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'Kesho' Scenario Development for Supporting Water-Energy Food Security under Future Conditions in Zanzibar

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Abstract: Social-ecological interactions mediate water–energy–food security in small developing islands, but community-scale insights are underrepresented in nexus research. These interactions are dynamic in their response to environmental and anthropogenic pressures and need to be understood to inform sustainable land use planning into the future. This study centered on bringing together diverse stakeholders to explore water–energy–food futures using the "*Kesho*" (meaning "tomorrow" in Kiswahili) scenario tool for two of the largest islands that comprise the Zanzibar Archipelago. The methodology comprised four core stages: (1) exploration of how past drivers of change impacted water–energy–food security; (2) modeling of a *Business as Usual Scenario* for land cover change; (3) narrative development to describe alternative futures for 2030 based on themes developed at the community scale; and (4) predictions about how narratives would shape land cover and its implications for the nexus. These results were used to model alternate land cover scenarios in TerrSet IDRISI (v. 18.31) and produce visual representations of expected change. Findings demonstrated that deforestation, saltwater incursion, and a reduction in permanent waterbodies were projected by 2030 in a *Business as Usual Scenario*. Three alternative scenario narratives were developed, these included *Adaptation*, *Ecosystem Management*, and *Settlement Planning*. The results demonstrate that the effectiveness of actions under the scenario options differ between the islands, indicating the importance of understanding the suitability of national policies across considered scales. Synergies across the alternative scenario narratives also emerged, including integrated approaches for managing environmental change, community participation in decision making, effective protection of forests, cultural sensitivity to settlement planning, and poverty alleviation. These synergies could be used to plan strategic action towards effectively strengthening water–energy–food security in Zanzibar.

Keywords: livelihoods; nexus; climate change; development; ecosystems; western Indian ocean

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1. Introduction

The interactions amongst land use, climate, and socio-economic changes impact the resilience and sustainability of social-ecological systems [1]. In small islands within the Western Indian Ocean (WIO), shifts in these dynamics have significant impacts on livelihoods and resource security—particularly as they are concentrated over smaller spatial extents [2]. Small islands in this region are undergoing rapid changes related to transitions to industrial fishing, exploitation of gas and oil, expansion of tourism, and urbanization—all of which degrade ecosystems and water resources that support local livelihoods [3].

Alongside social changes, climate change poses significant threats to local economies, many of which are informal. Communities on small islands are vulnerable to impacts such as rising sea levels, coastal erosion, drought, high wind speeds, erratic rainfall, and changes in sea temperature and acidity. Climate change also poses a threat to the unique biodiversity of the WIO, including its coral reefs, seagrasses, and mangroves, which are vital for coastal protection and supporting marine life [4].

As well as facing more incremental changes associated with climate change, communities living on small islands are exposed to natural hazards that include heavy rainfall, droughts, extremely high temperatures, storm surges, cyclones, and tsunamis [5]. All these pressures impact people and the way they interact with their environment to meet their needs [6].

There is a growing awareness that in these contexts' knowledge exchange and integration of local experience into decision making is key to building adaptive capacity [2]. Participatory scenarios can be used to consider how to manage the causes and consequences of complex social-ecological challenges, as they offer an opportunity to explore multiple and interacting pressures alongside effects on livelihoods [1,7,8]. By simulating different future conditions, scenarios can inform strategies, investments, and plans that are robust under a range of potential futures [1]. They can also help to pre-empt conflicting agendas and prepare for external influences [9–11]. This could support building the adaptive capacity of communities on small islands in response to social-ecological changes.

In a small island context, a water–energy–food nexus approach is critical for evaluating synergies and trade-offs of different land management decisions, given that they operate at tight spatial scales and effects can be rapid [12]. The water–energy–food nexus recognizes that systems are interconnected and interdependent. For example, in coastal island communities, water is essential for hydropower dams and irrigating agricultural areas, while energy is needed to pump, desalinate, treat, and distribute water as well as produce, process, preserve, and transport food [6,12]. Another example is forests and their role in protecting coastlines from inundation, which results in the salinization of agricultural soils [13] and available groundwater resources [14].

Analysis of the resource system allows the identification of effective policies for improving adaptive capacity [15,16]. For instance, previous research in Zanzibar identified solar as an important energy transition to disentangle from expensive dependencies for electricity from mainland Tanzania and ensure consistent pumping of water [17]. An integrated approach to exploring resource security across sectors could, therefore, potentially better inform where priorities are set and shifted.

Despite this need, there are a limited number of emergent studies exploring future options to support a sustainable water–energy–food nexus in small islands [12,18,19]. Even then, the studies tended to focus on broad system levels and did not capture more in-depth local interactions. This is an important gap to consider, given that social-ecological changes have multiple impacts across the water–energy–food nexus.

Considering that several layers of understanding are needed to fully unveil opportunities for addressing sustainability challenges, multiple perspectives from diverse stakeholders across scales and levels are needed. These include power hierarchies, access to knowledge and capacity, and can be nested across scales [20,21]. This would improve not only the feasibility and validity but also the uptake and concreteness of scenarios [22,23]. By positioning future scenarios around the water–energy–food security nexus, this study attempts to ensure that discussions respond appropriately to local needs.

The purpose of this research was to create scenario alternatives to address actual and emerging challenges for water–energy–food security experienced by local communities in a small island context. There were four core objectives: (1) to explore how key drivers of change operate spatially and temporally; (2) to develop a model for land cover change in a *Business as Usual* scenario for 2030 based on community-based insights; (3) to develop coherent and tangible scenario narratives using alternative themes generated by communities, *Ecosystem Management*, *Adaptation*, and *Settlement Planning*; and (4) to model land cover implications of alternative scenarios for water–energy–food security towards 2030.

Findings show that drivers of change might change the land cover and its potential impact on the water–energy–food nexus under alternative scenario trajectories. They also unveil alignments in strategic areas of focus for responding to and preparing for change across scenario narratives. Consequently, results could be used to help inform planned action towards local, regional, and national poverty alleviation and sustainability agendas.

2. Methods

2.1. Study Area

Zanzibar, a semi-autonomous territory that forms a political union with mainland Tanzania, is an archipelago in the Indian Ocean (Figure 1). Zanzibar's population stands at 1,889,773 [24]. Most of this population growth has been in urban areas, with growing disparities in welfare between the islands of Pemba and Unguja. Poverty levels based on household consumption stand at 25.7% [25].

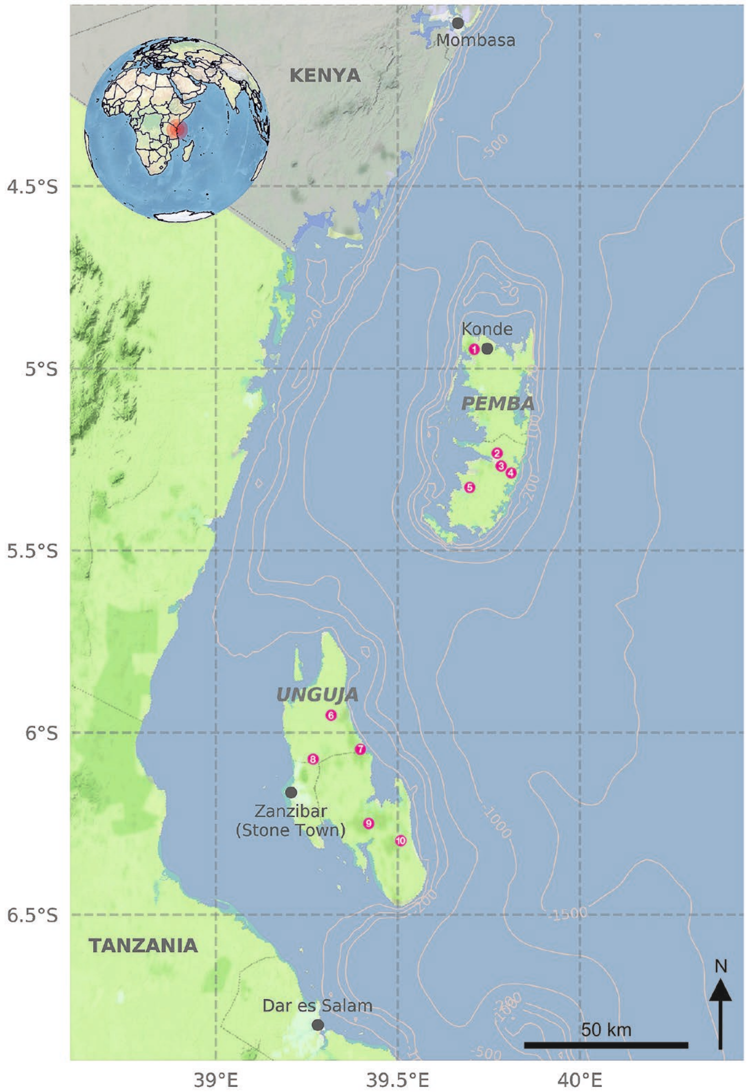


Figure 1. Location of Unguja and Pemba on the East African coastline, original map provided by [26] and adapted by [13] to include community-based workshop sites in Unguja (**left**) and Pemba (**right**).

Members of each of these communities were included as stakeholders in this study. Coordinates provided by the Department of Renewable and Non-Renewable Resources, Zanzibar. Pemba sites include villages: (1) Mji Mpya, (2) Macho Mane, (3) Mfikiwa, (4) Pujini, and (5) Chumbageni. Unguja sites include villages: (6) Kinyasini, (7) Pongwe, (8) Kizimbani, (9) Pete, and (10) Jambiani Kikadini.

The islands have a humid tropical monsoon climate with 1600–1900 mm annual rainfall and an average annual temperature of 27.5 °C [27]. There are four main seasons: "kaskazi" (hot season) between December and February; "masika" (long rainy season) between March and May; "kipupwe" (cold season with high winds) between June and September; and "vuli" (short rains) between October and December. However, climate variability is changing these more predictable patterns [28].

Key livelihoods include farming, fishing, and seaweed aquaculture [29]. The islands are experiencing fast rates of change, stimulated by population growth, migration, urbanization, tourism, and increased land demand for agriculture and forestry products [30]. Tourism contributed 29.2% of the 2022 GDP and resulted in investment in key services. For some villages, high levels of tourism have resulted in the loss of access to beaches and the sea, which has resulted in a loss of livelihoods [31].

Freshwater lenses above saltwater are the main freshwater sources in Zanzibar. Only 24% of rainwater is captured into groundwater, as approximately 44% evaporates and 32% is surface runoff [32]. Only 1.3% is captured for domestic and irrigation purposes through rainwater harvesting and remains underutilized on the island [33]. Recent research has indicated that groundwater abstraction in Unguja Island is higher than the rate of recharge. This means that groundwater is overexploited and exposed to pollution and saltwater intrusion [34]. Seasonal imbalances occur during the dry season when recharge is at its lowest, but abstraction rates are at their highest due to demands from tourism [34,35]. Saltwater intrusion is already widespread due to the pumping of groundwater from coastal aquifers [36]. Water is abstracted from springs and caves and supplied to communities through pipelines and public taps [35].

Zanzibar's electric grid is reliant on hydroelectricity generated on mainland Tanzania, which is carried through two underwater cables, one with a capacity of 100 megawatts to Unguja and another 25-megawatt cable to Pemba island [12]. Each island has substations to redistribute this electricity with significant wattage loss [17]. Demand for electricity is set to exceed the cable capacity in the next few years, with development outpacing capacity [17]. Because Zanzibar's electricity is generated in Tanzania, ZECO, the Zanzibari electrical distributor, pays the Tanzania Electric Supply Company (TANESCO, Tanzania's electrical provider) each month for the megawattage received [17]. To lessen the reliance on Tanzania for energy needs, Zanzibar has set a target of using 30% local renewables by 2030 [17].

Food security is a major issue in Zanzibar, with approximately 65% of households experiencing poor food consumption and 32% being severely food insecure [37]. Many households in Zanzibar depend upon subsistence activities, such as fishing and farming, to meet their food needs and are highly exposed to food insecurity because of stressors such as climate change alongside increased food demands from tourism [38].

2.2. Research Approach

The approach for research was based on principles outlined by a scenario analysis tool called "*Kesho*" (meaning "tomorrow" in Kiswahili) [39]. *Kesho* provides a structured framework allowing the participation of diverse stakeholders across scales to connect their insights directly into land cover modeling. The method has been applied in the Southern Agricultural Growth Corridor Kilombero, southwest Tanzania [23], in the Serengeti Landscape on pastoral transitions [1], to assess natural capital in Tanzania [40] and evaluate mountain social-ecological system transitions in Kenya and Ethiopia [41].

In the case of this research, the objectives of working towards water–energy–food security were developed through ethnographic research and confirmed after focus groups with village leaders and elders (number of participants (n) = 40). Transcripts and field notes of these discussions were inductively coded, and emergent themes were used to guide the rest of the research process [6]. Boundary conditions were spatially set to island level in Unguja and Pemba and temporally to 2030 to coincide with the 17 Sustainable Development Goals and the first-time horizon for Zanzibar's Development Vision for 2050 [42].

In the second stage, which took place from April to August 2019, scenario themes were co-developed by communities in community-based workshops in ten villages across the two islands (n = 142) (see Table 1). Communities went through a process of identifying key drivers of change and the impacts of land cover change on water, energy, and food. They made predictions for how drivers might contribute to challenges for water–energy–food security in the future. They then suggested several strategies that would be used to mediate these issues. The clustering and prioritization of these strategies lead to three core themes to frame future scenarios: *Ecosystem Management*, *Adaptation*, and *Settlement Planning* [13].

Table 1. Community workshop locations for the pre multi-stakeholder workshop preparation [13]. Locations represent diverse land cover types across both islands. The first five locations are on Pemba Island, and the last five locations are on Unguja Island.

Island	Workshop Group Location	Main Land Cover Type Represented
Pemba	Macho Mane	Peri-urban
	Mfikiwa	Commercial farming
	Pujini	Commercial farming and mangrove cover
	Chumbageni	Coastal area with mangrove cover and some tourism
	Mji Mpya	Protected forest
Unguja	Jambiani Kikadini	Coastal with high levels of tourism
	Pongwe	Coastal with medium levels of tourism and some mangrove cover
	Kinyasini	Peri-urban and commercial farming
	Kizimbani	Commercial farming (spice farming)
	Pete	Protected forest reserve and mangrove cover

The third phase, the focus of this article, involved scenario modeling, starting with land cover modeling of a *Business as Usual* scenario based on insights from the community-based workshops to inform variable section for causes of land cover change [13]. This was followed by two multistakeholder scenario workshops, which took place in October 2019 and involved both expert stakeholders and community representatives (n = 67). Stakeholders created narratives for alternative sustainable scenarios andpredicted how each of the alternative scenarios would alter land cover and the impact this might have on water–energy–food security for 2030. Land cover predictions made by participants were modeled to create spatially explicit visualizations of the scenarios centered on stakeholder perspectives.

2.3. Participant Selection

Two full-day scenario workshops were undertaken with local stakeholder participants, three Kiswahili-speaking facilitators, and the author, one in Macho Mane Pemba (n = 44) and one in Stonetown Unguja (n = 23). Stakeholders involved community representatives from all ten previous sites (one man, one woman, and the "*Sheha*" (village leader)). These stakeholders had been originally recruited by each village leader across the village sample sites to represent a diversity of ages, genders, and occupations. In each community workshop, participants selected two representatives to advocate for their views in the multi-stakeholder scenarios.

Members from Zanzibar's agriculture, forestry, environment, water, energy, and tourism departments attended alongside two non-governmental organizations, Milele Foundation (a sustainable livelihood organization) and Wildlife Conservation Society. These stakeholders were recruited through the support of fieldwork facilitators based at the Department of Forestry and Renewable and Non-Renewable Resources in Zanzibar.

At the Pemba workshop, 37% of the participants were women, and 63% were men. In the Unguja workshop, 48% of the participants were women, and 52% were men. This was achieved by specifying to community leaders and ministries that we were aiming for equal gender representation. At the village level, three out of ten village leaders were women, suggesting a move to more equal participation of women in leadership roles.

The participants were split into three working groups in each scenario workshop. These were organized to mix both community representatives and representatives from institutions together. Three Kiswahili-speaking facilitators supported the groups throughout the day, assisting those who were unable to read or write and explaining activity instructions.

All facilitators had undergone a one-day training with the lead author during the week preceding the workshops to become familiar with the workshop activities. During this training, the need to identify participant needs and encourage participation across age, gender, and background was discussed. Facilitators were asked to keep a record of any imbalances in contributions that they became aware of during the workshops.

2.4. Water–Energy–Food Context

Timelines were produced in which drivers of land use and land cover change influencing water–energy–food were identified from 40 years ago to the present day. Participants were asked to consider environmental, social, environmental, technical, and political drivers of change to avoid sectoral biases. The timeline was used on a horizontal axis, and on the vertical axis, trends in water–energy–food security were drawn. Each group discussed how the events on the timeline contributed to these trends and made notes on points made.

2.5. Spatial Mapping of Drivers

Groups reflected on the scale at which different drivers of change might be felt across the island (Unguja or Pemba) by 2030. Each group was given a blank map which just detailed "*Shehia*" (ward) boundaries. Group one colored and labeled areas in the island (Pemba or Unguja) where population growth would be highest and explained why. Group two did the same for climate change, and group three for socio-economic development.

2.6. Scenario Narrative Development

The third activity focused on the development of three alternate pathway trajectories based on themes that emerged during community-based scenario planning [13]. Group one explored improving the adaptive capacity of communities, group two focused on the protection and regeneration of ecosystems (including places of cultural and spiritual importance), and group three discussed sustainable settlement planning (summarized as *Adaption*, *Ecosystem Management* and *Settlement Planning*).

Participants were asked to describe what the islands would look like, how different elements interact, and what the day-to-day implications might be. These scenarios considered drivers that were both impactful and uncertain. Narratives were plausible and internally consistent, even when exploring extreme or unlikely futures. Each group had several guiding questions to prompt discussion (see Table S1).

2.7. Land Cover Change Predictions

Once pathway narratives were created, participants were asked to reflect on how pathways might influence land use and land cover by 2030. These included predictions of land cover conversions, the possible percentage change, and the likelihood of this occurring on a scale of 0 (not possible) to 4 (very likely), alongside explanations of where such change might occur. Participants were given a range of photographs of land cover types taken from the relevant island and land cover maps for Zanzibar from 2019 as guides.

Next, participants were then asked to reflect on how much land use or land cover change might impact livelihood aspects, including water, energy, food, health, and shelter (health and shelter added by participant request) on a scale from extremely positive to extremely negative for the year 2030.

3. Land Cover Modelling

3.1. Business as Usual Scenario

To model land use and land cover changes in a *Business as Usual* scenario, baseline temporal scope was defined for 2015 and 2017, and a future prediction for the year 2030. Land cover predictions for the 2030 baseline scenarios were produced using the Land Cover Modeler in the TerrSet Package of IDRISI (v. 18.31). Towo land cover maps for the years 2015 and 2017 were used as a baseline reference for change. Land cover maps obtained from *Copernicus* Global Land Service were used at a raster resolution of 100 m [43]. Land cover classes were modified in accordance with the local community and expert knowledge of the area. Change analysis was then applied to calculate transitions between land cover types (see Table S2 and Figure S1).

Transitions were grouped into four sub-models for Unguja and three sub-models in Pemba based on the learned understanding of drivers of land cover change developed through community-based workshops [13]. Within the transition sub-model structure, eleven independent spatial variables were included to potentially explain spatial changes in land cover; and included elevation, slope, distance from nearest protected areas, distance from the sea, distance from nearest roads, distance from settlements, distance from closed forest, distance from wetlands, distance from built-up areas, and soil composition (see Table S3). A Boolean layer was used to calculate the relative frequency of pixels that have undergone change, i.e., the evidence likelihood transformation [44]. Transitions of less than 250 pixels were excluded from the model to improve model accuracy (see Tables S4 and S5).

Multi-layer perceptron (MLP) analysis was then performed to calibrate each sub-model using dynamic learning rates. MLP analysis predicts the potential of a pixel to transition based on the explanatory power of the selected independent spatial variables. MLP then develops a model based on samples of pixels that went through the different transitions shown in the sub-model alongside samples that were eligible for transition but did not change [45,46]. Finally, Markov chain analysis was used to analyze the 2015 and 2017 land cover images and produce a transition probability matrix, transition areas matrix, and conditional probability images for the specified future date of 2030 [47].

Because the transitions to the built-up land class were few between 2015 and 2017, it was impossible to model this adequately using the MLP analysis. As settlement expansion and increased tourism infrastructure came up as major themes for land use and land cover change in earlier scoping research, it was decided that this needed to be sufficiently reflected in the baseline maps to provide a benchmark of potential change for the year 2030 [6]. Therefore, the transition to built-up land cover was projected separately and added to the BAU land cover maps (see Table S6).

Other *Kesho* applications explored the *Business as Usual* scenario in tangent to sustainable alternatives during the workshop process [1,23,40,41]. In this case, the *Business as Usual* model was created using insights from community-based insights [13] and then used as a reference point for predicting land cover change in other scenarios (i.e., "30% less built up transitions than a BAU scenario"). This was decided so that collaboration and co-creation amongst diverse stakeholders could focus on solutions and how to work towards positive outcomes.

3.2. Alternative Scenario Modelling

The next step involved spatially allocating land cover changes for each scenario alternative based on the perceptions, likelihood, and location of change identified during workshops. Boolean constraint maps were produced using the Reclass function in the TerrSet Package of IDRISI (v. 18.31) using perceptions of predicted land cover transitions. Spatial decision variable maps were created in ArcMap to include specific areas or conditions where change might occur. Additional variables that could affect the location of transitions were derived from both previous research employing scoping focus groups and community-based workshops [6,13] as well as wider literature [17,28,29,48].

A fuzzy module was used to convert all the decision variables into factor weights from 0 to 1. Within the fuzzy module, the parameters of each variable (i.e., monotonically increasing or decreasing) were specified. Using the Multi Criteria Evaluation module, the weight of influence of each decision variable was calculated based on the authors' understanding of the area.

The Multi-Objective Land Allocation (MOLA) function was then used to select the most spatially viable parcels of land for predicted transitions based on both the Boolean maps and likelihood indicators specified by communities. Within the MOLA function, the likelihood of change is area demand predictions specified by stakeholders were applied when calculating the objective weight of each land cover transition. The resultant spatial allocation maps were brought into ArcMap to model land cover for 2030 under each scenario using the conditional function in the spatial analyst toolbox (see Tables S7–S12). Land classes were simplified with the guidance of the Department of Forestry and Renewable and Non-Renewable resources to reflect local understandings of land cover types (see Tables S13–S15).

4. Results

4.1. Past Influences on Water–Energy–Food

In both islands there were several interrelated factors that caused land use and land cover changes, and ultimately affected water–energy–food security in the last 40 years. Participants detailed events that mediated the wider context in which the nexus operated; they also made specific links between their perceptions of water–energy–food and the events on their timelines, which are summarised below (Figure 2a,b).

In accompanying timeline notes, Pemba participants wrote that from the year 2000:

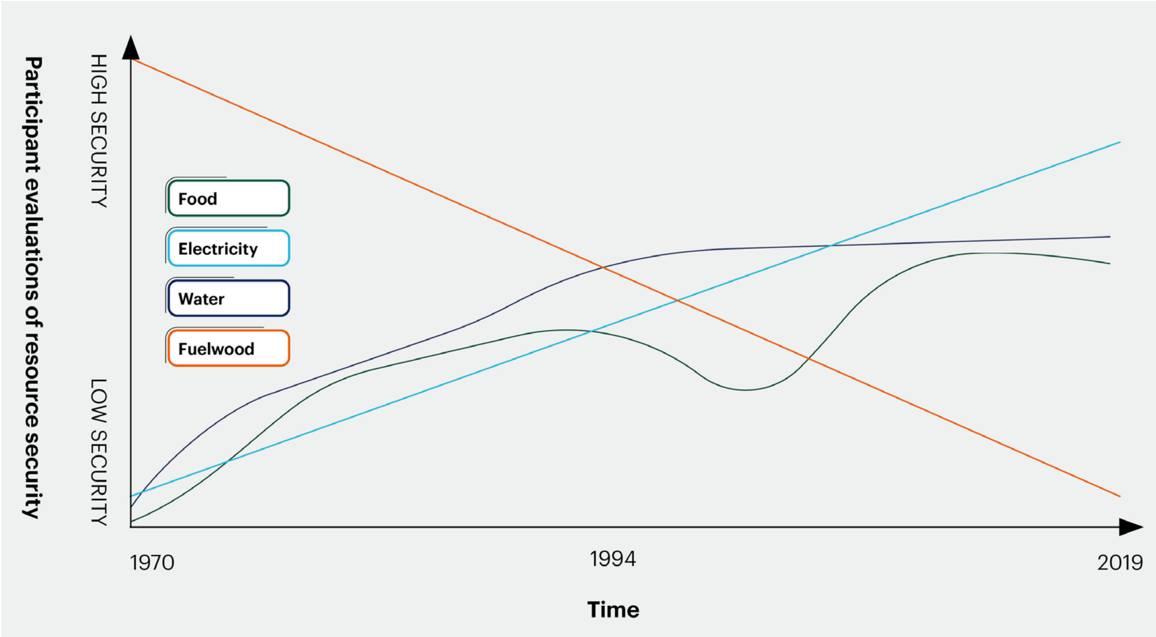
> *"Water has raised due to strong electric power and the strengthening of the water supply projects"* (Pemba, October 2019).

They also stated that food security was variable due to drought, floods, and inflation of imports seen from 1970 to the 1990s. Moreover, fuelwood supplies became increasingly degraded due to poor planning for road and building developments, excavation for water and electricity infrastructure, quarries for aggregates to make blocks for new buildings, and the creation of salt pools between 1990 and the 2000s.

In parallel to this, from the 2000s onwards, in Pemba, agriculture, trade, tourism, and urbanization were perceived to increase income and provide alternative routes for attaining water–energy–food security. Formal institutions and legal instruments were also introduced to inform land planning, which was thought to improve the sustainability of land use. However, from 2005 onwards, climate change, decreased soil fertility, and degradation of the natural environment hindered further improvements in nexus outcomes.

In Unguja, since the 2000s, participants commented that energy needs changed with the increase in trade and manufacturing, which saw greater electricity provision. Also, from the 2000s onwards, water supplies were thought to have become "*more modern*" as people transitioned from well water to piped water through the addition of new water infrastructure.

It was further mentioned that there was a lack of knowledge about water sanitation in the past and that greater awareness has helped to promote improvements. It was recognized that land shortages put pressure on farmers to increase yields, which led to a focus from the government to introduce inputs such as fertilizers and pesticides. Such land shortages also led to land conflicts and deforestation. Environmental degradation from 2005 was thought to have greatly reduced fuelwood supply (Figure 3a,b).



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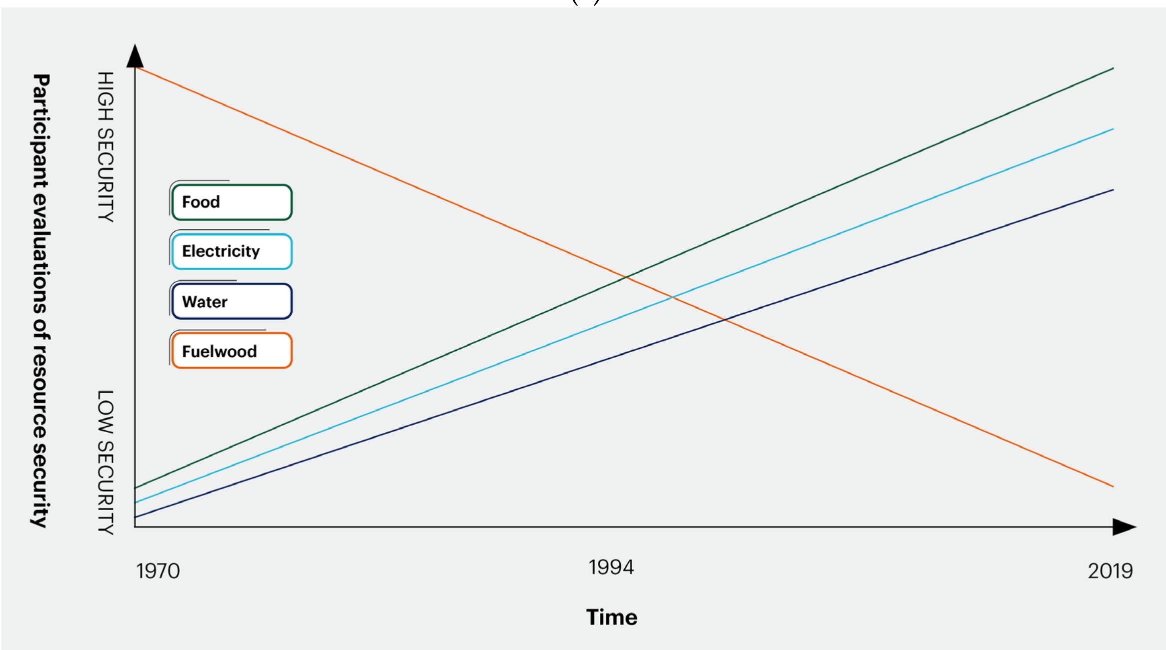
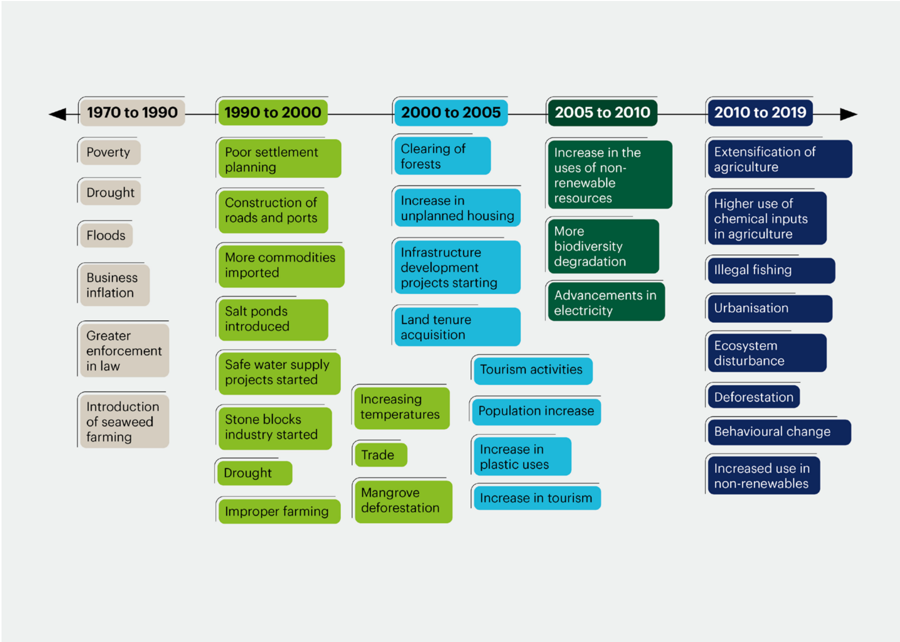


(**b**)

Figure 2. (**a**) Pemba water–energy–food security perceptions from participants; (**b**) Unguja water–energy–food perceptions from participants. In the workshops, participants drew timelines from 1970 onwards and added events to those timelines that impacted water–energy–food security. Above those timelines they drew line graphs depicting trends for water–energy–food security over that time. They then wrote notes to explain any connections they made between events on the timeline and their interpretation of water–energy–food security (see Figures S2 and S3 for original drawings).



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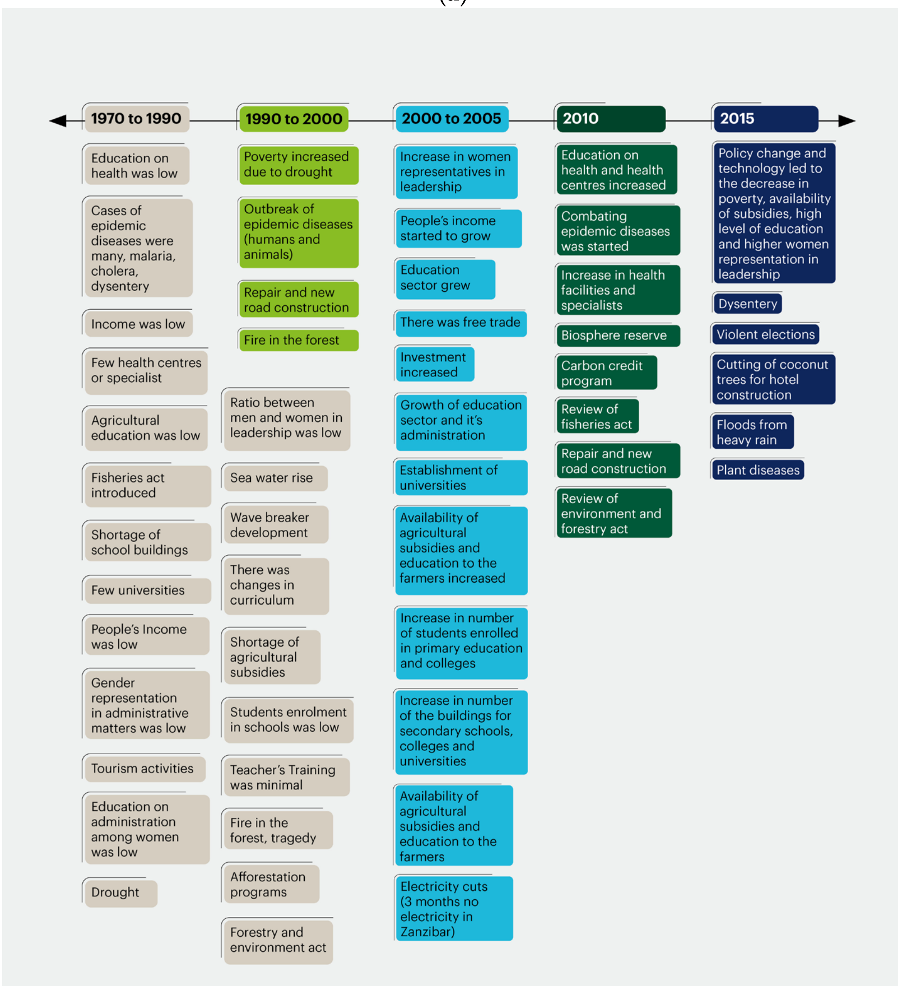


(**b**)

Figure 3. (**a**) Pemba timeline of events identified by participants which shaped water–energy–food security; (**b**) Unguja timeline of events which shaped water–energy–food security identified by participants.

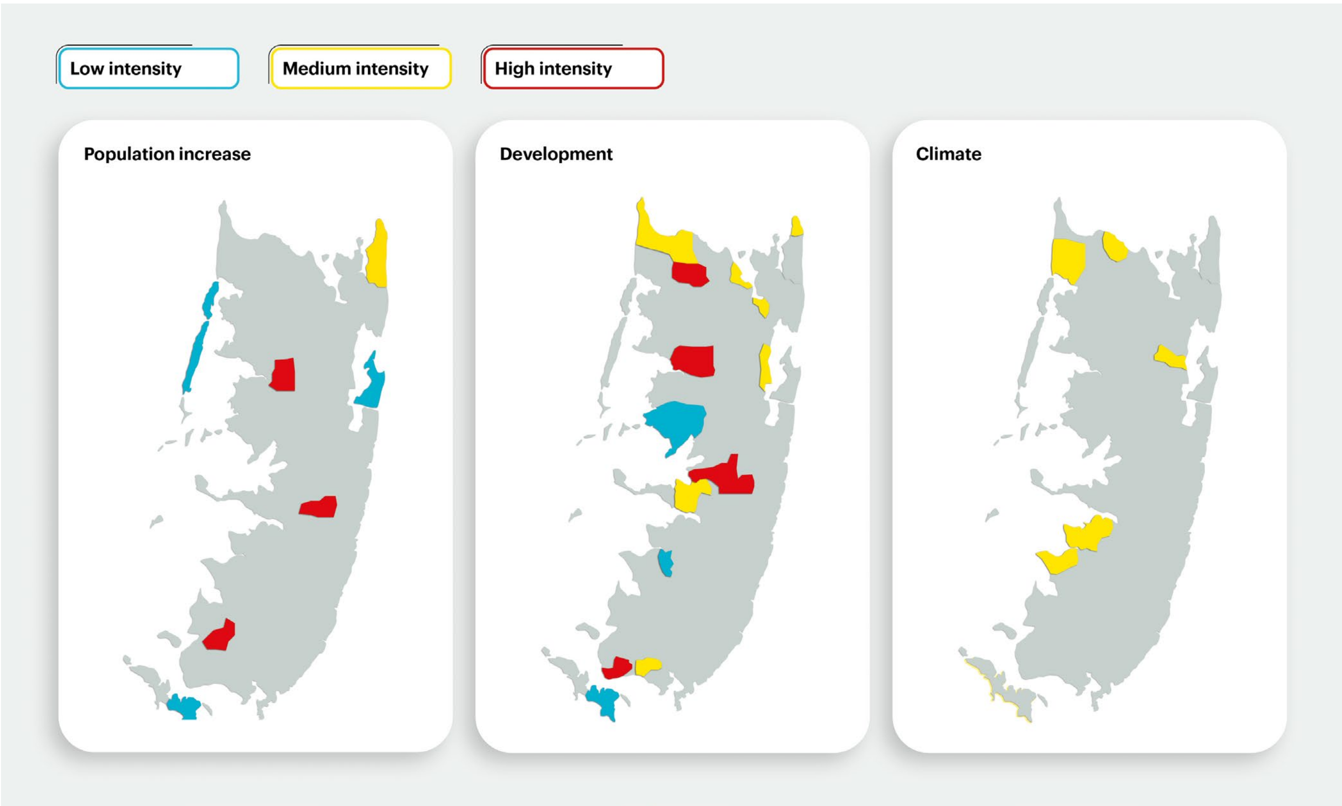
4.2. Spatial Distribution of Drivers of Change

Three key drivers of change were identified in community-based workshops held before the multi-stakeholder workshops: population increase through both migration and internal migration, socio-economic development, and climate change [13]. In the community-based workshops, participants focused on their locality, so to understand these at the island scale, participants were asked to code areas of impact from low to high.

In Pemba, population increase from internal movement and economic migration focused on urban centers, areas with natural capital for tourism, adequate land, productive fishing, or access to the port. Socio-economic development was expected in areas adjacent to existing urban centers, around the fishing port, and in specific sites of greater natural capital that could attract tourism. Both were thought to contribute to deforestation:

> *"Increase in population leads to scarcity of land for settlement and forest area decreases. Road constructions leads to disappearance of forest and people's settlement"* (Unguja, October 2019).

Climate change impacts were predicted in specific coastal areas where flooding events have been experienced previously or where there were greater levels of deforestation. Interestingly, stakeholders graded climate change impacts as medium intensity rather than high due to ongoing mitigation in place, including afforestation of mangroves, construction of seawalls, establishment of community forests, increased awareness, and enforcement of forest regulations (Figure 4a).



(**a**)

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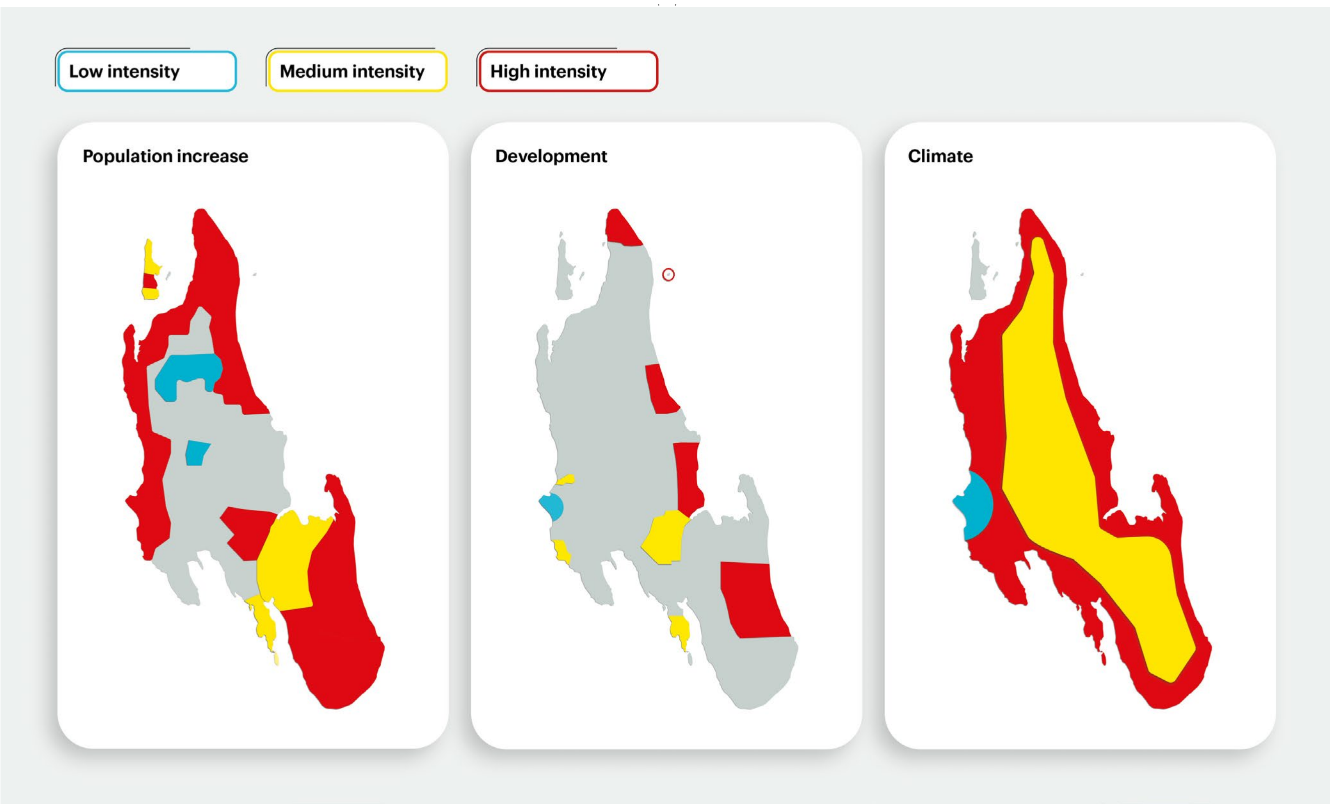


(**b**)

Figure 4. (**a**) Pemba drivers; (**b**) Unguja drivers. Population increase refers to internal migration, development is associated with socio-economic factors, and climate encompasses sea-level rise, severe weather events, and climate variability. Participants colored maps with their predictions and made notes to explain any specific connections. For development in Unguja, participants also predicted socio-economic development on one of the islets, circled in red.

Conversely, in Unguja, population increase from economic migration was expected to be more intense in the north and south coastal zones, areas that already experience high levels of tourism. This was thought to extend across the north-west coast, as coastal zones have been steadily developed for tourism infrastructure alongside other development projects. Development, on the other hand, was predicted to increase on the east coast in areas with current low levels of tourism. This was because of the establishment of development projects initiated as part of the Zanzibar Investment Promotion Authority (ZIPA) zones.

Unlike Pemba, where climate change impacts were predicted to be quite concentrated in certain places, participants in Unguja expressed concerns about the high intensity of pressures associated with wave overwash and salination of water wells across the entire coastal zone, due to deforestation on the coastline and frequent flooding (Figure 4b).

4.3. Alternative Scenario Narratives

Scenario narratives were summarised and written in Kiswahili by participants and then later translated into English (Table 2). There are some interesting commonalities between the three alternate scenarios. For instance, all scenarios recognize that sustainability requires an integrated response, social change, and poverty reduction. As such, water–energy–food impacts were often indirect and related to economic factors. One group explained that:

Table 2. Pathway narratives for 2030 scenarios based on themes generated from community-based workshops. Narratives are based on the translation of written narratives produced by subgroups in the multi-stakeholder workshops.

Scenario	Narrative Unguja	Narrative Pemba
Adaption	Adaptive capacity is enhanced through education and training across three key areas: entrepreneurship, cooperative group establishment, and community development projects. Such training recognizes how needs change over temporal scales and explores resource scarcity across spatial scales. This requires a coordinated response from a wide range of stakeholders across government sectors, development organizations, and private companies. To support this scenario, government bodies would review policies, laws, and guidance.	This scenario builds on existing innovative efforts to provide new ways to obtain income and encourage entrepreneurship and community environmental education. Existing barriers to adaptation are addressed through acknowledgment of the impact of poverty on readiness. Communities and individuals are now empowered to make changes to livelihoods to improve their outcomes. Education for communities is practical and involves multiple stakeholders across government sectors, NGOs, and community-based organizations. Policy between the health, education, and agriculture sectors is joined up to support adaptive capacity.
Ecosystem management	Natural forests are protected in small islands, wetlands, and areas supporting water reserves via gazettement involving communities from the beginning. To support this process, policies that connect land, forests, and fisheries are put in place, combined with continual awareness campaigns. Due to poverty and the current dependence on natural forests, efforts are made to ensure access to alternative resources and livelihoods.	This scenario emphasizes a multi-stakeholder response to strengthen laws around conservation, environmental education, and suitable land use planning. To conserve natural forests and water bodies, governing bodies have a broad overview of driving factors, such as development activities, population increase, lack of education, and poverty. Initiatives are underway to address how entrenched beliefs and traditional practices influence communities' motivation to change.
Settlement planning	This scenario focuses on youth employment, industry, and local investments. A national land use plan is developed, which considers settlement planning guidance and how economic growth relating to tourism coincides with settlements. This should be developed and supported by a coordinated team across sectors relating to land and settlements. Sanitation is continually improved through better access to cleaning facilities (i.e., waste management, sewage systems, and recycling facilities).	Settlements experience substantive changes associated with the growth of industries of agriculture, tourism, and extraction of gas and oil. This results in increased employment, business opportunities, community service, and infrastructure improvements. Spatially, land planning considers these impacts by enforcing the recommendations of environmental impact assessments and encouraging multi-story homes to make efficient use of the space available. Concurrently, this scenario protects customs, traditions, and norms for people in Zanzibar -to avoid disintegration, security challenges, and lifestyles. Cooperation between stakeholders, such as government, institutions, and civil society, is important to navigate the transitions appropriately.

> *"Land is the resource which contributes much in improving people's income through economic activities like agriculture, industries as well as investment in tourism"* (Unguja, October 2019).

Education through continual engagement of communities was seen as important for protecting forests and improving adaptive capacity. Settlement planning scenarios emphasized the need to plan for how economic transitions relating to tourism might socially impact communities.

But there were also calls for political attention to be given to certain actions; in Unguja, participants stated that:

> *"We beg the government for industries and investments in the country. We beg the government to improve cleaning facilities in our villages. The government should ensure employment for the youth"* (Unguja, October 2019).

Whereas in Pemba, participants called upon the government to

> *"Follow up the implementation of the policies and rules on urban planning"* (Pemba, October 2019).

This indicates that thought needs to go not only into policy creation according to needs but also into how that policy can be acted upon in a meaningful way.

4.4. Business as Usual and Alternative Scenario Modelling

Land cover modeling drew out the strong linkages between forests across the water–energy–food nexus. In Pemba, land cover transitions to forested wetlands occurred in the coastal fringes. In Unguja, transitions to wetland forest occurred on slow-draining soils further inland. This indicates that transitions to forested wetlands are not likely to be associated with reforestation but with flooding existing forest spaces through coastal flooding and heavy rainfall.

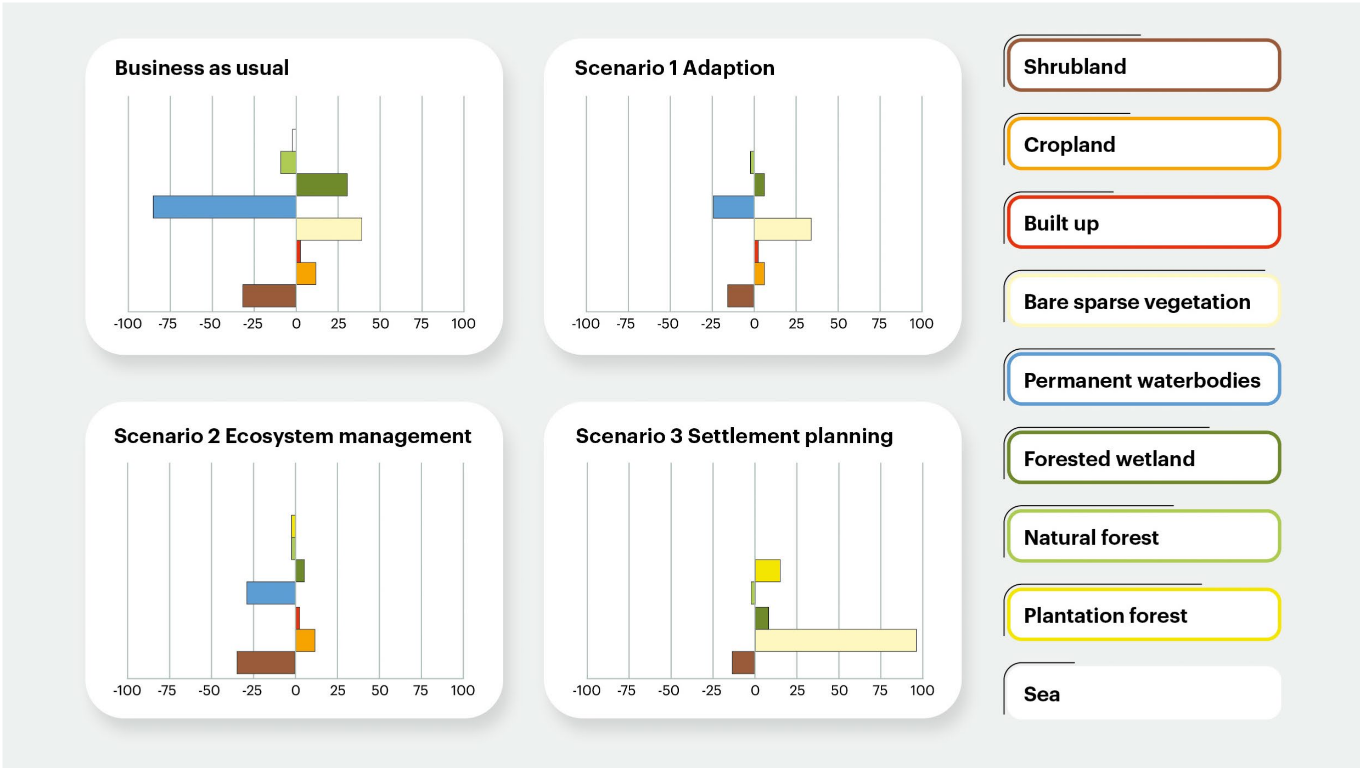
Deforestation was expected across all scenarios. For Pemba, the highest occurrence of deforestation (across natural forests) occurred in the *Business as Usual* scenario, followed by *Settlement Planning*, *Adaption*, and *Ecosystem Management*. Unsurprisingly, the *Ecosystem Management* scenario, which had the lowest expected rates of deforestation, was the only scenario that did not reduce permanent waterbody cover.

For Unguja, the highest rates for deforestation were seen in the *Business as Usual* scenario, but this was followed by *Ecosystem Management*, *Settlement Planning*, and then *Adaption*. The *Adaptation* scenario also saw the lowest amount of losses for permanent waterbodies.

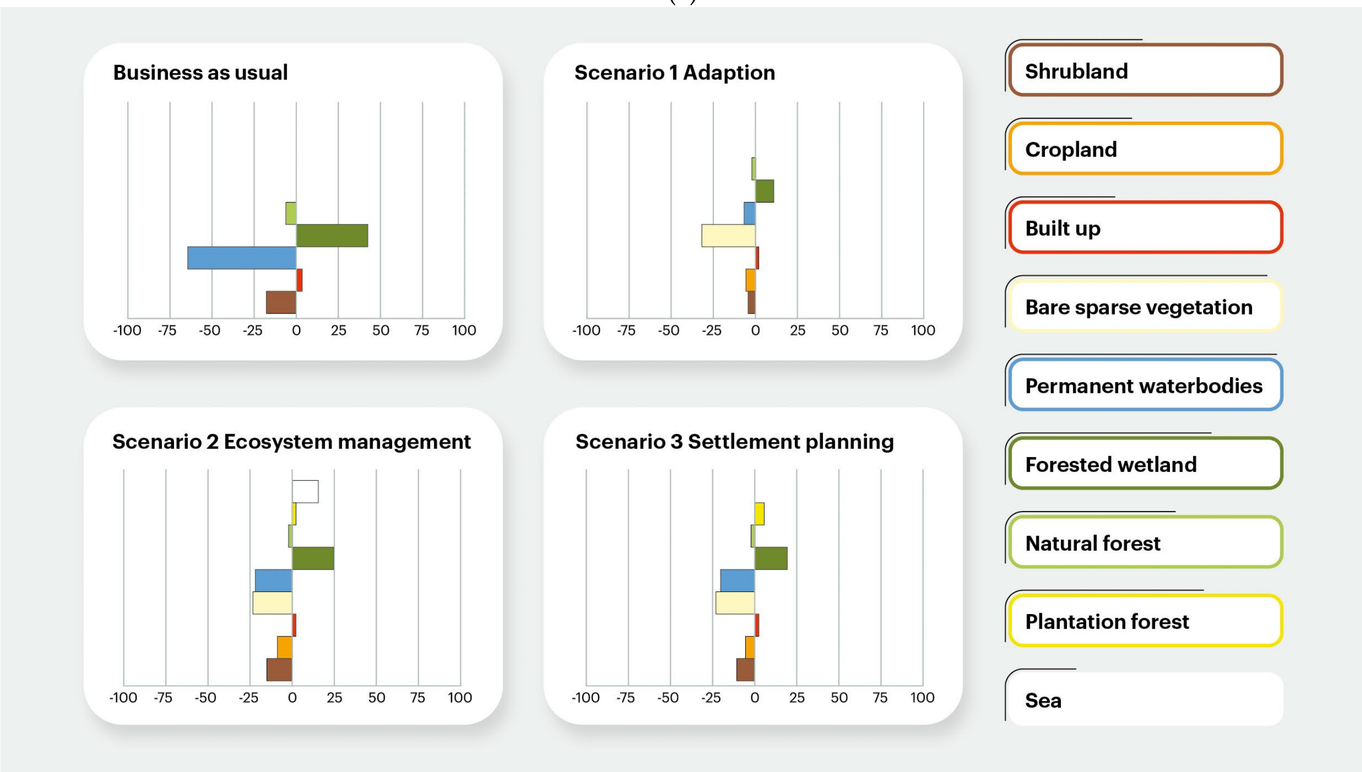
In Pemba, the *Adaptation* and *Ecosystem Management* scenarios included the expansion of cropland, whereas *Settlement Planning* involved more plantation forests. In Unguja, cropland expansion was not demonstrated in the alternative scenarios, however there was a focus on plantation forest expansion in both the *Ecosystem Management* and *Settlement Planning* scenarios (see Figures 5a,b and 6a,b and Table 3).

Table 3. Predicted land cover change for the *Business as Usual Scenario* and the three alternative scenarios (S1—*Adaption*; S2—*Ecosystem management*; S3—*Settlement planning*). The *Business as Usual* scenario in Pemba predicted sea level rise and encroachment onto land. The *Ecosystem Management* scenario in Unguja predicted a slight reduction in seaward extent due to mangrove reforestation.

	Pemba					Unguja				
Land classes	**2019 (ha)**	**BAU (ha)**	**S1 (ha)**	**S2 (ha)**	**S3 (ha)**	**2019 (ha)**	**BAU (ha)**	**S1 (ha)**	**S2 (ha)**	**S3 (ha)**
Shrubland	2.2	1.1	1.6	1.1	1.6	2.5	1.8	2.4	1.9	2.0
Cropland	1.4	1.7	1.5	1.8	1.4	1.1	1.1	1.0	1.0	1.0
Built up	0.8	0.9	0.9	0.8	0.8	2.3	2.4	2.4	2.4	2.4
Bare sparse vegetation	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Permanent water bodies	0.4	0.0	0.2	0.2	0.4	0.4	0.1	0.3	0.2	0.2
Forested wetland	4.8	8.9	5.4	5.4	5.4	3.5	8.4	4.2	5.0	5.0
Natural forest	21.5	17.8	20.9	21.2	20.4	36.3	32.3	35.8	35.4	35.5
Plantation forest	1.0	1.0	1.0	1.0	1.3	3.2	3.2	3.2	3.2	3.1
Sea (gains and losses)	-	0.5	-	-	-	-	-	-	-0.2	-

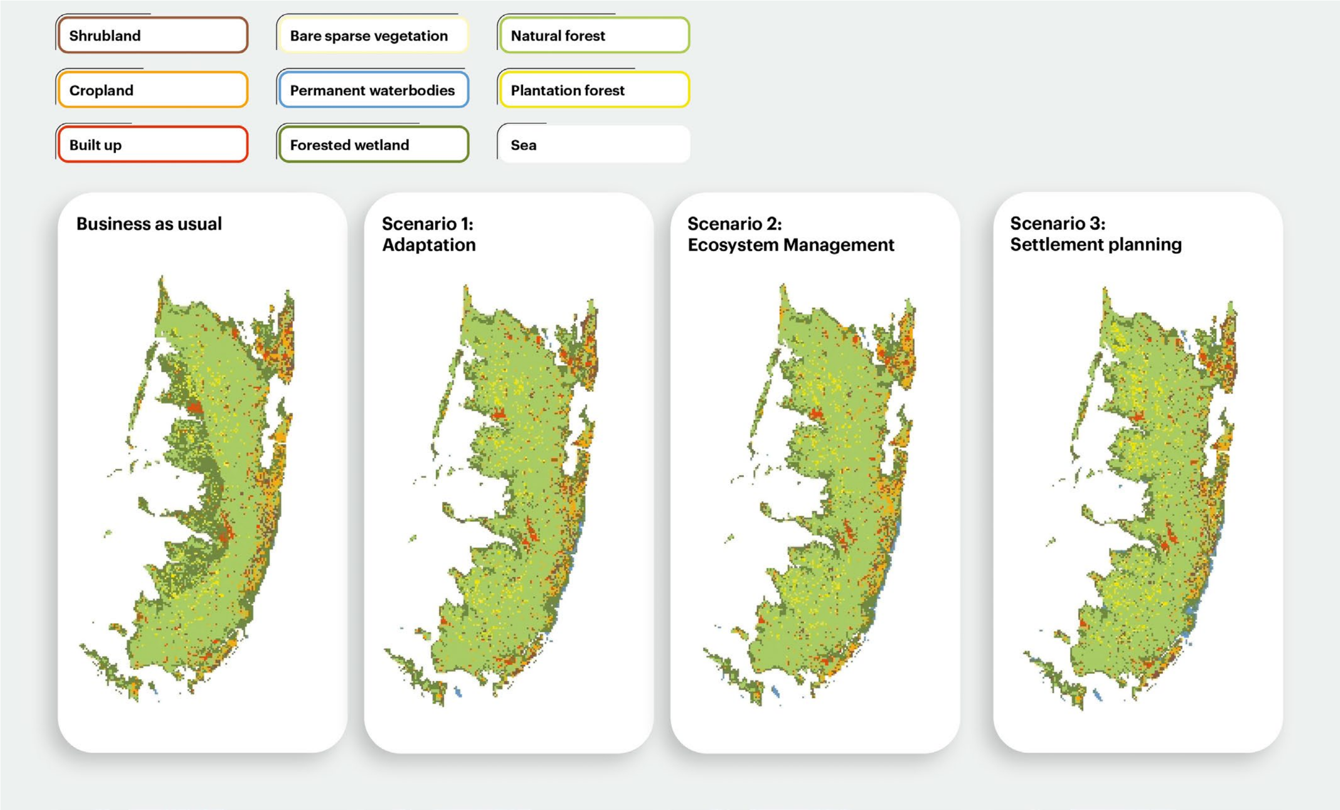


(**a**)

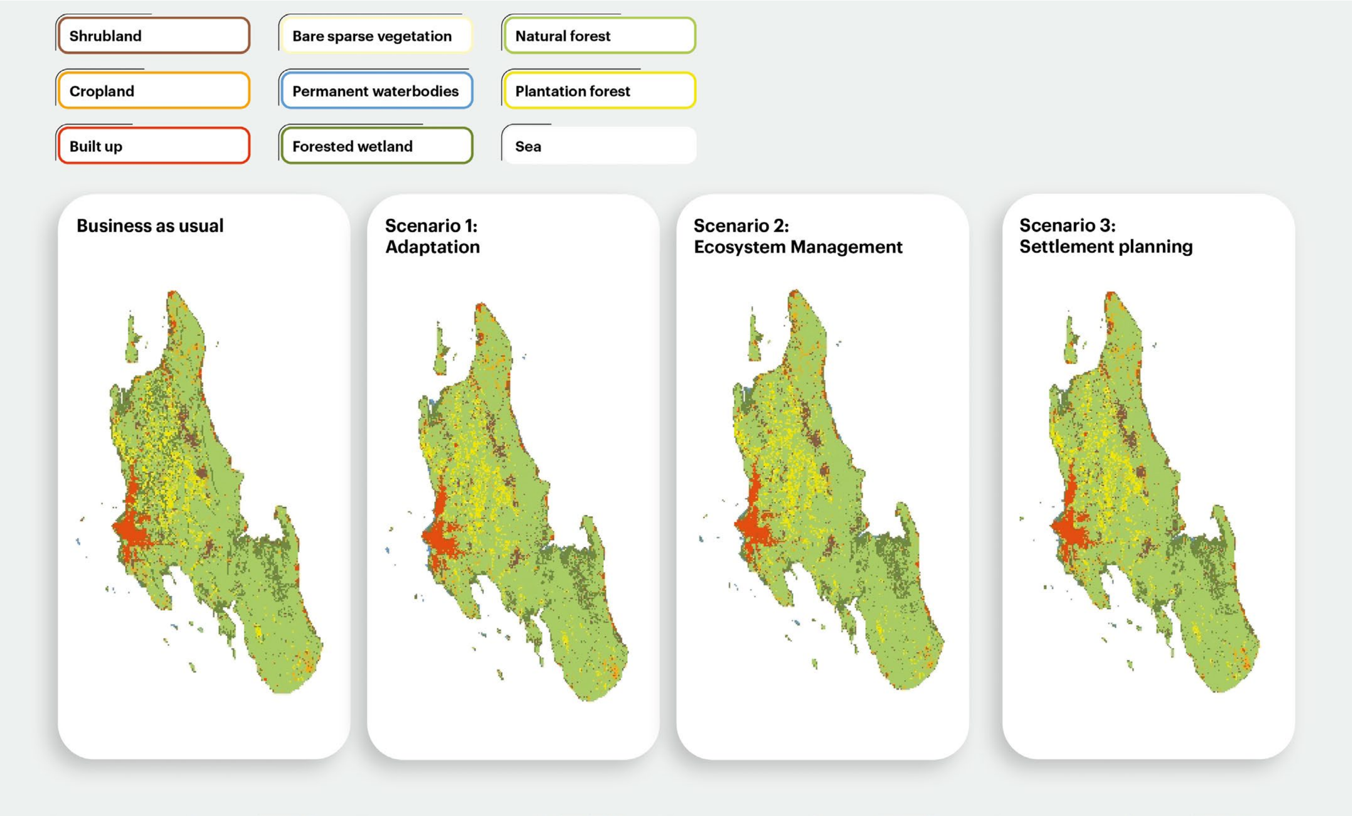


(**b**)

Figure 5. (**a**) Pemba land change; (**b**) Unguja land change. Percentage of land cover change for each land class between the present day and 2030 for the *Business as Usual* scenario, plus the three alternative scenarios, *Adaption*, *Ecosystem Management*, and *Settlement Planning*, developed in the workshops according to the modeling outcomes.



(**a**)



(**b**)

Figure 6. (**a**) Pemba land change map; (**b**) Unguja land change map. Maps depict land cover associated with the *Business as Usual* scenario and the three alternative scenarios, *Adaption*, *Ecosystem Management*, and *Settlement Planning*, according to modeling outcomes.

4.5. Overall Impacts of Scenarios on Water–Energy–Food

Considering the overall water–energy–food evaluation for each scenario, the *Settlement Planning* scenario for Pemba came out as the most effective at supporting resource security. In Unguja, the overall mean for water–energy–food evaluation was similar, but the *Ecosystem Management* scenario was predicted to support water–energy–food security most effectively (Table 4).

Table 4. Evaluation of how each scenario will impact livelihood aspects, starting with water, energy and food, and additional concerns, health, and shelter, by request of the participants on a scale of −4, very bad, to 4, very good.

		Water	Electricity	Gas	Firewood	Food	Health	Shelter
Pemba	Adaption	1	2	1	−1	1	1	1
	Ecosystem Management	0	0	1	−1	0	1	1
	Settlement Planning	2	3	1	−1	0	1	1
Unguja	Adaption	2	3	3	1	3	3	2
	Ecosystem Management	4	3	2	2	3	3	2
	Settlement Planning	4	3	1	−1	3	3	1

Across nearly all the scenarios, except for the *Adaption* and *Ecosystem Management* scenario for Unguja, the security of fuelwood supplies was thought to likely reduce. Participants in Pemba explained that:

> "*Clean and affordable energy seems to be weak due to large number of people using firewood which is its affordable and accessible*" (Pemba, October 2019).

Participants predicted that as fuelwood supplies become more unsustainable, other forms of energy use (predominantly gas) would increase. At the same time, barriers to its accessibility were mentioned:

> "*Gas energy is not strong due to lack of awareness among the community as well as the high price*" (Pemba, October 2019).

Participants conveyed a wish to protect forests for ecosystem benefits, including coastal protection, air quality, and soil structure. But they also recognized the challenge this posed for meeting their needs for energy, construction, and extraction of other non-wood resources, such as medicinal plants.

In Unguja, the *Ecosystem Management* and *Settlement Planning* scenarios both predicted high levels of water security despite the loss of permanent waterbodies shown in the land cover predictions. This potentially arises from an assumption that positive improvements would continue from witnessing the previous introduction of water infrastructure. There could also be a disconnect in understanding the extreme pressures regarding over-extraction and lack of foresight about climate change impacts.

When evaluating the overall effectiveness of the alternative scenarios to meet resource needs, participants felt it was important to consider health and shelter due to the implicit effects resource changes have on these two factors.

5. Discussion

The *Business as Usual* scenario gives a strong indication that saltwater incursion is likely to increase, as well as flooding of inland spaces where soil composition and land use do not promote adequate infiltration. Alongside this, the spatial analysis shows deforestation and a likely reduction in permanent water bodies. This aligns with previous research, indicating that small WIO islands face serious freshwater shortages resulting from environmental change and deforestation [49]. These risks are then often compounded by social factors such as inadequate funding for adequate water infrastructure, inequality of access, and rapid changes to watersheds and groundwater [48]. Although all alternative scenarios envisaged some continued deforestation of natural forests, some were more effective than others in mediating this. As well as pointing out areas of concern, scenarios offer an insight into where cropland expansion or plantation forest could take place, which could strengthen water–energy–food security.

By bringing together diverse stakeholders, scenarios provide more holistic evaluation strategies to secure water–energy–food into the future [1]. While no one scenario offered an ideal set of solutions for addressing environmental challenges and meeting water–energy–food security, several cross-cutting themes for future planning that support resource security became apparent. These included integrated approaches for managing environmental change, community participation in decision-making, effective protection of forests, cultural sensitivity to settlement planning and development, and poverty alleviation. Because of these emergent alignments, this discussion will focus on examining how scenarios could support strategic action toward water–energy–food security, and, more broadly, the 17 Sustainable Development Goals. Although the scenarios did not explore beyond the 2030 time horizon, they offer insights that can contribute to the achievement of Zanzibar's Development Vision for 2050 towards their 2030 targets [42] and wider agendas for sustainable land management, such as the African Agenda for 2063 [50].

5.1. Integrated Planning across Sectors

Within workshops, participants emphasized the value of the cross-cutting nexus government approach, which explicitly facilitates cross-linking between water–energy–food issues. This aligns with recommendations from the most recent SDG progress report, which state that "*epistemic communities need to reflect the diversity of society, and their interactions will need to be far more multi-directional and multi-disciplinary, so they can effectively address complex and interlinked challenges and goals*" (p. 91) [51]. Zanzibar's 2050 Development Vision also sets out to develop linkages across all sectors [42]. More generally, wider research states that an integrated approach for water–energy–food is seen as essential for future security [52]. Efforts should, therefore, pay attention to how meaningful collaboration happens.

Supporting collaborative practices across sectors might require the designation of specific roles to identify overlapping areas of interest where different groups might be able to contribute more integratively [53]. Resourcing aimed at cross-sector working groups might also be needed to stimulate more coherent action. Further to this, multi- and trans-disciplinary action requires critical reflections on power distribution and accountabilities [54]. Consequently, reflexivity is needed to surface participants' positionality (including their values and beliefs) and challenge underlying assumptions and power relations [55,56]. This can provide a more accurate and nuanced understanding of the impacts of actions undertaken and avoid a culture of silence where fundamental issues remain unresolved [57].

5.2. Community Participation in Decision Making

Participants advocated for participation in decision making. Integrating bottom-up experiences of all segments of populations and subnational identities into policy decision making has been shown to result in tangible synergistic solutions that are actionable [58] and key for the delivery of the SDGs [51]. While horizontal linkages for cohered responses to change can be enabled through common peer-to-peer understanding, vertical dialogues connecting experience to policy are often limited [59]. Moreover, while community-level insights are often acknowledged as important to developing a holistic understanding of complex issues, they are not drawn upon directly but through advocates such as NGOs, as in the case of the development of Zanzibar's 2050 vision [42]. This said, there is a movement towards people-focused processes for development; for example, the Africa 2063 vision outlines key stakeholder groups for consultation, including women and youth [50].

Specific to this research focus, there is an increasing awareness that social-ecological understandings for water–energy–food systems are missing in nexus analysis, which risks inadequate management [60,61]. But for effective elicitation, attention needs to be given to what prevents effective participation [20,21,62,63]. For instance, communities may lack trust in authorities due to past experiences of exploitation or broken promises. This mistrust can lead to reluctance to participate in new initiatives. Self-esteem, capacity, gender dynamics, and differences in education can also impact the dynamics and communication in participatory methods [21].

In this study, preparatory work was carried out at the community level to inform the framing of the multi-stakeholder workshops to try to enhance agency. Nonetheless, there were still barriers to participation in the multi-stakeholder workshops, which could have influenced the results. These were predominantly around differences in literacy and education, which affected the confidence of individuals to participate. Facilitators were aware of and mediated these challenges through supportive discussion and confidence building around the value of insights from community perspectives. But, this observation serves as a reminder that there can still be an imbalance of community voice representation even when represented in multi-stakeholder workshops.

5.3. Protection of Remaining Forests

Scenario narratives advocated for more regulation and protection of forests, especially those known to play a critical role in protecting coastlines from rising sea levels and the increased frequency of severe storms [64]. Key elements in this regard include restoring natural barriers like mangroves, which can help protect against erosion and flooding, as well as creating buffer zones and regulating coastal development and construction away from high water marks [65,66]. Awareness campaigns and education around certain themes, such as deforestation, were highlighted as central to aligning communities to land use policies. For instance, previous research in Zanzibar found that education about the ecological links between mangrove ecosystems and resources such as fish was key to obtaining management support [67].

Concurrently, it was recognized that alternative energy provision interventions are needed so that people are not adversely affected by restricted access to forest resources, which they depend on for energy needs [68]. As part of the Zanzibar Vision for 2050, there is a focus on extracting offshore oil and gas, which has tensions with international goals for reducing the use of fossil fuels [69]. Transitioning to gas usage for cooking also ultimately depends on people's capacity to afford this as a fuel source.

There are broader links to energy that need to be considered within energy security transitions. Zanzibar's strong dependence on mainland Tanzania remains a constraint to development as demand is expected to exceed cable capacity within the next few years due to the introduction of new hotels [17]. Lack of energy results in frequent power cuts and water extraction and supply challenges. There is also a constant tension between Zanzibar and TANESCO (Tanzania's electrical provider) because of excessive unpaid electricity bills, resulting in threats to cut off power supply [17]. This would have extremely negative implications for the provision of water, which depends upon electricity for pumping.

Renewable energy has some capacity to reshape energy relationships and enhance resilience. For instance, ZAWA (Zanzibar's water authority) has begun installing solar water pumps [17]. Solar is viewed as a more feasible alternative for households who cannot afford to connect their homes to the national grid. When this research was conducted, connection costs were variable, and the onus for expanding electric infrastructure was placed on the user. Since then, ZENCO (Zanzibar's electricity provider) has announced a flat rate of 200,000 TSH (around 85 USD). While this is a fairer approach, it is still out of reach to many citizens. As a result, solar remains a more viable option, especially for those without land ownership, as it is an investment that could be relocated.

5.4. Centralising Community Needs in Planning

Findings revealed a need for more consideration of diverse needs to design the most effective use of the space. Whilst there is an acknowledgment of unplanned settlements and challenges regarding poor sanitation and energy infrastructure, Zanzibar's 2050 Vision plans do not yet explicitly address this, especially in rural areas. At present, there is a limited understanding of how the built environment impacts the water–energy–food nexus [70]. Houses in rural settlements are mostly built without formal planning and are socially constructed in relation to how people organize their lives [71]. More interrogation is needed to explore how the current nature of settlements aligns with opportunities for strengthening water–energy–food security, but also how it might constrain it.

What also came through within the research process was the concern that participants had about development trajectories in terms of their suitability with social values and livelihoods. There was a strong advocation for settlements to have a degree of separation from tourism centers. Given that tourism is a vital part of Zanzibar's economy, it is essential to implement sustainable tourism practices that do not adversely affect the vital ecosystems or cultural heritage that local communities value [72,73]. At present, the benefits of tourism are not distributed amongst the local communities. Conversely, they have seen a reduction in quality and availability, increases in the price of locally caught fish, and conflicts with coastal zone use [31,38,72].

Looking forward, there are also several considerations that need to be made to improve community resilience to outlined drivers. Improved drainage systems, erosion control measures, and construction of infrastructure that is resilient to climate change impacts will be key in adapting to and mitigating the impacts of environmental changes [8]. Building guidelines should be revised to encourage the construction of energy-efficient buildings, incorporating renewable energy sources such as solar and wind power, thereby reducing dependency on non-renewable energy and forest products. Green infrastructure spaces and rain gardens could also aid in water management, improve water and air quality, provide local space for food production, and mitigate urban heat island effects [8].

5.5. Poverty Alleviation

Communities further sought to harness opportunities to strengthen their livelihood outcomes and, in turn, water–energy–food security. There was a call for more support for entrepreneurship, which could also see Zanzibari's connection to tourism-related opportunities. There was also a demand for adopting more innovation, for instance, in the farming sector. Community development, together with education, was also seen as important for stimulating skills and broadening opportunities from urban to rural communities. Further to this, there were ideas around how communities could organize themselves to develop co-operatives, which might stimulate funding streams for development activities. Zanzibar's Development Plan for 2050 has a strong focus on diverse income opportunities and seeks to stimulate opportunities across agriculture, finance, trade, tourism, blue economy, creative and digital, and oil and gas sectors [42]. It also seeks to create better links between tourism and local produce as well as support training to increase people's capabilities to enter the workforce [42]. More in-depth planning is needed to ensure people can harness potential opportunities through subsidized training programs and advisory groups to connect local people to employment opportunities.

5.6. Limitations

Whilst findings contribute to understanding how land cover change could impact water-energy-food security in Zanzibar, there are limitations to the research. Firtsly, the *Business as Usual* scenario modeling used land cover maps over a close time series to project land cover changes for the future. It would be more suitable to analyze changes over a longer time interval, but this was not available at the time of analysis. The *Business as Usual* map, alongside the alternative scenario maps, should not be interpreted as accurate representations of the future but as comparative visuals of alternative approaches for managing drivers of change into the future to guide decision making.

Moreover, though there was a concerted effort to bring together diverse stakeholders, it is worth reflecting on who was not involved. For instance, migratory groups from the Masai Mara periodically travel to and from Zanzibar for work during the high tourism season. They interact with the landscape to meet their needs and, therefore, have an influence on the nexus—but were not included in visioning for the future. Similarly, international migrants who have settled in Zanzibar were not involved but often have an impact on land cover through building or tourism-related business.

Moreover, while efforts were made to reduce bias for the sampling of participants by setting out specific guidance for the recruitment, there is some likely bias evident in the results in using village leaders as gatekeepers. For instance, a likely over-representation of the current political party.

Finally, ideally, all stakeholders should have had the opportunity to give feedback on the results and further modify the land cover maps. In this case, it was not possible due to the global pandemic in 2020.

5.7. Future Considerations

Though the research process was able to draw out planning approaches that could support water–energy–food security through the mediation of drivers of change, there was no one set of solutions that completely addressed resource challenges, and deforestation was still expected to occur to some extent across all the scenarios modeled.

Whilst scenario methodologies are useful for working with the future and challenging assumptions behind societal patterns, they can be seen as limited as they tend to focus on plausible futures. This can mean that they don't always sufficiently challenge systematic failures that might require more transformative change [74]. This study focused on 2030, but having a longer time horizon could help participants explore more ambitious interventions, but at the same time, it means working with greater uncertainty. Future research could valuably employ more "pathways"-type future approaches such as Three Horizons, working with local participants to collectively envision their desired futures and creatively identify necessary actions for supporting transformation [74].

Another consideration here is the lack of consideration towards global influences when exploring water–energy–food security to local land use. Communities in small islands are net importers of food and, therefore, are highly exposed to food price spikes [75]. While subsistence farming is an important aspect of meeting food needs, climate change, land use competition, and poor soil fertility contribute to reduced yield [76]. Though results are useful for building a picture of place-based water–energy–food security understandings, there is a need to capture global influences and their impacts across these more local scales. This might be achieved by involving trade, geopolitical, and global conservation experts in the workshop dialogues.

Further work is also needed to explore the wider implications of informal migrant settlements and the social-ecological interactions of migrations within the water–energy–food nexus. Unplanned urban sprawl from both local populations and migrant settlements can lead to expansions into natural environments or agricultural land, as in the case of Chuini Zanzibar [77]. Social-ecological relationships underpinning water–energy–food security might be especially precarious for migrant populations because of land tenure insecurity. For instance, those renting property or land can be more reluctant to invest in infrastructure such as electricity because they could be forced to move [17]. Therefore, what might be happening is a divergent set of social-ecological relationships for migrant populations compared with Zanzibari communities. These need to be understood so that they can be captured in future scenarios.

6. Conclusions

As communities in small islands within the Western Indian Ocean have strong social-ecological relationships within the water–energy–food nexus, they are well-positioned to explain the implications of different types of pressures and how this mediates these relationships. This study provides an example of how community insights can be integrated with active decision makers to evaluate the impact of alternative interventions more effectively. Findings reveal important understandings with regard to where drivers of change might most impact water–energy–food security and offer socially acceptable interventions to mediate such.

Results could inform near-term land use planning that can enhance climate-resilient rural livelihoods, better conservation outcomes, and sustainable tourism development. Specific policy recommendations arising from this work include: (1) focusing conservation and forest regeneration efforts around areas predicting a loss in permanent water bodies; (2) working with communities and hoteliers to reforest coastlines to provide protective buffers against storm surges at a landscape scale; (3) invest in solar infrastructure for water pumps to limit disruptions in supply caused power outages; (4) actively support the establishment of woodlots for producing fuelwood at scale, while also investing in long term sustainable energy transitions; (5) a focus on local enterprise and the development of skills to harness emergent opportunities; and (6) enhance adaptive capacity of communities through training in innovative agricultural methods.

As well as more specific policy outcomes, the results from the study also advise on processes for how policy decisions should arise, with community involvement and integration between sectors being key. Enhanced participation from communities at the onset of landscape planning was thought to provide a better opportunity for protecting community values and culture. Productive discourse and co-development of strategic action involving relevant organizations were thought to be important for increasing Zanzibar's capacity to support better water–energy–food outcomes.

Understandings from communities and experts about social-ecological interactions within the water–energy–food nexus also indicate that scenario alternatives would operate differently for the different islands, demonstrating the importance of understanding the social, environmental, and economic contexts and how they might connect to national policies.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/land13020195/s1, Figure S1. Map of Unguja and Pemba islands and land use and land cover for the year 2019 (when fieldwork was conducted); Figure S2. Pemba; Figure S3. Unguja; Table S1. Guiding questions for scenario narrative formation in Pemba and Unguja multistakeholder workshops; Table S2. Land cover class descriptions used in initial modelling process (note these were later simplified further); Table S3. The data sources for variable land cover modelling; Table S4. Sub model details for transition potential maps explaining land cover change between 2015 and 2017 in Unguja; Table S5. Sub model details for transition potential maps explaining land cover change between 2015 and 2017 in Pemba; Table S6. Area of built up land cover class; Table S7. Modelling conditions for the adaptive capacity scenario in Pemba. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S8. Modelling conditions for the adaptive capacity scenario in Unguja. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S9. Modelling conditions for the ecosystem management scenario for Pemba. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S10.

Modelling conditions for the ecosystem management scenario in Unguja. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S11. Modelling conditions for the settlement planning scenario in Pemba. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S12. Modelling conditions for the settlement planning scenario in Unguja. Likelihood of land transition ranges from 1 (least likely) to 4 (most likely). Relationship of the influencing variables to the pattern of transition described as monotonically increasing (the further away from the variable the more likely the transition), monotonically decreasing (the further away the variable is the less likely the transition); Table S13. Percentage differences in land cover area between the present day actual land cover and the predicted values for the BAU scenario for 2030 in Pemba; Table S14. Percentage differences in land cover area between the present day actual land cover and the predicted values for the BAU scenario for 2030 in Unguja; Table S15. Details of land cover consolidation for final map images and calculations.

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