that wild honey is in high demand for both dietary and medicinal purposes, which further increases its economic value (Luano interview 4). Similar studies in South Africa have also shown how the commercialization of honey has enhanced household welfare, particularly among women, by providing a steady income source (Taruvinga et al., 2023).

However, the environmental consequences of wild honey harvesting are of major concern. Farmers reported the unsustainable practice of cutting down trees to access honey, particularly when beehives are positioned high in the trees (*CF* Interview 16,10,11., Kapiri Interview 13, Kapiri FGD 1), which is corroborated by research highlighting how unregulated honey hunting can lead to deforestation and forest fires (Ricketts & Shackleton, 2020). In the Kapiri focus group, respondents noted that these fires often occur when honey hunters use fire to smoke out bees, leading to unintended forest destruction (Kapiri FGD 1). This practice, while economically beneficial in the short term, jeopardizes forest ecosystems and biodiversity, which could have long-term repercussions for communities reliant on forest resources (Mickels-Kokwe, 2006; Mulenga et al., 2011). Additionally, the drive to meet the growing demand and earn more income has led some households to introduce additives to honey to increase volume which is dangerous especially for innocent people using it for medicinal purposes *etc.* (Chongwe FGD 2).

Moreover, as farmers compete for honey, the destructive behaviors mentioned also indicate a lack of awareness regarding sustainable harvesting practices (*CF* Interview 11). This reflects findings from Lowore (2020), who noted the need for improved training and equipment to mitigate environmental harm. To address these challenges, promoting sustainable beekeeping through formal initiatives, such as the introduction of artificial beehives, could help reduce reliance on destructive practices highlighted in Kapiri FGD 1 and supported by the findings of (Ricketts and Shackleton (2020). However, ongoing obstacles, such as insufficient financial support and limited market access, remain key barriers to the sustainable expansion of the honey sector (Hamauswa et al., 2017). The Mkushi farming block farmers association have an organisation called North Swaka Trust (NST) which is a non-profit organisation that aims to restore and protect the natural biodiversity of the North Swaka and Mkushi Headwaters Forest Reserves to better the ecosystem, the livelihoods of the local communities and the businesses that operate in the area (Stone, 2024). The initiative among other things,

promotes sustainable bee keeping. Thus, while wild honey collection offers substantial economic benefits, achieving a balance between income generation and environmental preservation requires increased investment in sustainable practices and broader conservation efforts.

*Traditional beer*

The integration of self-financed solar photovoltaic (PV) systems in rural Zambia has multifaceted environmental and social implications, particularly in relation to traditional beer production, a prominent source of income for some rural households. Traditional beer production, primarily led by women, has contributed significantly to household income, enabling investments in essential goods such as solar lighting systems, roofing materials, and mobile phones (Chongwe Interview 2). This mirrors the broader trend in sub-Saharan Africa, where traditional beer plays a crucial role in rural economies, offering a sustainable livelihood for many, especially in regions with limited formal employment opportunities (Sawadogo-Lingani et al., 2021). Despite these economic benefits, the commercialization of traditional beer raises important concerns, including adverse social and environmental consequences, as observed both in the empirical evidence and existing literature.

From a social perspective, alcohol abuse has become a pervasive issue in rural communities, exacerbated by the accessibility of traditional beer, particularly potent variants like "kachasu". This has led to increased incidents of domestic violence, criminal activity, and the spread of sexually transmitted infections (STIs), including HIV, as evidenced by interviews with local farmers (Chongwe FGD 1; Mkushi Interview 4). Similar patterns of alcohol-induced social disruption have been documented in other sub-Saharan regions, where traditional alcohol consumption has been linked to heightened sexual risk behaviors and increased HIV transmission (Rich et al., 2015). The economic dependency on beer production, while providing short-term gains, poses long-term risks to community health and social stability, as alcohol expenditure often detracts from critical household needs such as food security (Paltzer et al., 2021).

Environmentally, the production of traditional beer also presents significant challenges. The brewing process, which often involves the use of locally sourced grains, can lead to the overexploitation of agricultural resources and environmental degradation, a trend seen in other industries such as charcoal production (Gumbo et al., 2013). Additionally, health risks related to poor brewing practices are prevalent. As highlighted in Kapiri FGD 1, some brewers introduce chemical catalysts to expedite fermentation, potentially leading to the presence of harmful toxins. The contamination of local water systems and grains, as observed in similar cases in Tanzania and Zambia, underscores the urgent need for improved brewing and storage practices to mitigate public health risks (Kachapulula et al., 2017; Ministry of Information, 2024).

*Wild fruits*

The interplay between self-financed solar photovoltaic (PV) systems and the commercialization of edible non-timber forest products (NFTPs) such as wild fruits in rural Zambia presents both opportunities and challenges. Edible wild fruits, including Masuku (Uapaca kirkiana), Impundu (Parinari curatellifolia), and Intugulu (Afromomum africanum), have emerged as essential resources for rural households, contributing significantly to income and food security. This aligns with literature indicating that wild fruits comprise approximately 80 % of the total fruit intake in rural Zambian households (Ickowitz et al., 2021). Farmers have reported earnings of between $4 (K100) and $20 (K500) per day from the sale of fruits during peak seasons, which provides critical support for household expenses such as school uniforms, airtime, and solar lighting loans (Mkushi Interview 1; Kapiri Interview 7).

However, the economic benefits associated with these wild fruits are counterbalanced by sustainability concerns. For example, Imfungo (Anisophyllea boehmii) trees sometimes badly damaged to access the fruits on big trees (Mkushi FGD 1). Additionally, interviewees noted the declining numbers of wild fruit tree due to practices such as charcoal production and agricultural land clearing (Chongwe Interview 2). This trend echoes findings that highlight the overharvesting of wild fruits driven by economic incentives, which threatens biodiversity and ecosystem stability (Hudson et al., 2020; Murye & Pelser, 2018). The interplay of economic pressures and environmental degradation raises a critical question regarding the sustainability of these resources. While the commercialization of wild fruits could potentially enhance rural economies, it necessitates the implementation of sustainable harvesting practices to prevent further depletion of vital species.

Local farmers also highlighted the socio-cultural value of wild fruits, describing them as "a source of strength," especially during labour-intensive activities such as farming (Chongwe FGD 1). This aligns with existing literature that emphasizes the nutritional and medicinal significance of edible NFTPs in rural diets (Mutelo et al., 2022). Furthermore, the processing of Impundu fruits into syrup for preservation underscores the value of wild fruits in enhancing food security, as households can store them for extended periods (Kapiri FGD 1). Nonetheless, barriers to sustainable income generation persist, including health risks from aflatoxin contamination in certain fruit species, which complicates market participation (Kachapulula et al., 2019). The lack of community-based management systems and regulatory frameworks further exacerbates these challenges, limiting the effectiveness of conservation efforts (Anyango et al., 2018).

*Leafy vegetables and tubers*

The integration of income-financed solar photovoltaic (PV) systems in rural Sub-Saharan Africa highlights the complex relationship between environmental sustainability and income generation through the use of natural resources. In Zambia, wild vegetables, tubers, and munkoyo roots have traditionally provided rural households with essential dietary nutrients and supplemental income. Empirical evidence reveals that these resources serve as both a subsistence strategy and a vital means of income, particularly in economically constrained areas where solar lighting costs are financed through low-income sources like the sale of these natural products (Chongwe Interview 3; Kapiri Interview 17).

Households collecting wild vegetables and tubers benefit significantly from their consumption and potential sales, with wild vegetables like Amaranthus, Sesamum angustifolium, and *Bidens pilosa* used frequently as food and sold for income. However, despite their contributions, interview data from the Kapiri and Mkushi regions show that income generated from selling wild vegetables is often inadequate relative to the labour involved (Mkushi Interview 1; Kapiri FGD 2). This finding aligns with literature indicating that wild vegetables in sub-Saharan Africa are often stigmatized as "food for the poor," undermining their commercial potential (Mercy et al., 2017; Qwabe & Pittawaty, 2023). Furthermore, access to these resources is increasingly constrained due to deforestation and agricultural expansion, which drives harvesting efforts further from settlements (Steel et al., 2022., Kapiri FGD 2).

The economic benefits of selling wild products remain marginal, typically yielding limited income that covers basic household needs but fails to provide substantial financial uplift. For instance, a significant proportion of rural Zambian households, approximately 86 % and 73 %, engage in the collection of wild vegetables and tubers, respectively (Steel et al., 2022), yet empirical accounts suggest that sales rarely exceed minimal earnings (Chongwe FGD 1). However, the cash flow from even these minor transactions supports essential expenses, such as contributions toward household energy costs through solar lighting loan repayments (Kapiri Interview 17; Chongwe Interview 1). The low financial returns are compounded by consumers' negative perceptions, where wild foods are less preferred than Western vegetables, impacting rural vendors' profitability (Mkushi Interview 4., Qwabe & Pittawaty,

2023).

Environmental impacts of wild product collection are another concern. Excessive harvesting and forest clearing have reduced the availability of key species like the munkoyo shrub (Rhynchosia venulosa), which, due to its importance for local beverages, faces sustainability challenges (Kapiri FGD 2., Steel et al., 2022)). Literature echoes these challenges, citing overharvesting, biodiversity loss, and unsustainable land-use practices as significant risks to the wild edible plant ecosystem (Murye & Pelser, 2018; Pitso & Lebese, 2014). Furthermore, with the collection of 380 million litres of wild food annually, there is considerable strain on forest resources that serve multiple ecological roles (Steel et al., 2022). For instance, Kalaba et al. (2009) documented the extensive degradation of Zambian forests and corresponding biodiversity declines, requiring stakeholders to travel longer distances for collection (Steel et al., 2022).

Efforts to promote the conservation and sustainable use of wild vegetables and other plant species are crucial. Researchers have noted the importance of supporting the formal cultivation and market development for indigenous species to alleviate pressure on wild populations and improve income prospects for rural communities (Arumugam et al., 2020; Ochieng et al., 2019). Additionally, fostering local awareness about the nutritional value and environmental benefits of indigenous plants could mitigate social stigma and bolster both consumption and commercial demand, providing a pathway to enhance food security and income stability in these communities (Mungofa et al., 2018; Qwabe & Pittaway, 2023).

## Recommendations for policymakers and practitioners

Transitioning to self-financed solar photovoltaic (PV) systems in rural Zambia presents an opportunity to enhance energy access while addressing environmental and social challenges linked to edible non-timber forest products (ENTFPs). Key recommendations for fostering sustainable solar PV adoption, leveraging local income from ENTFPs, are outlined below.

### *Promotion of sustainable beekeeping and market access development*

The Ministry of Green Economy and Environment, in collaboration with the Forestry Department and NGOs such as North Swaka Trust (NST), should facilitate the adoption of artificial beehives and sustainable honey harvesting techniques. Financial incentives and training programs should be introduced to support rural beekeepers in reducing deforestation caused by destructive harvesting methods. Additionally, partnerships with private sector actors like Zambezi Gold Honey Ltd. can help expand market access, ensuring rural farmers receive fair prices for sustainably harvested honey. Government-backed certification schemes could enhance the credibility of sustainably sourced honey, increasing demand both locally and internationally.

### *Regulation and public health awareness in traditional beer production*

The Ministry of Health, in partnership with the Ministry of Local Government and Rural Development, should implement regulatory frameworks that address the health risks associated with informal beer brewing. Training programs should be conducted in rural communities to promote safe brewing practices and prevent the use of harmful additives. NGOs such as the Zambia Association for Public Health (ZAPH) can support awareness campaigns on responsible alcohol consumption and its social implications. Simultaneously, microfinance initiatives could offer alternative income sources, reducing economic dependency on beer production while mitigating public health concerns.

### *Establishment of community-based wild fruit conservation programs*

The Ministry of Agriculture and the Department of National Parks and Wildlife should collaborate to develop community-led wild fruit conservation programs. Encouraging agroforestry and sustainable harvesting methods will prevent ecosystem degradation. Organizations like the Zambia Forestry and Forest Industries Corporation (ZAFFICO) and the World Wide Fund for Nature (WWF) Zambia can provide technical support and funding for reforestation efforts targeting endangered wild fruit species. Additionally, integrating wild fruits into formal agricultural value chains could boost rural economies, with cooperatives linking small-scale harvesters to urban markets and export opportunities.

### *Incentivizing indigenous vegetable cultivation and market integration*

The Ministry of Agriculture, in partnership with Zambia Agricultural Research Institute (ZARI) and the Food and Agriculture Organization (FAO), should promote the cultivation of indigenous vegetables through seed distribution programs and farmer training initiatives. Enhancing the commercial appeal of traditional vegetables requires consumer awareness campaigns emphasizing their nutritional and economic value. Additionally, partnerships with retailers like Shoprite and local agribusinesses could facilitate the integration of wild vegetables into mainstream markets. Expanding irrigation and storage infrastructure will also enhance productivity, ensuring rural farmers can sustainably scale up indigenous vegetable production.

### *Strengthening legal frameworks for forest resource management*

The Ministry of Lands and Natural Resources, together with the Zambia Environmental Management Agency (ZEMA), should strengthen policy enforcement to curb deforestation linked to wild food harvesting. The introduction of community forest management agreements can empower local groups to oversee resource conservation while benefiting from sustainable economic activities. International development partners such as the United Nations Development Program (UNDP) and the African Development Bank (AfDB) can support financing mechanisms that incentivize rural households to engage in eco-friendly livelihood practices. Additionally, digital monitoring systems using satellite imagery can track deforestation trends, ensuring timely interventions.

## Conclusion and contribution to knowledge and future direction

### *Summary of key findings*

This study highlights the crucial role of edible non-timber forest products (ENTFPs) in financing solar photovoltaic (PV) adoption among rural Zambian households. Wild honey, traditional beer, wild fruits, and leafy vegetables contribute significantly to income but pose environmental risks such as deforestation and biodiversity loss. Social concerns, including alcohol abuse and unsustainable harvesting, further complicate the benefits. While ENTFPs enable solar access, balancing economic gains with sustainability remains a challenge. Strengthening conservation efforts, promoting sustainable harvesting, and improving market accessibility are essential for ensuring long-term environmental and socio-economic stability in rural communities.

### *Contribution to knowledge*

This research advances understanding of rural electrification by linking solar PV adoption with ENTFP-based income. It demonstrates how rural households leverage natural resources to finance decentralized energy solutions while navigating economic and ecological constraints. The study enriches the discourse on informal financing mechanisms for solar access, emphasizing the trade-offs between income generation and environmental sustainability. Findings provide insights for policymakers and practitioners seeking to enhance rural energy transitions through context-specific strategies that align

economic development with conservation priorities. This research informs future interventions promoting sustainable rural livelihoods through renewable energy adoption.

*Introduction of the RUDSHAM framework and its novelty*

The RUDSHAM framework offers a novel approach to analysing solar PV adoption within rural, resource-dependent communities. It integrates socio-economic and environmental factors, providing a structured tool for assessing the viability of decentralized energy solutions. By contextualizing the motivations, barriers, and sustainability concerns of solar adoption, RUDSHAM advances the theoretical understanding of rural energy transitions. Its application extends beyond Zambia, offering a framework adaptable to similar settings globally. The model's novelty lies in its comprehensive perspective, guiding policymakers, researchers, and development practitioners in designing interventions that align energy access with sustainable natural resource management.

*Future research directions*

Longitudinal studies assessing the long-term socio-economic and environmental impacts of ENTFP-driven solar adoption are needed. Investigating market development strategies, including value addition and certification for ENTFPs, could enhance economic opportunities. Additionally, analysing regulatory frameworks and policy influences on ENTFP commercialization and solar adoption would strengthen sustainability efforts in rural electrification.

*Study limitations and recommendations for future research*

Future studies should expand geographical scope, integrate multimethod approaches, and assess technological innovations that support both energy access and environmental conservation. Addressing these limitations will enhance understanding and inform more effective rural development strategies.

## CRediT authorship contribution statement

**Hillary Chanda:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Eugene Mohareb:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Michael Peters:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Chris Harty:** Supervision, Methodology, Funding acquisition, Conceptualization.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2025.101694.

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