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A Tool for the Assessment of Forest Biomass as a Source of Rural Sustainable Energy in Natural Areas in Honduras

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Abstract: Forest biomass as a rural sustainable energy source has received much attention in recent years due to its major economic, social, and environmental benefits. This research focuses on an adapted methodology based on parameters of the Evaluation of Ecological Integrity for using site-specific information as a tool for the assessment of forest biomass as a source of rural sustainable energy in Honduras, focusing on the Central American Pine–Oak Forests. The parameters used were Percentage of Forest Cover (FC), Patch Area (AREA), Fractal Dimension Index (FRAC), and Proximity Index (PROX). The goal was an average index rating of 5 for an ecosystem which is intact or in its natural state. The findings showed an ecosystem degradation that was outside the range of acceptable variation with a simple average of 1.75, which is far lower than the target rating of five (5.0); the forest cover loss was 40% of the total area. This surprising finding shows that immediate intervention is required to maintain this ecosystem, and that if action is not taken, the ecosystem will suffer severe degradation. Decision makers must consider this methodology for using site-specific information and ensure that local communities are involved in restoring the ecosystem.

Keywords: ecological integrity; renewable energy; rural sustainable energy; forest biomass; Honduras

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1. Introduction

Finding sustainable energy supplies has become an important issue for decision-makers worldwide [1]. Conventional energy sources such as natural gas, oil, coal, or nuclear [2] cause heightened levels of Greenhouse Gas (GHG) emissions, which increase global warming [1].

The last report published by the Intergovernmental Panel on Climate Change (IPCC) affirms that human influence on the climate is clear; the recent anthropogenic emissions of greenhouse gases are at their highest-ever recorded levels [3].

A consequence of this situation is that the traditional linear models of economy and production have become unsustainable [4,5]; therefore, Markard et al. [6] suggested that it is necessary to design new, more renewable technologies for the transition to more sustainable sociotechnical systems. These systems should be based on a greater use of renewable energies which use less natural raw materials, such as forest biomass [7,8]. This specific example is becoming more prominent as an alternative to fossil fuel energy sources [9]. Current studies consider forest biomass as an important economic resource for the bioeconomy [10,11]. Consequently, its proper use and management can bring major economic and environmental benefits since the use of biomass favors the reduction of carbon dioxide gases. Using a renewable raw material to generate sustainable energy is cheaper than using fossil fuels, and it is also cheaper to produce [12].

Paradoxically, the sources of forest biomass are forested areas, which, in certain parts of the world, are found in protected natural spaces. Published at the same time as the sixth IPCC report, and with a similar impact, the FAO and the UNEP, in their 2020 report, note that deforestation and forest degradation continue to occur at alarming rates, and this is contributing significantly to the current loss of biodiversity. The food systems that humans rely on and their ability to adapt to future changes depend on this biodiversity [13]. According to the Protected Planet Report [14], 15.4% of the world's terrestrial and inland water areas are within areas with a protected status. Central America and South America are the two regions with the highest percentage of terrestrial and inland water protected areas (28.2% and 25%, respectively). In these two regions, most countries have more than a quarter, and even up to half, of their total area under protection. It is estimated that, globally, 880 million people spend part of their time collecting firewood or producing charcoal, most of whom are women and children. Local communities tend to be small in some areas of low-income countries where forest areas and forest biodiversity are high, and they also have high poverty rates [13].

According to the Latin American Energy Organization (its Spanish acronym is OLADE) [15], the relationship between energy and poverty has been clearly identified as a critical aspect that needs to be considered if sustainable development is to be achieved in developing countries. This is especially true for biomass that is required for cooking, heating, and generating energy. In the Central American region, the energy pattern shows that there is a pronounced trend towards the use of traditional energy sources in the poorest countries of the region. In 2020, OLADE estimated that 20 million people of the Central American population were dependent on firewood. According to Rodríguez [16], in Honduras alone, the consumption of firewood makes up 47% of the total primary energy consumption. This anthropogenic behavior puts a lot of pressure on natural forests, and it also has a major role in ecosystem deterioration, as many forest management practices are unsustainable. Other Central American countries, such as Guatemala, Nicaragua, and El Salvador, have levels of firewood consumption that average 39%. This excessive use of forest biomass creates a human impact on ecosystem processes which could alter the organization of these processes at multiple spatial scales [17]. Furthermore, according to Nelo et al. [18], deforestation in Honduras reached 43,588 ha per year between 2012 and 2016, an increase of 70% when compared with the deforestation rate for the period 2000–2012. The Mesoamerican region possesses 12% of the world's biological wealth in just 2% of the planet's territory.

The Central American Pine–Oak Forest is located in this ecoregion, which is one of the 17 regions that make up the Neotropical Tropical and Subtropical Coniferous Forests biome. The territorial area that encompasses the Pine–Oak Forest is home to at least 18 million inhabitants, according to the most recent population censuses from each country. Approximately 47% and 28% of the total population reside in Guatemala and Honduras, respectively. In the case of Honduras, 35% of the population within the ecoregion lives in poverty, and many of these people are indigenous ethnic groups [19]. The climate in the areas that sustain a pine–oak forest is typically cooler and drier than that found in the lowlands, and, therefore, human inhabitants have favored these areas since pre-Colombian times. Consequently, these forests have probably suffered from the most consistent and long-term degradation caused by humans of any forested area in Honduras [20].

These anthropogenic disturbances are the main stressors that affect environmental balance by creating fragmentation, causing the deterioration of landscape connectivity, and altering Ecological Integrity [21]. Kohl et al. suggest that the use of forest biomass as a renewable energy source is associated with the loss of forests or protected natural spaces, and more profoundly with the loss of ecological functionality. They claim that the use of forest biomass requires sustainable management based on tools that make it possible to assess and facilitate decision-making [22].

There are many tools used for assessing the loss of forest resources and natural ecosystems. However, the use of Light Detection and Ranging (LiDAR) and digital aerial photographs allows detailed spatial and three-dimensional information about the forest structure to be obtained [23]. Spatially explicit information is particularly valuable to managers as it helps monitor forest degradation [24]. Additionally, Life Cycle Analysis (LCA) has been used to evaluate the potential impacts generated by the loss of availability of timber forest resources [25]. The Fuzzy Analytic Hierarchy Process (AHP), a hybrid approach of fuzzy logic and multi-criteria decision-making, was adopted to investigate and reveal the levels of importance of sustainability in forest management [26]. Ecological integrity assessment is one of the tools used not only for measuring conservation goals, but also for setting them. It also assesses threats to biodiversity, identifies monitoring and research needs, and communicates management information to non-specialists [27]. Herrera-Fernadez and Corral [28] have adapted the work of Parrish et al. [29] in order to establish a methodology which has an indicator that allows the measurement and monitoring of the ecological integrity of the protected areas of the Central American System of Protected Areas (its Spanish acronym is SICAP). Other authors, such as Robert et al. [30], Hasan-Rezaa and Abdullaha [21], and Burke et al. [31] have presented indicators related to ecological integrity to assess forest management. However, in certain parts of the world, economic and technical issues, a lack of information, and local living conditions make it difficult to use these management tools. Gareau [32] argued strongly that the failure to conserve natural resources in the protected natural area of Cerro Guanacaure, Honduras, is a consequence of the park regulations having been designed exogenously, with a lack of understanding of socially differentiated local conditions and without providing a feasible solution to resource degradation.

Faced with increasing levels of ecosystem degradation, scientists and professionals aim to preserve Ecological Integrity by restoring habitat functions. These functions are defined as the capacity of an ecosystem to provide wild species of plants and animals with refuge and spaces for reproduction [33]. Well-managed forests can maintain a community of organisms with functional organization such as that found in natural areas [30]. Environmental Sustainability (ES) refers to the minimum impact on the environment in comparison to traditional technologies and fossil fuels of small-scale renewable energy systems. This concept is linked to technical sustainability, as maximizing the life span of equipment reduces the number of replacement pieces needed, which, consequently, reduces the generation of waste that can negatively impact the environment [34]. Therefore, Environmental Sustainability is closely related to Ecological Integrity (EI), which, according to Cartel et al. [35], is defined as "the extent to which the composition, structure, and function of an ecosystem fall within their natural range of variation".

According to Syahputra et al., Renewable Energy is a type of energy that can be replenished, and its use focuses on energy efficiency, energy conservation, environmental diversification, and community integration [36]. Therefore, this concept is linked to Rural Sustainable Energy, which, according to Romero, Piñeiro, and Pérez [37], is a central concept of current political agendas aimed at fostering a sustainable energy transition that can be linked to the development of rural areas. This transition is crucial to improving the social, economic, and environmental benefits of renewable energies, especially those related to heating and cooking, such as firewood. The raw material that has been considered for this transition is forest biomass, which is a biodegradable element generated in the form of waste during wood production and processing, as well as during sanitation cutting [38]. Additionally, ancestral traditions need to be examined by using scientific strategies to explore the role these traditions have, and their compatibility with forest conditions. These strategies should use criteria and indicator frameworks (C&I) as platforms to include community needs and objectives in management decisions which offer a holistic approach [39]. Therefore, conservation efforts should frequently focus on minimizing the real threats to forests that could affect these strategies, but this is often carried out in such a way that there is no clear understanding of the site-specific factors that affect the composition and structure of local forests, or of the magnitude of the threat to the forests [31].

In this work, a simple methodology is presented that allows an indicator based on criteria related to Ecological Integrity to be obtained. This methodology, among others, is used to evaluate the current state and sustainability of the natural ecosystems that are being put under pressure by energy generation in rural areas in Honduras. The study was carried out in the forests of Honduras that make up the Mesoamerican ecoregion known as the Pine–Oak Forest, which is a natural area of great ecological wealth. Despite the importance of this type of forest, it is an ecosystem that has one of the lowest levels of legal representation in the conservation mechanisms in the region; very little research has been carried out on this ecosystem, and it is not valued as much as it should be [19]. In Honduras, the value of biomass resources of the pine–oak ecosystem is underestimated, and they have been misused due to a lack of research and the absence of suitable technology, especially technology related to bioenergy.

The current work presents a diagnosis of the current situation to give visibility to and increase understanding of the current pressure to which natural ecosystems of great ecological wealth are being subjected in an area of the world that is characterized by a lack of research. According to Banaś and Utnik-Banaś [40], using timber from multifunctional forests for energy production can be economically viable and environmentally friendly when it is consistent with the principles of sustainable management. The purpose of the current study is to provide a simple and site-specific assessment tool focusing on the state of a natural area subjected to the intensive extraction of forest biomass for the energy use of rural sustainable energy to improve the decision-making process for Sustainable Forest Management in natural areas in Honduras.

2. Materials and Methods

2.1. Study Area

The pine–oak ecosystem is mainly spread across the uplands of the Sierra de Madre de Chiapas, Mexico/Guatemala; across the Sierra del Merendon, Guatemala/Honduras; and south into northern Nicaragua. The most outstanding characteristic of this biome is the diversity of the pine (>100 *Pinus* spp.) and oak (>150 *Quercus* spp.) species, which, according to Muller [41], adapt well to variable climatic conditions and natural fires [42]. These pine–oak forest formations often form intricate mosaics and complex successional interactions extending up into broadleaf cloud forests at higher altitudes. This biome is currently threatened by agricultural expansion, logging, firewood extraction, forest fires, and pests. According to the Honduran National Institute of Forest Conservation (ICF) [43], Honduras covers 112,492 km^2 of land, with 53,981.37 km^2 of that area in forest cover, representing 48% of the total surface area. The country has 91 protected natural reserves with a total area of forest cover of 21,270.4 km^{2,} which is distributed as follows: 17,717.4 km^2 of wet broadleaf forest, 1487.6 km^2 of dense coniferous forest, 544.7 km^2 of mixed forest, 410.6 km^2 of mangrove forest, 859 km^2 of sparse coniferous forest, 213.8 km^2 of deciduous broadleaf forest, and 37.3 km^2 of floodable wet broadleaf forest. According to the Honduran National Institute of Statistics, the coniferous forest covers 30.9% (1,951,977.87 ha) of the total forest area [44]. Honduras was selected as the location to be studied due to its abundance of coniferous forest biomass, the recent increase in deforestation rates mentioned earlier. as well as nearly half of primary energy needs of communities being met by the use of firewood.

The study area as shown in Figure 1, considered in this research is a nature reserve made up of the pine–oak ecosystem that is representative of this country and covers an area of 4552 ha that is managed by the National University of Forest Sciences (its Spanish acronym is UNACIFOR). Three important aspects of the study area were considered: (1) It has a very low economic growth rate of 2.65%, according to the World Bank [45] and income levels have been very low in the last decade, meaning that it has become an increasingly peripheral and economically marginalized region; (2) it has a variety of Sustainable Energy

Resources; and (3), most communities are located on the periphery of the nature reserve from which the energy resource is obtained.

Figure 1. Location of the study area in the department of Comayagua, Honduras.

The methodology used in this study consisted mainly of (1) satellite-image processing using specialized software to measure forest cover degradation (forest cover loss over a given time period); and (2) the evaluation of the Ecological Integrity of the Pine–Oak Ecosystem using Landscape Metrics with key indicators: Patch Area (AREA), Fractal Dimension Index (FRAC), and Proximity Index (PROX).

2.2. Satellite Image Processing

The first step in the investigation consisted of processing satellite images by using a Geographic Information System (GIS) with QGIS software to measure coverage and find the percentage of degradation [46]. The results presented here were obtained by processing Landsat 8 TM satellite images [47], and then, the loss of forest cover over a 6-year period was compared to the period from March 2014 to March 2020. The percentage of forest cover loss was obtained by using a multi-temporal analysis proposed by Sanhouse-Garcia et al. [48] that uses multiple source data; the data from 2014 came from the RapidEye sensor [49] with a spatial resolution of 5 × 5 m per pixel. This information was obtained from the Honduran Map of Land Use and Forest Coverage prepared by the Forest Monitoring Unit of the National Institute for Forest Conservation and Development, Protected Areas, and Wildlife [50]. For 2020, the data used came from Landsat 8 images with a resolution of 30 × 30 m per pixel with a Supervised Classification [51] using the QGIS Semi-Automatic Classification Plugin [52]. As mentioned earlier, these tools were used to assess the loss of forest resources and natural ecosystems and to obtain detailed spatial and three-dimensional information about the forest structure [23]. This methodology was used to acquire spatially explicit information, which is particularly valuable to managers when monitoring forest degradation [24].

2.3. Evaluation of Ecological Integrity

According to De Juan et al. [53], Ecological Integrity (EI) is a methodology that seeks to capture the complex nature of ecosystems and their interaction with local communities. This process helps translate scientific terminology into operational language to educate society. This is achieved with an approach that simplifies complexity by using scientific knowledge to identify which components reflect the state or changing state of an ecosystem. In this case, the methodology mainly consisted of reviewing the scientific information on the study area considering four fundamental elements adapted from Parrish, Braun, and Unnasch [29]. These elements are: (a) identification of a limited number of conservation objects; (b) identification of Key Ecological Attributes (KEA) for each of these targets; (c) identification of acceptable ranges of variation for each attribute measured with indicators; (d) rating of the conservation state of each target, based on the analysis, to see if the ranges of variation are acceptable. The core components of the evaluation included the key ecological attributes and the acceptable range of variation for the indicators, which, according to Herrera and Corrales [28], should have at least one key attribute and indicator with a quantifiable scale that has been developed for each conservation target.

According to Huang et al. [54], "Nowadays, numerous forest management strategies have been introduced and implemented worldwide for a long time. However, the knowledge about the impacts of alternative management strategies on forest multipurpose management practices is still insufficient". In this case, there was not enough information available for the rest of the KEA, so a preliminary empirical analysis was carried out. The experts considered that the preliminary analysis was sufficient to review and make the respective suggestions. This procedure consisted of two basic tasks: (a) to collect and analyze the data for monitoring; and (b) use the results of this analysis to determine the appropriate category for each indicator. The indicators were rated using the scale: "Excellent", "Very good", "Good", "Fair", and "Poor", as defined in Table 1 below.

Table 1. Rating of each indicator and assigned value.

Qualification	Value	Description
Excellent	5	The ecosystem is intact or in its natural state.
Very good	4	Desired state however, it requires some human intervention to maintain the natural ranges of variation.
Good	3	The ecosystem requires intervention to maintain it.
Fair	2	Anthropogenic activities have a considerable impact on the ecosystem's natural conditions, and it is vulnerable to severe degradation.
Poor	1	The ecosystem is severely affected by anthropogenic activities.

Once the indicators were rated, the simple average of the indicators for each conservation element was estimated, using the numerical values assigned in the previous procedure. This value was compared to the values in Table 2 below.

Table 2. Rating of each conservation element according to the simple average of the respective indicators.

Value	Category
$\geq$4.0	Excellent
3.0–3.99	Very good
2.0–2.99	Good
1.0–1.99	Fair
<1.0	Poor

After finding the rating of each conservation element, the respective category was designated by assigning the desired value of each indicator ("Excellent", "Very good", "Good", "Fair", and "Poor"). As mentioned earlier, Parrish et al. [29] propose a methodology with an indicator that allows the measurement and monitoring of the ecological integrity of the Central American System of Protected Areas (its Spanish acronym is SICAP) which is not specific enough to be replicated in natural areas in Honduras. Robert et al. [30], Hasan-Rezaa and Abdullaha [21], and Burke et al. [31] are some of the experts who present indicators related to ecological integrity to assess forest management; however, it must be noted that economic and technical limitations, and a lack of information make it difficult to implement these indicators.

According to Gareau [32], the failure to conserve natural resources in Honduras is a consequence of park regulations having been designed exogenously with a lack of understanding of socially differentiated local conditions and without providing a feasible solution to resource degradation. Therefore, the methodology presented in this study aims to use site-specific information as a tool for the assessment of forest biomass as a source of rural sustainable energy in natural areas in Honduras. The methodology considers ancestral traditions by using scientific strategies to explore the role of these traditions and their compatibility with forest conditions. It also uses criteria and indicator frameworks (C&I) as a platform to include community needs and objectives in management decisions which offer a holistic approach to the sustainability of local environmental contexts [39]. Site-specific factors determined conservation efforts that affect the composition and structure of local forests to reduce the magnitude of the threat to them [31]. The C&I results were based on Landscape Metrics: Patch Area (AREA), Fractal Dimension Index (FRAC), Proximity Index (PROX).

2.3.1. Patch Area (AREA)

According to Slattery and Fenner [55], the areas of different land class types in a given landscape has a significant impact on the types of species that a landscape can sustain. Fragmentation can affect a landscape in several ways, such as a reduction in total forest area and a reduction in mean forest patch size. A raster categorical data patch is a group of contiguous cells of the same class. Therefore, a patch is the basic semantic unit in raster categorical data and usually corresponds to an entity or a discernible real-world area [56]. This indicator was considered because of its importance in conservation activities in fragmented landscapes, which is, in part, the situation in Honduras. Conservation efforts in Honduras have largely focused on keeping remaining large patches intact, and often ignoring the increasingly important role of smaller patches in the conservation of the remaining vegetation. As habitat loss increases in fragmented landscapes, there is an increasing need to measure the relative contribution of all patches (large and small) to overall ecosystem persistence. This should be done in a way that helps deliver effective conservation strategies aimed at preventing the death of ecosystems. For some animal communities, actions focused on protecting large patches are critical, but for many others, protecting and managing small patches is crucial for community persistence [57]. Most of the natural protected areas in Honduras are basically small patches connected by narrow pieces of forest.

2.3.2. Fractal Dimension Index (FRAC)

The Fractal Dimension Index (FRAC) describes the irregular, fragmented patterns found in nature [58]. This index also estimates a continuous grouping of grid cells representing the same landscape features, how this measurement is related to its edge, and how it can be modified to address diversity [59].

This index was selected because changes in ecosystems are highly complex, heterogeneous, and extremely difficult to measure with a single scale. This difficulty is caused by the presence of human communities in the buffer zones of natural protected areas in Honduras where there are irregular and fragmented patterns. Fractal geometry has been used to quantitatively estimate the extent of irregularity in ecosystem changes. Other metrics are also being used to study changes in forest ecosystems. However, fractal geometry has been effective in measuring ecosystem components in a range of ecological conditions [60].

2.3.3. Proximity Index (PROX)

A proximity index (PROX) quantifies the spatial context of a habitat patch in relation to its neighbors. The index distinguishes the distribution of small habitat patches from clusters of large patches [61]. An evaluation of the relationship between PROX and variations in the spatial characteristics of clusters of patches showed that a reduction in the isolation of patches within a cluster produced exponential increases in PROX, and that an increase in the size of these patches produced a more modest linear increase in PROX. Based on the research conducted by Slattery and Fenner [55], the search radius used in this study for the mean proximity index was 100 m. A similar pattern was displayed at the search radii of 20, 50, 100, 500, 1000, and 10,000 m, but 100 m was chosen as the most suitable distance to represent a species crossing between two patches. This index measures the movement of individuals between resource patches in a given landscape, which is why this index is important as a determinant of population persistence, population size, and genetic diversity. Thus, researchers are extremely interested in measuring connectivity, which is defined as the degree to which a landscape facilitates or impedes movement between resource patches [62].

2.4. Statistical Analysis

The results were validated with field visits. For the analysis of ecosystem heterogeneity [63], a 7-band Landsat 8 network was used and processed using FRAGSTATS software as shown in Figure 2. The metrics considered were Patch Area, Fractal Dimension Index, and Proximity Index.

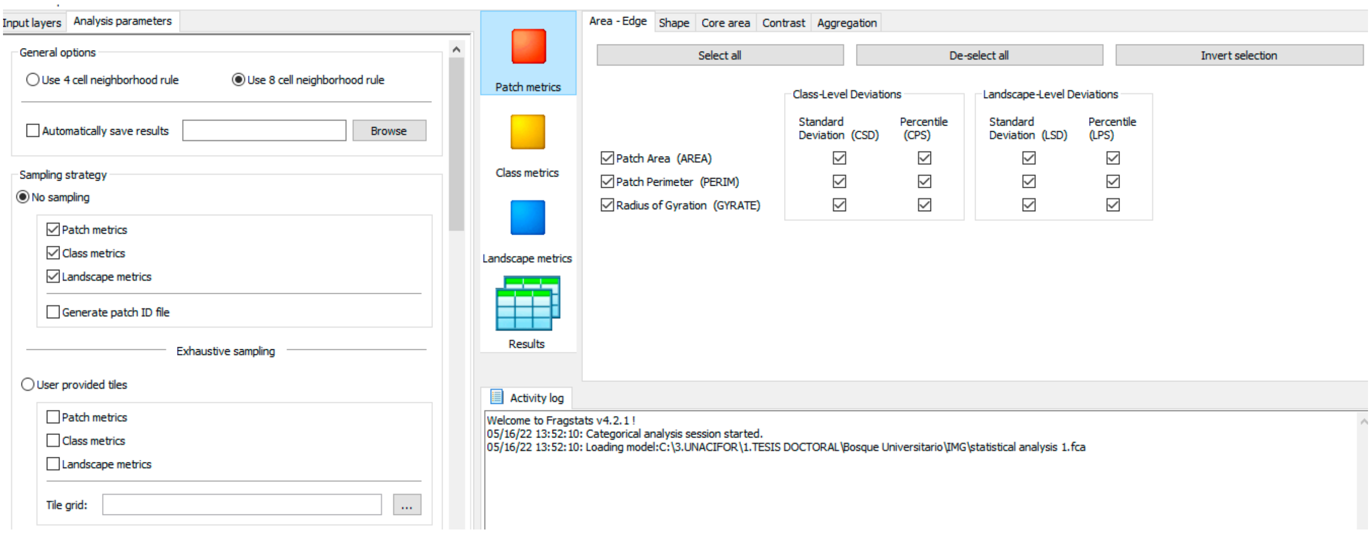

Figure 2. Landscape metrics.

3. Results

The results presented here are The evaluation of Ecological Integrity based on the conservation target Ecological Systems—"Forests" and are provided below by describing the results for each of the four key ecological indicators followed by a summary of the findings.

Evaluation of Ecological Integrity

Although some KEAs and indicators were identified for other conservation targets, such as Hydrological Systems (lentic and lotic river ecosystems), Ethnic Cultures, and Wildlife, the current study only focused on the conservation target "Ecological Systems" (pine–oak ecosystem) to identify potential sources of sustainable energy in the form of forest biomass [64]. Table 3 shows one of the results obtained from the experience of the group of experts on the types of indicators to be evaluated, which are (a) Indicator 1—the percentage of forest cover loss, which is defined as the loss of tree cover per year and is measured as a percentage of the total area, (b) Indicator 2—the patch area, which determines the area covered by forests and is somewhat different from the area surrounding it, (c) Indicator 3—the fractal dimension index which is a landscape index [65] that provides a measure of spatial pattern complexity which allows simulated and real landscapes [66] to be compared by looking at the geometry of different patterns, and (d) Indicator 4—the Proximity Index, which considers the size and proximity of all patches within a specific search radius.

Table 3. Selected conservation targets.

Conservation Target	Category	Key Ecological Attribute	Indicator	
Ecological Systems Forests	Size	Forest cover	(1)	% of forest cover (FC)
	Condition	Size of the habitat	(2)	Patch Area (AREA)
	Context	Fragmentation Connectivity	(3)	Fractal Dimension Index (FRAC)
			(4)	Proximity Index (PROX)

These four (4) indicators will help to assess the current state of the "forest" conservation targets so they can be used for sustainable energy generation purposes; likewise, according to Bendek, Sebestyén, and Bartók [67], it will be necessary to establish a monitoring program for the conservation of species in peripheral rural communities which base their development on sustainable energy.

The results of the analysis of each indicator were obtained by establishing ranges of variation as follows:

For Indicator 1, that is, the percentage of forest cover loss (deforestation over 6 years), the following ranges of variation were established: Poor (25%), Fair (11.0–24.99%), Good (5.0–10.99%), Very good (4.99–0%), and Excellent (0%). With this indicator, it was found that 40% of the total surface of the ecosystem is deforested, as shown in Figures 3 and 4, as well as in Table 4.

Figure 3. Forest cover loss in 2014 (in red).

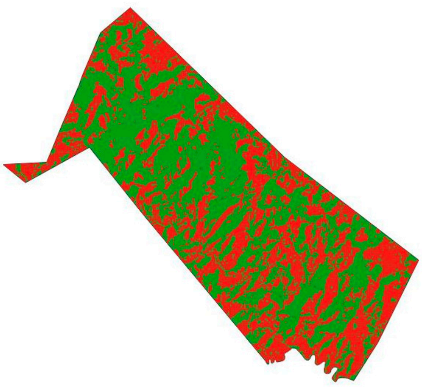

Figure 4. Forest cover loss in 2020 (in red).

Table 4. Summary of the data processing results of the conservation target "Forest".

Forest Cover Loss	AREA (Ha)		Forest Cover Loss in Hectares	Loss in %
	2014	2020		
Forest Non forest	3752 800	2601.82 1950.18	1833	40
Landscape Metric			Simple averages	
1.	Patch Area (AREA)		2.0 ha	
2.	Fractal Dimension Index (FRAC)		1.06	
3.	Proximity Index (PROX)		100 mt	

This finding indicates that if no action is taken in the short term, the conservation target "Forest" will be vulnerable to severe degradation. In other words, the Ecological Integrity of Forest Cover is given a "Poor" category result, which is outside the acceptable variation; therefore, human intervention will be necessary to maintain the natural ranges at an acceptable level.

For Indicator 2, called Patch Area (AREA), the following ranges of variation were established: Poor (9.99 ha), Fair (10–50 ha), Good (49.99–100 ha), Very Good (99.99–150 ha), and Excellent (>150 ha). According to McGarigal and Marks [68], with this indicator, the smaller the patch size, the greater the influence of external factors. In other words, the species are more vulnerable to threats such as diseases and fires. Larger and more heterogeneous patches are more likely to sustain a greater richness and diversity of species within their ecosystems. On average, it was found that the Patch Area is 2.0 hectares, and, like the previous indicator, it is in the "Poor" category, meaning that immediate actions are required to restore the ecosystem.

According to McGarigal [69], Indicator 3, the Fractal Dimension Index, has a range between $1 \leq \text{FRAC} \leq 2$. Fragments with very irregular shapes have longer edge lengths; the larger the fragment, the greater the chance of finding more heterogeneity in the topography, alterations in the edges, and height differences in the vegetation.

The natural borders of the vegetation have more complex forms. In this study, the variation range was established as follows: Poor (1.75–2.0), Fair (1.49.9–1.75), Good (1.24.9–1.50), Very good (1.24.9–1.00), and Excellent (<1.0). The simple average obtained for the Fractal Dimension Index was 1.06, a result that falls into the category of "Very good". In other words, even though the forest is fragmented, it resembles the complex forms of the ecosystem in its pristine state; however, human intervention is required to keep the ranges at an acceptable level.

The last indictor analyzed was the Proximity Index (PROX), which, according to McGarigal and Marks [67], considers the size and proximity of all patches within a specific search radius, which, in this case, was 100 m. PROX increases as the area within a certain search radius is occupied by patches of the same class; its effects on animal and plant species are a function of the dispersal capacities of each species and the nature of the surrounding matrix.

The ranges of variation established for this indicator were: Poor (≥75.0 m), Fair (50–74.99 m), Good (25–49.99 m), Very good (0–49.99 m), and Excellent (≥0 m). A result of 100 m was obtained, and therefore the results for this indicator are classified as "Poor", meaning that restoration programs will be required to improve the current state of the ecosystem. Table 4 presents a summary of the results obtained after performing the analysis of the indicators on forest cover loss and the landscape metric using a quantitative method with satellite image data.

Table 5 is a summary of the assessment of conservation targets, their key ecological attributes, indicators, and ecological integrity of the ecosystem.

Table 5. Evaluation of conservation targets, their key ecological attributes, indicators, and ecological integrity.

Key Ecological Attribute	Category	Result of Indicator from Table 4	Allowable Range of Variability					Current Qualification according to Table 1	
			Poor	Fair	Good	Very Good	Excellent		
Forest cover	Size	% Forest cover loss Indicator 1: 40%	25%	11–24.9%	5–10.9%	4.9–0%	0%	Result 1	Goal 5.0
Size of the habitat	Size	Patch Area (AREA)—ha Indicator 2: 2.0 ha	≤10	10–49.9	50–99.9	100–149.9	≥150	1	5.0
Fragmentation	Condition	Fragmentation Index (FRAG) Indicator 3: 1.06	1.75-2.0	1.49.9–1.75	1.24.9–1.50	1.25–1.00	<1.0	4	5.0
Connectivity of the ecosystem	Connectivity	Proximity Index (PROX)—m Indicator 4: 100 m	≥100	75–99.9	50–74.9	0–49.9	≥0	1	5.0
Simple Average 1.75									

It shows that the Ecological Integrity rating of the ecosystem, using a simple average of the indicators of Forest Cover, Patch Area (AREA), Fractal Dimension Index (FRAC), and Proximity Index (PROX), is 1.75 ("Poor"), which is outside the range of acceptable variation.

This result is far from the goal of five (5), which, according to Brown et al. [27], indicates that immediate intervention is required to maintain the ecosystem (see Figures 1 and 2, forest cover loss, in red). Therefore, if appropriate and timely management actions are not taken, the conservation target "Forest" will be vulnerable to severe degradation. Therefore, in cases like this, Theau, Trottier, and Graillon [70] suggest that a monitoring and restoration program is needed which involves local communities in the sustainable management of forest biomass.

4. Discussion

The overall picture that emerges from this study is that all the factors considered here could be involved in ecosystem deterioration. A set of interlinked, anthropogenic activities, practices, and circumstances appear to be the basis for forest cover loss as stated by the IPCC, which suggests that anthropogenic emissions of greenhouse gases are at their highest-ever levels [3]. The findings confirm what the FAO and UNEP stated about deforestation and forest degradation: they continue to occur at alarming rates [13]. Similarly, there is concern about the amount of firewood consumption, which in Honduras alone amounts to 47% of the total primary energy consumption. This indicates the great amount of pressure being put on natural forests by anthropogenic activities [16]. In Honduras, 35% of the population within the ecoregion lives in poverty, and many of these people are from indigenous ethnic groups [19]. It is important to emphasize that these anthropogenic disturbances are the main stressors creating fragmentation, causing deterioration of landscape connectivity, and altering Ecological Integrity in the ecoregion [21].

However, as discussed earlier, the methodology proposed by Parrish et al. [29] allows the ecological integrity of the protected areas of the Central American System of Protected Areas (its Spanish acronym is SICAP) to be monitored and measured. Gareau's argument [32], which states that the failure to conserve natural resources in the natural protected areas of Honduras is determined as a consequence of park regulations, which show a lack of understanding of socially differentiated local conditions, and they do not provide a feasible solution to resource degradation. This shows why this transition is crucial for the improvement of the social, economic, and environmental benefits of renewable energy sources, especially those related to heating and cooking, such as firewood. In this regard, conservation efforts should focus on minimizing the real threats to forests that could affect these services at a local level, but they often do so without a clear understanding of site-specific factors that affect the composition and structure of local forests, and the magnitude of the threat to them is also underestimated [31]. Therefore, the methodology presented in this study aimed to use site-specific information as a tool for the assessment of forest biomass as a source of rural sustainable energy in natural areas in Honduras. This methodology considered ancestral traditions and used scientific strategies to explore the role of these traditions and their compatibility with forest conditions. It also used criteria and indicator frameworks (C&I) as a platform to include community needs and objectives in management decisions which offer a holistic approach to the sustainability of local environmental contexts [39].

The methodology presented here is a simple adaptation of Parrish et al. [29], which allows the loss of forest biomass to be evaluated and locally managed. Unlike the other methodologies that have been mentioned in the introduction, this methodology is easier for local communities and technicians with economic and technical difficulties to apply and understand. Natural resource management shows that global strategies often conflict with the environmental view held by government groups involved in protected area declaration and management. Failure to conserve natural resources is a sign that exogenously designed park regulations, coupled with a lack of understanding of local socially differentiated conditions, do not provide a feasible solution to resource degradation. People living in protected areas are interested in survival, but first world ecological values are often imposed on them, and these values are incompatible with their way of life [32].

5. Conclusions

This research provides evidence to show that forest biomass is an important source of sustainable energy for rural communities in Honduras, however, anthropogenic activities, such as unsustainable forest management are causing deterioration. Therefore, the results show that the importance of raw materials such as forest biomass in the pine–oak ecosystem is currently underestimated, and these materials are often not used sustainably as a result of poor forest management, lack of research, and the absence of proper technology, especially technology related to bioenergy. Greater awareness surrounding forest management should be promoted in local community biomass supply programs, especially regarding firewood, pellets, and briquettes. Restoration and Sustainable Forest Management practices appear to offer the most reliable means of conserving ecosystem Ecological Integrity. This is of the utmost importance in the context of maintaining the quality and supply of forest biomass for use in rural households.

Regarding the Evaluation of the Ecological Integrity of the conservation target "forest" and its Key Ecological Attributes: Forest Cover, Habitat Size, Fragmentation, and Connectivity of the ecosystem, it can be concluded that the indicators of:

1. Percentage of Forest cover falls under the "Poor" category (40% loss); therefore, the indicator is outside the acceptable variation, meaning human intervention will be necessary to maintain the natural ranges at an acceptable level.
2. The Patch Area is 2.0 hectares, and, like the previous indicator, it is in a "Poor" category, which requires immediate actions to restore the ecosystem.
3. The Fractal Dimension Index obtained a simple average of 1.06, a result that falls under the category of "Very good", in other words, even though the forest is fragmented, it resembles the complex forms of the ecosystem in its pristine state; however, human intervention is required to keep the ranges at an acceptable level.
4. The Proximity Index obtained a result of 100 m; therefore, it is classified as "Poor", meaning human intervention is required to restore its ecosystem.
5. In general, the Evaluation of Ecological Integrity of the pine–oak ecosystem is affected by anthropogenic activities with an acceptable range of variation with a simple average of 1.75, which is far lower than the goal of five (5), indicating immediate intervention is required to maintain its ecosystem. Therefore, if the actions of Sustainable Forest Management are not carried out in an appropriate and timely manner, the conservation objective "Forest" will be vulnerable to severe degradation. Therefore, implementing this methodology is recommended, as well as using criteria and indicator frameworks (C&I) as a platform to include community needs and objectives

in management decisions which offer a holistic approach to sustainability of local environmental contexts.

As this work shows, this methodology provides a simple and site-specific assessment focusing on the state of a natural area subjected to the intensive extraction of forest biomass for energy use. It also facilitates decision-making in the management of protected natural areas in Honduras.

Finally, further research is necessary for ecosystem improvement; therefore, the next article will focus on at least the five most important species for renewable energy provision at local levels using a participatory action research approach in the same study area.

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