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Dynamics of refugee settlements and energy provision: the case of forest stocks in Zambia

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Abstract

Purpose – This article aims to investigate the impact of (1) the establishment of a refugee settlement, (2) the energy demand of a host and refugee population, (3) the residence time of refugees and (4) interventions in the energy sector on sustainable utilization of the forest.

Design/methodology/approach – Refugee movements from the Democratic Republic of Congo and settlement construction in a Zambian host society provide the setting. An agent-based model is developed. It uses survey data from 277 Zambian households, geographic information system coordinates and supplementary data inputs.

Findings – The future forest stock remains up to 30 years without an influx of refugees. Refugee developments completely deplete the forest over time. The settlement construction severely impacts the forest, while refugees' energy needs seem less significant. Compared with the repatriation of refugees, permanent integration has no influential impact on forest resources. Interventions in the energy sector through alternative sources slow down deforestation. Once a camp is constructed, tree cutting by hosts causes forest covers to decline even if alternative energy is provided.

Practical implications – The analysis is useful for comparable host–refugee settings and United Nations High Commissioner for Refugees interventions in settlement situations. Forest and energy sector interventions should involve host and refugee stakeholders.

Originality/value – This article adds value through an agent-based model in the Zambian deforestation–refugee context. The study has a pilot character within the United Nation's Comprehensive Refugee Response Framework. It fills a gap in long-term assessments of refugee presence in local host communities.

Keywords Agent-based model, Comprehensive refugee response framework, Deforestation, Energy provision, Integration, Sustainable development, Refugee camp, Zambia

Paper type Research paper

1. Introduction

The current number of refugees is at an all-time peak. At the end of 2020, the number of refugees worldwide was 26.4m due to persecution, conflict, violence, human rights violation or events seriously disturbing public order. Conditions are particularly vulnerable in

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developing countries, where most refugees live in countries neighboring their country of origin. The African continent is particularly prominent in this context, which accounts for around one-third of all refugees (UNHCR, 2021). A large proportion resides in about 800 camps on the continent (Maystadt *et al.*, 2020), often in poor rural areas where inhabitants struggle to make a living (Maystadt and Verwimp, 2014). Many refugees spend years to decades in camps (Esses *et al.*, 2017), with an average length of displacement between 10 and 15 years (Devictor and Do, 2017).

Scientific evidence highlights heightened environmental impacts caused by a settlement (Maystadt *et al.*, 2019; Fisk, 2019) and increased competition for scarce natural resources between hosts and refugees (Agblorti and Grant, 2019; Barman, 2020). Researchers particularly emphasize forest loss, i.e. deforestation, due to the development of a settlement (Maystadt *et al.*, 2020; Tafere, 2018) and the respective population pressure (Bernard *et al.*, 2020). However, the protection of forests is of paramount importance: they play an essential role in the nutrition of rural communities (Delvaux and Paloma, 2018; Rowland *et al.*, 2017) and impact households' food security (Mbow *et al.*, 2014). Forest products also support income generation, which makes them particularly attractive for resource-poor farmers (Langat *et al.*, 2016; Leßmeister *et al.*, 2018). In addition, rural households are highly dependent on forest resources as their primary source of energy (Bwalya, 2013). Finally, forests contribute to ecosystem services (Brockerhoff *et al.*, 2017).

Despite the recent attention to various refugee issues, more research is needed on long-term assessments of refugee presence in local host communities (Al-Husban and Adams, 2016; Kreibaum, 2016; Maystadt and Duranton, 2018). Most of the current studies on refugee influxes focus on short-term consequences (Salehyan, 2019), but many refugee crises are protracted, and while camps exist for several decades (see Alix-Garcia *et al.*, 2018; Tafere, 2018), they grow from remote tent settlements to city-sized camps (see Al-Husban and Adams, 2016; Maystadt and Duranton, 2018). Several authors emphasize the importance of addressing the neglected issue of sustainability when assessing the impacts of refugees on host communities (Al-Husban and Adams, 2016; Leiterer *et al.*, 2018; Tafere, 2018). Therefore, this paper gains relevance in the context of Sustainable Development Goals (SDGs). As part of Agenda 2030, including refugees in regular development planning is essential, for instance, on SDG 15 (Life on Land).

The article investigates a case study region in rural Zambia. Deforestation is a severe problem in this country because of clearing forests for agricultural purposes (Gronau *et al.*, 2018; USAID/Zambia, 2016; Vinya *et al.*, 2012). Human energy requirements further exacerbate forest degradation (Baltruszewicz *et al.*, 2021) as trees are cut down for firewood or charcoal production (Matakala *et al.*, 2015). The Zambian deforestation rate is among the highest in the world (Parduhn and Frantz, 2018). Deforestation estimates range from 250,000 to 300,000 hectares per year (Day *et al.*, 2014; Matakala *et al.*, 2015). In late 2017, northern Zambia became an immigration hotspot as thousands of Congolese crossed the border in response to local conflicts. The Zambian government set up a settlement called the "Mantapala settlement" and rolled out the Comprehensive Refugee Response Framework (CRRF) by the United Nations (UN) (UNHCR, 2019).

The problem of deforestation and unsustainable forest utilization, recent refugee movements from the Democratic Republic of Congo (DRC) and the subsequent settlement construction in a Zambian host society provide a suitable setting to explore this topic. This paper aims to contribute to the literature by answering the following four research questions: what is the impact of (1) the establishment of a refugee settlement, (2) the energy demand of a host and refugee population, (3) the residence time of refugees and (4) interventions in the energy sector on sustainable utilization of the forest stock? The methodology of agent-based modeling (ABM) is applied to answer these questions. To our knowledge, this article is the first study that uses an agent-based model in the Zambian deforestation–refugee context. Within the scope of the CRRF of the UN, the study has a pilot character.

2. Literature review

Several studies confirm that refugee camps intensify environmental stress (Alix-Garcia *et al.*, 2018; Barman, 2020; Fisk, 2019). A higher rate of deforestation is visible in the Cox's Bazar refugee camp in Bangladesh, holding nearly one million people. Refugees and native migrants seeking economic opportunities are drivers of this deforestation (Dampha *et al.*, 2022). For the Cox's Bazar refugee camp, the literature suggests a visible effect even in protected areas, indicating the importance of suitable strategies to protect the environment (Hasan *et al.*, 2021). Tafere (2018) finds that deforestation (for camp and shelter construction and agricultural purposes), firewood extraction (for energy production), water pollution, soil overexploitation and biodiversity destruction are environmental effects in and around selected refugee camps in East Africa. The author concludes that refugees are usually settled in environmentally sensitive rural areas, and especially the initial arrival phase of refugees, when the settlement is established, is accompanied by severe environmental impacts. Literature suggests geographical differences are important for environmental effects, including the pressure of the population size (Abel *et al.*, 2021). Leiterer *et al.* (2018) estimate a decrease in forest covers up to 50% in areas around a refugee settlement in South Sudan, caused by the need for camp and road construction materials and daily domestic energy consumption. A possible conflict area is natural resources in settlement surroundings, i.e. the competition for scarce natural resources between local communities and refugees (Aregai and Bedemariam, 2020; Barman, 2020; Bernard *et al.*, 2020; Fisk, 2019; Gronau and Ruesink, 2021). A sudden rise in population leads to increased socioeconomic conflicts because the demand for space and energy rises while the environmental quality decreases (Maystadt *et al.*, 2019). Drawing on data from five refugee camps in Ghana, Agblorti and Grant (2019) found that over 50% of the host–refugee conflicts between 2003 and 2014 related to using environmental resources, such as cutting trees for fuelwood and charcoal. According to Aregai and Bedemariam (2020), refugees' negative impacts intensify when accommodated in a large camp in one location. Smaller groups evenly distributed throughout an area have less effect on the environment. It is not used as intensively and therefore has more time to recover. However, Smith *et al.* (2019) find no evidence of environmental impacts from the presence of refugees in Ethiopia and Djibouti.

Focusing on the methodology of this article, ABM is used in a wide range of refugee-related settings, such as the spread of cholera (Crooks and Hailegiorgis, 2014), humanitarian assistance policies for health and safety (Anderson *et al.*, 2007) and behavior of military groups within refugee camps (Johnson *et al.*, 2009). In addition, the literature focuses on disaster-driven (climate change) migration (Entwisle *et al.*, 2016), system support for refugee settlement planning (Drakaki *et al.*, 2018) and predictions of refugee movements (Suleimenova *et al.*, 2017). Emphasis is on migration simulations to analyze human migration's influencing factors (motives), behaviors and decision-making (Klabunde and Willekens, 2016). Concerning host societies, Drakaki *et al.* (2018) highlight the need to incorporate host communities in ABM refugee considerations. Finally, ABM is applied in the forest context (Deadman *et al.*, 2004; Heckbert *et al.*, 2010; Manson and Evans, 2007). Evans and Kelley (2008) assess South Central Indiana's transition from deforestation to forest regrowth. Zhang *et al.* (2022) highlight the interrelation between humans and the environment and find targeting-specific plots with restoration policies useful. Other researchers examine the effects of changes in land-use policies on forest covers (Guzy *et al.*, 2008; Robinson and Brown, 2009) and the adaptation to changes in the forestry sector (Blanco *et al.*, 2017). Purnomo *et al.* (2013) use ABM to implement measures aligned with the UN initiative on reducing emissions from deforestation and forest degradation (REDD+) in developing countries. From a methodological perspective, this research article adds to the scientific literature by applying the methodology of ABM to a Zambian case study in the deforestation–refugee context.

3. Methodology and data

3.1 Study area

The study area, Mantapala, is situated in the Luapula Province, bordering the DRC. It locates in a rural forest area, about 20 km from the nearest small town, Nchelenge, and over 1,000 km from the capital, Lusaka. The area has poor infrastructure and is marked by severe poverty and food insecurity (Gronau and Ruesink, 2021). Subsistence agriculture and forest resource extraction are important parts of households' livelihoods in Mantapala (Gronau *et al.*, 2018).

The Miombo woodland dominates the forest landscape, which suffers from high deforestation (Chidumayo, 2019a). Major drivers of forest degradation are the extraction of wood for energy (Baltruszewicz *et al.*, 2021) and forest clearing for agriculture (Day *et al.*, 2014; USAID/Zambia, 2016; Vinya *et al.*, 2012). In the province, more than 90% of households live without an electricity connection. Accordingly, firewood and charcoal generate almost all energy for domestic use (Central Statistical Office, 2016). The use of forest resources is unsustainable (Syampungani *et al.*, 2009) because of continued high annual deforestation rates (Day *et al.*, 2014; Matakala *et al.*, 2015). Area records show that the forest area in Mantapala has declined significantly since 1990 (Gronau *et al.*, 2018). On the contrary, the Zambian population increased continuously, with annual population growth rates between 2 and 3.5% (World Bank, 2021), further increasing pressure on forest resources.

Zambia is important in providing refuge for displaced people from the fragile DRC. Recurring security issues in late 2017 caused thousands of Congolese to cross the northern Zambian border to seek protection. The Zambian government decided, in early 2018, to establish the "Mantapala settlement" because of the continuous population influx. The camp is located within a rural host society of 277 households (1,673 residents) from eight villages. Each village comprises about 10–80 households within a radius of 9 kilometers (km) around the settlement (Gronau and Ruesink, 2021). In total, the Mantapala area covers about 13,000 hectares (Gronau *et al.*, 2018). Around 8,000 hectares relate to the settlement, accommodating about 15,231 Congolese (UNHCR, 2020a). In total, 3,650 refugee households reside in the Mantapala settlement (UNHCR, 2018). Hence, the settlement occupies more than half of the study area, and the host-to-refugee ratio is approximately 1:10. Zambia provides a favorable policy environment for refugee integration into host societies. The country follows international conventions on the rights of refugees and asylum seekers and the UN 2030 Agenda to "leave no one behind." In addition, the country collaborates with the United Nations High Commissioner for Refugees (UNHCR) and UN agencies to achieve sustainable solutions for host–refugee communities in line with the SDGs (UNHCR, 2020a). As a result, the Zambian government rolled out the CRRF in November 2017 (UNHCR, 2019).

3.2 Data collection

The paper takes advantage of census data collected on 277 households from eight villages in April 2018 during a four-week field research as part of the "Food Security in Rural Zambia (FoSeZa) project funded by the German Federal Ministry of Food and Agriculture. In each household, the head was interviewed using a structured questionnaire, including information on various areas of life. For more information on the data collection and study site, see the following recent publications: Gronau and Ruesink (2021) and Stadtbäumer *et al.* (2022).

3.3 The methodology of agent-based modeling

ABM is an innovative research approach to conduct computer-based experiments. It is a computational methodology to explore complex systems. The core idea is to model agent–environment interactions. An agent represents an autonomous individual element, subject to certain heterogeneous properties (characteristics) and behaviors (actions and goals). The environment (setting) is the landscape in which agents interact (Wilensky and Rand, 2015). ABM's bottom-up approach features nonlinear model dynamics (interactions) driven primarily by microlevel behavior development (Filatova *et al.*, 2016). Individuals' resulting decisions and interactions determine dynamics at the macro level (Wilensky and Rand, 2015). The investigation of heterogeneous (individual) agents is a key characteristic of ABM (Britz *et al.*, 2013).

3.4 Description of the agent-based model

The overall purpose of the model is to simulate the future development of the forest stock in a rural host–refugee setting in Zambia. It aims to investigate sustainable forest utilization and its implications for the energy sector. Furthermore, the model seeks to analyze the impact of future developments as it connects to refugee and forestry management plans and is thus useful to policy-makers and decision-makers.

The model distinguishes between two types of agents, namely humans and trees. *Humans* represent the household level. The model differentiates between initial, new and refugee households. Household agents are mobile and can move around the whole area to (1) cut trees and/or (2) slash and burn trees for agriculture. (1) Tree cutting involves two goals: fulfilling their energy requirement and/or housing material and sales. Households' individual tree-cutting behavior (number of trees cut per year) links to current energy needs. (2) The humans' slash and burn procedure connects to an indicator of whether slash and burn is practiced, a goal of the behavior and the current number of trees slashed and burned by households. The targets refer to a period of one year before the decision is made again. According to the household survey, the initial host community is heterogeneous, with individual values for each variable. Population growth in the study area translates into the new (additional) households, whose characteristics derive from the survey and are assumed to be homogeneous. For the refugee development in the study area, a second type of agent is implemented into the model, namely refugee households. Despite their different attributes, the same behavioral rules apply to all households. The third type of agent is *trees*. Their attributes are *growth* and *weight*. Trees are immobile, but households interact with trees through their cutting behavior. If a household cuts down a tree and/or engages in slash and burn agriculture, the tree dies, i.e. it disappears from the model. However, the model includes annual forest regrowth.

The model environment is the structure in which the agents live and interact. The area consists of individual patches. Each patch represents 1 km^2, summing up to 130 patches, i.e. a representation of the 130-km^2 study area. Based on GIS (geographic information system) data, the distribution of households, villages and the settlement reflects the geographic structure of the study area. One time step (tick) in the model represents one month. The time horizon of the model is 30 years. Global variables are a year counter, a seed for reproducibility, the number of cut trees and energy gained from trees.

Each model run starts with the initialization procedure. Specific actions are performed monthly (each model tick) and at the beginning/end of a year. Each time step, the households can cut down trees and/or practice slash and burn to fulfill their targets. As long as they do not reach their goal, households continue to cut trees if available. As a result, trees can die at any time step, which reduces the number of trees. Humans can store trees if they reach a surplus within the period. New households emerge at the end of a year, according to the population growth rate, and new trees appear based on the forest regrowth rate.

The most important design concepts are tree-cutting behavior and slash and burn activities as a cultivation practice. Deforestation emerges because of this human behavior. Each household cuts trees to achieve its goals, i.e. to gain energy, housing, sales of firewood and charcoal (living) and/or for land generation (slash and burn). Figure 1 provides an

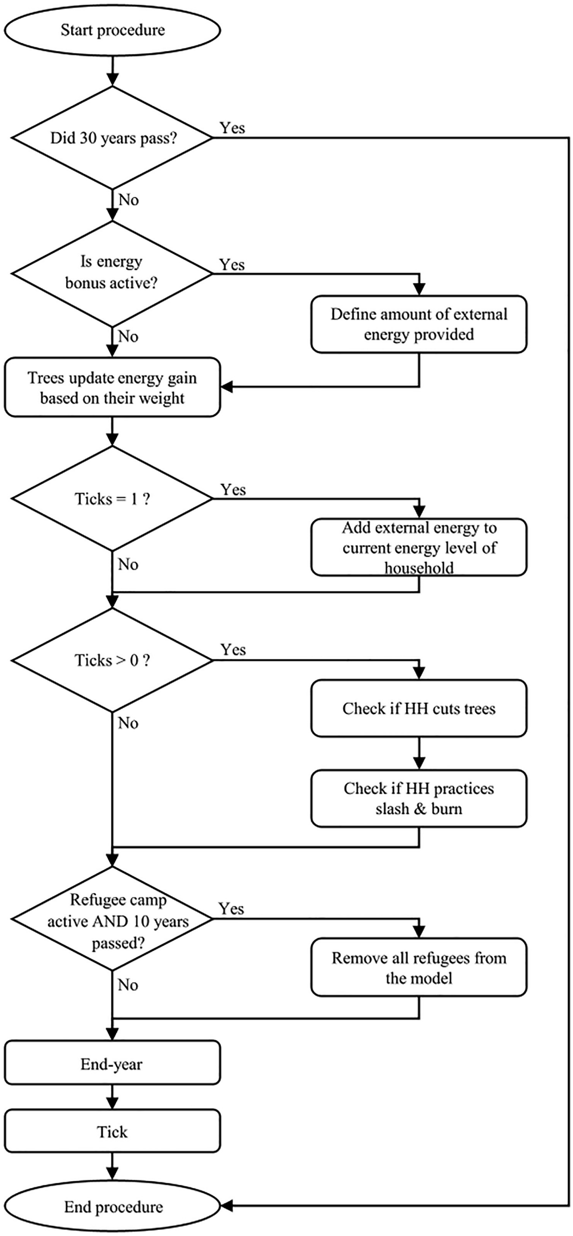

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Figure 1.
Flowchart of actions

overview of the procedures within the agent-based model. It represents the actions and decisions of agents in the model each year. External energy adds to the households' energy level in the first month of each year (ticks = 1).

Further important procedures conducted each month (if ticks > 0) are "check if household cuts trees" and "check if household practices slash and burn." These actions represent deforestation behavior. The "end-year" procedure operates after 12 ticks (one year) to check if a household can achieve its goals and adjust the current number of trees. Additionally, the year counter increases by one, trees are growing by weight and new trees and households are created based on growth rates.

The main model output is the forest stock development over time. We use population size/pressure, regrowth patterns and the timeline to analyze sustainable forest utilization. Household behavior is constant. Each household has yearly goals to fulfill energy requirements and tree requirements for other purposes, like housing or selling charcoal. It stops cutting trees and/or practicing slash and burn if it reaches the targets. A human seeks the nearest tree to its location. While a household moves and interacts with the tree system, the trees are static agents and distributed randomly. Host households are located in their respective villages, and the refugee households are distributed around the central point of the camp based on global positioning system (GPS) coordinates. The location of newly created households by population growth is random, as well as the location of newly created trees. Since the model works with randomness, all simulations are run multiple times. Households are represented as individual agents, while one tree in the model is assumed to represent 100 trees in the real world. At the end of each year, the model reports the number of trees, total population size and number of unsatisfied households. A household is unsatisfied if it cannot reach one of its goals for the year. Finally, it evaluates sustainable forest utilization. The analysis uses the NetLogo software for ABM (see Wilensky and Rand, 2015).

Model data are primarily from the household survey, and scientific literature complements the input parameters. To locate households, GPS data are utilized. Table 1 provides an overview of the parameters for the agent-based model. The energy content of a tree is calculated to reveal the number of trees needed to fulfill households' energy demands. For calculating the weight of a tree, the aboveground biomass for Wet Miombo forests, which is 82,700 kg per ha (Chidumayo, 2019b), is divided by the tree density. The average weight of a tree in Mantapala is thus 138 kg. The tree energy content per kg is 13.3 megajoule (MJ) (Francescato *et al.*, 2008). Hence, the net energy value of a tree is estimated at 1,835 MJ. Dividing households' yearly energy needs (57,000 MJ) by the energy content of a tree (1,835 MJ per tree) reveals the necessary number of trees to fulfill the energy demand per household (31 trees). According to the yearly tree growth, the energy provision of a tree increases. As a result, the amount of energy a household obtains from cutting a tree depends on the age and the resulting weight of a tree.

The agent-based model aims to analyze deforestation behavior under different conditions. Four scenarios are conducted to evaluate sustainable forest utilization. It is assumed that a declining forest stock in the ABM indicates nonsustainable forest use behavior, and the *Maximum Sustainable Yield* is exceeded (collapse of the forest). Table 2 provides an overview of the simulations.

First, a baseline simulation investigates the situation before establishing the refugee settlement. It focuses only on the rural community, forest characteristics and population growth. The baseline provides a benchmark and enables the comparison of the model outcome without external influences with the other scenarios.

Second, a "no-show" refugee simulation constructs the settlement without refugee arrivals. The analysis of this scenario visualizes the individual effect of the space needed for the settlement. This way, it is possible to differentiate between the impact of the settlement construction and the energy demand of refugees.

Third, the refugee simulation considers constructing an 80-km^2 settlement area and subsequent deforestation, i.e. reducing 4,792,000 trees from the forest stock. This reduction of trees represents space and wood needed for the housing of the refugees. The simulation

Variable	Value	Source
Mantapala area	13,000 ha	Gronau *et al.* (2018)
Owned land	2,280 ha	Survey data
Forest area	10,720 ha	Own calculation
Tree density, Miombo forests	599 trees per ha	Chidumayo (2019b)
Total number of trees in Mantapala	6,420,681	Own calculation
Average tree growth for Miombo forests	2,490 kg per ha	Chidumayo (1991)
Yearly growth of a tree in kg	4 kg per tree	Own calculation
Tree growth rate	3%	Frost (1996)
Number of initial households	277	Survey data
Village coordinates	1–8	GPS data
Population growth rate	3%	World Bank (2021)
Refugee camp coordinates	9	GPS data
Size of refugee settlement	8,000 ha	UNHCR (2020a)
Destroyed trees by camp construction	4,792,000 trees	Own calculation
Number of refugee households	3,650	UNHCR (2018)
Refugees using firewood for energy	88%	UNHCR (2020b)
Yearly rural energy requirement/demand	57,000 MJ per household	Baltruszewicz *et al.* (2021)
Aboveground biomass, Miombo forests	82,700 kg per ha	Chidumayo (2019b)
Average weight of a tree in Mantapala	138 kg per tree	Own calculation
Energy content per tree per kg	13.3 MJ	Francescato *et al.* (2008)
Energy content of a tree in Mantapala	1,835 MJ	Own calculation
Number of trees to fulfill households' yearly energy demand	31 trees	Own calculation
Papyrus area in Mantapala	30 ha	Gronau *et al.* (2018)
Harvesting potential of papyrus	90%	Gronau *et al.* (2018)
Conversion factor for substituting forestland against wetland	1.05	Gronau *et al.* (2018)
Protected trees by papyrus utilization	16,173 trees	Own calculation
Yearly initial and refugee households' tree utilization for energy	121,737 trees	Own calculation
Share of tree protection by papyrus utilization for energy	10%	Own calculation

Source(s): Authors' own presentation

Table 1. Input data for the agent-based model

Simulation	Purpose	Options	Variable changes
Baseline	Provide a baseline without external changes	None	None – baseline
Refugee settlement	Effect of refugees on forest stock	A: permanent residence	Refugees stay in model
		B: 10-year residence	Refugees are excluded from the model after 10 years
Refugee settlement without refugees	Find the effect of a settlement construction on the forest stock	None	The settlement area reduces the number of initial trees
Energy sector interventions	Investigate the effect of different policy approaches on forest resources	1: 100% external energy	External energy = average yearly demand
		2: 50% external energy	External energy = average yearly demand/2
		3: 10% external energy	External energy = average yearly demand/10

Source(s): Authors' own presentation

Table 2. Overview of simulations

considers two variations: (1) permanent residence of refugees. It is a proxy for the CRRF policy, anticipating refugee integration into host communities (see Gronau and Ruesink, 2021). (2) A 10-year limit on the residence of refugees. It represents the average length of displacement of refugees (see Devictor and Do, 2017).

Fourth, based on the previous simulation, energy intervention simulations, in the form of alternative/external energy provision, seek to reduce the pressure on forest resources. The households receive a fixed amount of external energy at the beginning of each year on top of their current energy stock. Agents thus do not solely rely on wood to fulfill their energy demand, leading to reduced cutting levels. Each household adjusts the value of the variable external energy according to the chosen scenario. A rural Zambian household's average yearly energy demand is used as guidance. Three variations of alternative (external) energy supply/provision are investigated: the alternative energy source provides (1) the full, (2) the half or (3) one-tenth of households' energy demand. A hypothetical local energy grid is established for the case where all (100%) and a half (50%) of the population's energy demand are provided. An alternative power supply system proposed for rural communities is a hybrid renewable energy system (HRES). An HRES relies on multiple energy technologies (solar photo voltaic, wind, batteries and biogas generators) to secure a reliable power supply backed up by diesel generators in emergencies (Neves *et al.*, 2021). The third variation uses papyrus as an alternative energy source, a suitable wood fuel substitute. Based on wetland and papyrus data (Gronau *et al.*, 2018), the average tree density per hectare (Chidumayo, 2019b) and rural households' average energy demand (Baltruszewicz *et al.*, 2021), it is estimated that papyrus resources could account for around 10% of the energy demand in Mantapala. Therefore, the fourth simulation approach shows the effect of different policy approaches on forest resources in a refugee context.

4. Empirical results and analysis

4.1 Baseline simulation

The baseline simulation reveals a future forest stock and rural population development without refugees. The agent-based model shows that the number of trees and households increases over time. The number of households more than doubled within 30 years after the setup, and the forest stock remains. Agents extract less than the *Maximum Sustainable Yield*. However, the general trend in Zambia is deforestation (Day *et al.*, 2014; Matakala *et al.*, 2015; Parduhn and Frantz, 2018). Two model parameters need attention here: the tree growth rate might overestimate the forest stock development (set too high), whereas the population growth rate might underestimate the pressure (set too low).

4.2 Refugee settlement simulation

In the refugee settlement simulation A, refugees are integrated into the host society and stay permanently. Because of the influx of population and the construction of the camp, the initial number of households is higher, and the number of trees is lower than in the baseline (Figure 2). The population is continuously increasing every year, which is accompanied by a decreasing forest cover over time. Given that one tree in the model represents 100 trees in real life, the households in the model store these trees until they use up their stock and collect wood again. This storage behavior of most households reveals a stronger tree decline after three and six years (years of cutting), followed by less cutting in between as the spare firewood from the stock can be used. According to this simulation, in 2024, the forest system will collapse. By adding refugee developments to the model, the runtime is drastically reduced to six years, i.e. after six years, all trees disappear. Significantly, the drastic reduction of the forest stock by the settlement construction affects regrowth, followed by higher

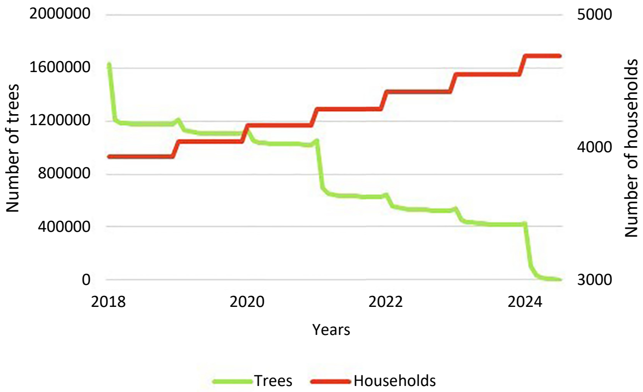

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Figure 2. Refugee settlement simulation A with permanent residence

population demand for energy, leading to unsustainable forest use. An assumption that needs attention is the representation of 100 trees as one tree in the model setting. Even households with a lower demand are forced to cut 100 trees. However, the excess can be stored and transferred to the following years. The model's last year is thus an indication of the earliest full forest degradation, but it can be assumed that some trees remain longer until complete deforestation occurs.

The results of a 10-year limitation (Simulation B) are similar to the permanent residence case (Simulation A). The restriction is irrelevant as the forest system is wholly degraded after six years. If the camp closes earlier, forest stocks could have been preserved a little longer, but the stand will still not recover. Therefore, it is essential to establish community programs to address critical developments in the living environment of refugees and hosts at an early stage (Gronau and Ruesink, 2021).

4.3 Refugee settlement simulation without refugees

In this simulation, the refugee settlement area is cleared of trees, but no refugees arrive. The results are shown in Figure 3. The construction of an 80-km^2 settlement area reduces the forest stock by 4,792,000 trees. The forest system cannot recover from this shock despite

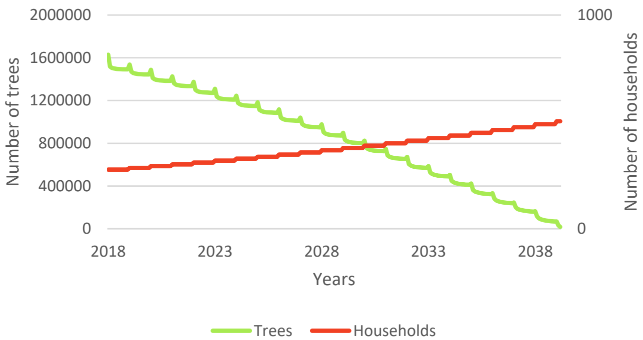

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Figure 3. Refugee camp simulation without refugees

considering tree growth rates. While the number of households is increasing, tree numbers decline over time. After 21 years, in 2038, the forest stock is completely exhausted. The results underline creating space for the camp by cutting trees is already too much for the forest stand. After the settlement construction, tree utilization by the host community is too high for sustainable forest recovery. Thus, while refugees accelerate deforestation, the destruction of forest stocks is not caused by the refugees themselves but by the construction and space requirements of the camp.

4.4 Simulation of energy sector interventions

A hypothetical local energy grid provides the populations' full energy demand in simulations A1 and B1. A 100% energy provision is facilitated by an HRES, i.e. no need for any household (initial, refugee, new) to cut down trees for energy. The energy simulation investigates the permanent (A1) and 10-year limitation (B1) cases. Results are identical for the first 10 years (Figure 4). In 2028, the population in Simulation B1 decreases sharply due to the repatriation of the refugees but then rises again, driven by continued population growth of the initial households (host society). Compared to simulations A and B without an alternative energy supply, the model's runtime extends by 18 years. Energy sector interventions would be successful because the forest stock would last 18 additional years.

Despite an alternative energy supply, the simulations are unsustainable because the forest will be degraded entirely in 2042. However, regardless of the refugees' residence and although the populations' total energy demand is covered, the forest stock decreases in both simulations. Deforestation still exists and is practiced only by the inhabitants of the villages (new and initial households) for housing materials, sales of firewood and charcoal (income generation) and land generation through slash and burn agriculture. Therefore, less trees are needed than in the baseline scenario, but the forest use is not sustainable. The provision of 100% of the energy demand leads to a steady decrease in tree resources despite the repatriation of refugees. They do not cut trees because the external energy covers their demand completely. It does not impact tree resources whether they leave after 10 years or not. The main issue, therefore, is the massive deforestation caused by the camp construction (8,000 ha of forestland), which has already put too much pressure on forest resources to recover in combination with the continuous resource demand by the host community. Hence, it is not a matter of the energy needs of the refugees.

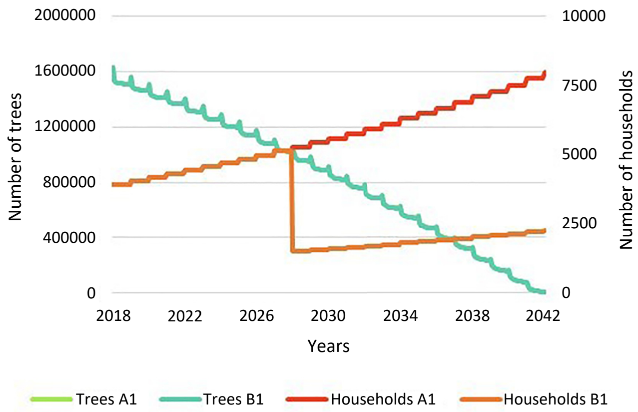

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Figure 4.
Simulation A1 and B1

Simulations A2 and B2 assume a hypothetical local energy grid (HRES) provides half the energy demand. The population is growing over time (Figure 5), but with the outflow of refugees in 2028, the population in B2 declines. Forest covers show a negative trend, regardless of the length of stay of refugees. Providing half of the energy demand extends forest survival by four years to 2028, compared to the simulation with no energy intervention (A and B), but still undercuts the 100% provision (A1 and B1). An intervention in the energy sector for alternative energy provision expands the runtime, but forest utilization is still not sustainable.

The third energy sector intervention investigates papyrus bioenergy supplies as an alternative. Papyrus covers one-tenth of the energy demand of each household (Figure 6). The population steadily increases over time, whereas the forest stock is declining. After seven years, in 2025, the forest stock will be thoroughly degraded. The two simulations have no visible difference as the forest stocks are depleted before the refugees leave. The utilization of papyrus as an energy alternative is no sustainable solution. Providing 10% of the energy demand is insufficient, and households still have to cut trees for energy purposes. The

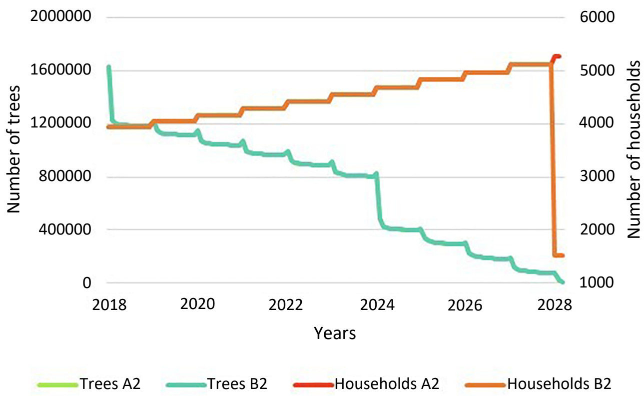

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Figure 5.
Simulation A2 and B2

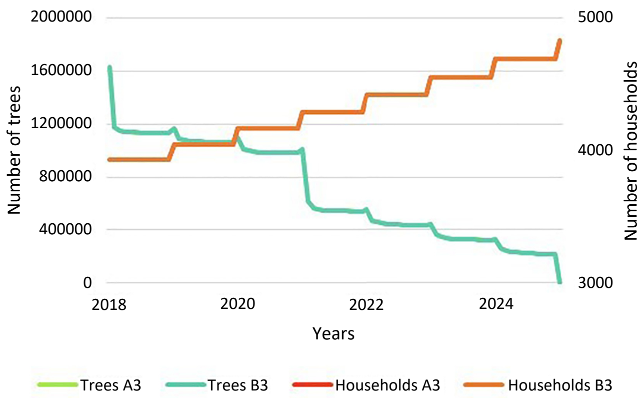

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Figure 6.
Simulation A3 and B3

simulation is similar to the ones without alternative supply (A and B). However, it can postpone complete deforestation for another year (2025 instead of 2024) and thus be a possible intervention. A critical issue is a sustainable use of wetlands, which suffers from increasing pressures (Gronau *et al.*, 2018). Overall, energy sector interventions for alternative supplies are helpful in the study area as long as it reduces the pressure on the existing forest stock.

4.5 Sensitivity analysis

Key parameters are varied to perform a sensitivity analysis. The uncertainty of input data and the robustness of the model are investigated. The agent-based model's critical and influential factors are population and tree growth rates. Several compositions were tested (a combination of varying population growth at 2% and 3% and tree growth rates at 3% and 5%). The ABM simulations show the deforestation trend is visible in all cases, independently of the population and tree growth rate modifications. None of the parameter modifications can maintain the initial forest stock. Even if key parameters are changed, the overall trend remains the same, indicating a robust ABM.

5. Conclusions and policy implications

The paper aimed to investigate the impact of refugees on deforestation in Zambia. An agent-based model was developed, covering a host–refugee society, settlement construction, tree cutting and forest stock development. The research aimed to answer four questions: what is the impact of (1) the establishment of a refugee settlement, (2) the energy demand of a host and refugee population, (3) the residence time of refugees and (4) interventions in the energy sector, on sustainable utilization of the forest stock?

The scientific analysis pointed to six factors requiring (political) attention: (1) the baseline simulation indicates future forest utilization of the rural community without the influx of refugees is sustainable. The tree population persists for up to 30 years despite usage by the rural population. (2) Refugee developments completely deplete the forest over time. With the construction of a refugee settlement, the forest stock drastically reduces, and tree utilization is no longer sustainable. (3) The settlement construction has the most severe impact on the forest, while the energy needs of refugees seem less significant for the outcome. (4) It is not of high importance for the forest resources whether refugees permanently integrate into the host society or leave after 10 years. (5) Interventions in the energy sector through alternative sources slow down the process of deforestation and, thus, the pressure on forest stocks. Possible implications for forest sustainability are hybrid renewable energy systems and papyrus bioenergy. Even though the simulations cannot establish a sustainable use of forests, they can improve the situation. (6) Once a camp is constructed, the cutting of trees by hosts for housing, sales and agriculture (slash and burn) causes forest cover to decline, even if alternative energy is provided. The refugees themselves do not cut down trees. These findings are significant as they illustrate how complicated it is to reverse negative effects on forest stocks caused by settlement construction if many refugees arrive in an area. Therefore, additional measures to energy alternatives have to address deforestation and account for this issue. One possibility is reforestation efforts by the government/organizations and/or educational programs on the importance of addressing integration. Without these countermeasures, the integration of refugees can be aggravated as natural resource conflicts can arise.

The study revealed interesting directions for further research. Additional behavioral aspects of households can extend the agent-based model, for example, a reflecting behavior if resource scarcity becomes obvious and behavioral changes are needed. Furthermore, input data can be further specified (e.g. estimations of the initial forest stock and household energy requirements based on data approximations). Regulations provide an interesting field of further research, for example, facilitating the regrowth of trees by a minimum diameter to cut a tree and/or reforestation measures (Syampungani *et al.*, 2017). Simplification of the agent behavior and model environment is a further issue. While both population groups interact with the environment, an interaction between them is not part of the model. Potential for improvement lies in the representation of 100 trees by one tree in the model, which forces households to cut 100 trees at a time. A storage option addressed this modeling approach. Finally, transparency and reproducibility of simulations and results must be considered, which are elementary components of good science communication (see Spenst and Gronau, 2022).

Integration of refugees into host societies is part of the UN CRRF policy. Camps are built close to host community villages, often within a radius of 10 km. However, establishing the camp and using forest resources by refugees may lead to resource competition with the host society, which would be counterproductive to integration (Gronau and Ruesink, 2021). Although there are advantages to the host community and refugees living close to each other, the camp size should be critically chosen to support integrative approaches.

The ABM analysis provides a scientific tool with hands-on results to understand deforestation in host–refugee settings. Even though the analysis is specific to a Zambian context, it is (1) useful for research in comparable host–refugee settings searching for durable solutions, (2) applicable to other CRRF countries or states applying the policy approach and (3) helpful for UNHCR interventions in refugee settlement situations. The normative framework of the CRRF provides a policy foundation for more integrated host–refugee societies and is subject to long-term processes. Forest and energy sector interventions should involve all stakeholders, especially hosts, and refugees.

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