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FACULTY OF MECHANICAL ENGINEERING

SUSTAINABLE ENRGY ENGINEERING DEPARTMENT

Site suitability analysis of solar powered non wooden biomass briquetting plant in Gambella Region

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Declaration

I, under signed, declare that this thesis proposal entitled by “Site suitability analysis of solar powered non wooden biomass briquetting plant in Gambella Region” is my original work and has not been presented by any other person for an award of a degree in this or any other university, and any information or material used in this thesis from external sources had been appropriately acknowledged.

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Candidate Signature Date

This research proposal has been submitted with our approval as advisors, examiner and supervisor for the degree of Master of Science in Sustainable Energy Engineering.

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Executive summary

Biomass briquetting can provide a great opportunity for alternative cooking energy source; improve living standard of the people and ensure sustainable development of county. The finding of this research reveal that Gambella region is blessed with abundant biomass with savanna and woody savanna covering 77% of the land in the whole region that's more of forest and agricultural waste. Making use of these resources can ensure both renewable and sustainable cooking energy supply. Therefore, this thesis aims to select optimal site for the establishment of solar powered non-wooden biomass briquetting plant throughout the region. Different spatial and non-spatial data such as solar radiation, slope, land use/land cover (LULC), proximity distance to road, proximity distance to river, and proximity distance to town have been used to identify and map the area. These parameter data are taken from 30 meter resolution of DEM such as solar radiation, slope and river streams. Collection 6 MODIS (Moderate Resolution Imaging Spectroradiometer) Land Cover shape file was downloaded from earth explorer at resolution of 500m which was then reclassified based on the legend and resampled to 30m resolution. Analytical Hierarchy process (AHP) was used for calculation of the criteria weighted overlay to produce a suitable solar farm site map.

The result indicates the availability of raw materials which is land use land cover in this context is most influential factor with weight of 46.58% followed by strength of solar radiation (20.42%), slope (15.52%), proximity to road (8.26%), proximity to river (5.46%) and proximity to town (3.77%). With the suitability of each parameters and application of weight in ArcGIS spatial analysis tool, suitability map was produced and the highly suitable map is located along North-South line through central Gambella Region covering an area of 12,094.49 km^2 that is 47% of the study area.

Key words: AHP, GIS, Multi-criteria analysis, pairwise comparison, Site suitability, Gambella Region, Non-wooden biomass, briquetting plant.

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Acronyms

AHP - Analytic Hierarchy Process
DEM - Digital Elevation Models
CI - Constancy index
CR - Constancy Ratio
GHG-Greenhouse gas
GIS-Geographical information system
GDP-Growth domestic product
FDRE-Federal democratic republic of Ethiopia
GPS-Global positioning system
LULC-Land use land cover
IEA- international Energy Agency
MCDM/A-Multi-criteria decision making/analysis
NASA- National Aeronautics and Space Administration
PV-Photovoltaic
RI-Random Index
SMCEM-Spatial Multi Criteria Evaluation Method
SRTM-Shuttle Radar Topography Mission
USGS-United States Geological Survey
UTM-Universal Transverse Mercator
MODIS-Moderate Resolution Imaging Spectroradiometer
SECAP-Developing a sustainable energy and climate action plan
WSM-Weighted sum method
WPM- Weight product method
ELECTRE-elimination for choice translating reality
PROMTHEE-Preference making organization method for enrichment evaluation
MAUT-Multi-atribute utility theory
CP- Compromise programming
TOPSIS-Technique for order preference by similarity to ideal solution

1. Introduction

1.1.Background

Energy is at the heart of most critical economic, environmental and developmental issues facing the world today. Clean, efficient, affordable and reliable energy services are indispensable for global prosperity. Developing countries in particular need to expand access to reliable and modern energy services if they are to reduce poverty and improve the health of their citizens, while at the same time increase productivity, enhancing competitiveness and promoting economic growth (Owar Othow, Legesse Gebre, and Obsi Gemeda 2017).

The world is not investing enough to meet future energy demands, and policy and demand curve uncertainties pose a strong and volatile risk to the energy market. Spending on transitions is slowly increasing, but far below what is needed to sustainably meet the growing demand for energy services (Cozzi and Gould 2021).

Ethiopia's energy consumption and production are increasing, but the gap is widening, leading to increased imports and energy instability. In addition to energy use, the impact on carbon is increasing as energy use comes primarily from sources such as charcoal, firewood and cow dung. In fact, the majority of the population relies on traditional biomass sources such as wood, agricultural residues and animal manure, exacerbating environmental and land degradation problems. Free trade policies and the development of urbanization, mainly due to the growth of the service sector, are also contributing to this. Energy consumption is also affected by the flow of movement from rural to urban areas, primarily to cities such as Addis Ababa (Ramakrishna and Ramakrishna, 2014). Ethiopia, especially Gambella is blessed with huge biomass resource including forest, grass, shrub and also agricultural residue but the utilization is considerably poor causing destructive deforestation of the land. Sharp rise in regional population due to the influx of refugees from South Sudan is among the primary causes of deforestation in Gambella followed by high urbanization rate.

Bioenergy is a complex energy system. Various raw materials, technology paths, and final products include the conversion of biomass into energy. Bioenergy is currently the world's largest source of renewable energy, accounting for more than two-thirds of the renewable energy mix. In the total energy scenario, bioenergy accounts for 13-14% of total energy consumption. Given the important role of bioenergy in the overall energy mix, this sector has not received much attention due to the lack of awareness of the potential benefits of bioenergy utilization. Second, it is important to note that there is a global and regional shortage of reliable and up-to-date bioenergy data. Due to the informal and regional nature of most raw materials and techniques used in bioenergy production, it is very difficult to collect, analyze and report accurate and timely information on bioenergy development (Association 2020).

Ethiopia is one of the fast growing countries among the least developed with energy consumption depending mainly on biomass fuels and with limited access to modern energy sources. The country is endowed with vast energy resources of 30,000 MW hydropower resources, 1387 million TOE biomass resources, 17.5 million TOE agricultural residue, over 100 billion cubic meter of natural gas, 4000MW geothermal energy, 40.3 million tons of coal and oil shale and vast resources of solar and wind energy, it has not been able to develop, transform and utilize these resources for optimal economic development.

Ethiopia's heavy reliance on traditional biomass is causing a slew of environmental and socioeconomic issues, including soil erosion, water pollution, indoor air pollution, and, most importantly, deforestation, which is wreaking havoc on the country's limited forest resources (Feleke et al. 2020). Furthermore, the environmental impacts as a result of emissions of greenhouse gases (GHG), CO2, SOx, and NOx etc. during combustion and utilization of the non-renewable energy resources is a driving force towards the use of alternative, renewable and sustainable energy sources for domestic cooking, space heating, heat and power generation and heating of rural and urban households' particularly in developing countries. Under Net Zero Emissions (NZE), global CO2 emissions in 2050 will be Net Zero, and all non-CO2 emissions (such as methane) will be reduced rapidly. Temperature rises will reach up to over 1.5 ° C around 2050. Then, as non-CO2 emissions further decrease, the temperature begins to drop slowly, and by 2100 the temperature rise will drop to about 1.4 ° C. Differences in temperature rise between scenarios have serious implications for global ecosystems and human well-being. The greater the temperature rise, the greater the risk of bad weather such as extreme heat, droughts, river and coastal floods, and crop failures (Cozzi and Gould 2021)

Non-wooden biomass feedstock such as Oxytenanthera abyssinica, Arundinaria alpina, Acacia melifera, and Prosopis juliflora have emerged as one of the most promising choices as cooking fuels due to their ample availability and would play a significant role in bioenergy (i.e. densified bio-briquettes) production processes (Kuti 2007). However, owing of their low bulk density, low calorific value (CV), and enormous volumes of smoke produced after combustion, these biomass resources are difficult to manage, store, and transport in their natural or raw state as fuel. Applying effective and efficient briquette techniques is one way to improve the calorific value (CV), bulk density, and handling techniques of such forest biomass.

Densification of biomass wastes into fuel briquettes is one of the promising alternative biomass energy technologies that can help mitigate the negative effects of traditional biomass. Briquettes made from biomass and biomass wastes have demonstrated their ability to ease cooking energy poverty while also providing environmental and socioeconomic benefits in many developing nations (Tekle and Lecturer 2017).

In large scale briquette production industry, continues and heavy production is very difficult to achieve with inconsistent power supply and use of backup generator or any other non-renewable energy source to power the plant could lead to unavoidable release of carbon dioxide which is

GHG; therefore, another intervention like solar powering of the plant could be better remedy due to its consistence and availability.

In many parts of the world, the primary source of energy for such vital activities as cooking and space heating is burning wood and other agricultural products. An increasing population using a dwindling resource of combustible biomass materials will eventually result in a shortage of those materials unless steps are taken to reverse the trend. One means of making more efficient use of existing resources is through the use of briquetting. Briquetting involves collecting combustible materials that are not usable due to a lack of density, and compressing them into a solid fuel of a convenient shape that can be burned like wood or charcoal.

In general term briquette is pressurized form of lose waste of biomass intended to produce fuel of high energy density; to ease the transport, clean combustion; reduce greenhouse gas release, less cost and can be made from waste biomass; perfect utilization of resources. Furthermore, briquetting of forest and agricultural wastes can be a solution to variety of problems such as deforestation, fuel handling, energy density, carbon dioxide emission and postharvest management of an agricultural land.

The efficiency of any production plant is primarily affected by the environmental condition which requires preliminary investigation of the potential site. Many factors have to be considered to investigate the suitability of briquetting site that include but not limited to distance from the road, distance from the towns, and the land use land cover that basically shows the biomass availability and restricted area. In this context, availability of solar radiation will be included as criteria to ensure maximized plant economic efficiency and environmentally safe operation of the briquetting plant.

1.2.Statement of the problem

Gambella regional State in Ethiopia is blessed with abundant biomass like wood, grasses, shrub and agricultural residue among which wood is overexploited leading to large scale deforestation and other subsequent effects including but not limited to; land degradation, adverse global warming, and health related issues. Illegal charcoal producers are cutting and supply woods directly or in form of charcoal produced by traditional pyrolysis. Most people in Gambella are practicing traditional cooking style causing inefficiency in cooking, polluting the environment and cost more due to low energy density to meet their energy demand. Instead of cutting wood that are not considerably renewable, there is huge biomass in the region in form of grass, shrub, agricultural waste and forest waste that can be utilized by applying appropriate technology. Briquetting could be the right solution to sustainably meet the cooking energy demand of the people in Gambella if sustainably produced in plant but the important issues is where to install the briquetting plant as the distribution of resource is considerably different at different locations and the overall efficiency is affected by local factors. Therefore, to achieve maximum overall performance of the plant, decision makers need site suitability analysis finding to locate the plant in term of area where there can be central or distributed production plant. GIS based multi-criteria decision making approach will be considered in this research to find out suitable site for installation of solar powered forest and agricultural waste briquetting plant in Gambella Region considering reasonable criteria.

1.3.Objective

1.3.1. General objective

The general objective of this study is to evaluate and identify the suitable site for installation of solar powered forest and agricultural waste briquetting plant in Gambella Region.

1.3.2. Specific Objectives

- To asses non-wooden biomass potential of the region from land use land cover
- To compare/weight potential parameters affecting solar powered non-wooden biomass briquetting plant in Gambella Region.
- To localize candidate site for solar powered non-wooden biomass briquetting plant in Gambella Region with the help of AHP and GIS.

1.4.Research questions

1. How do I estimate the biomass potential of the region
2. What factors are influencing the performance of solar powered non-wooden biomass briquetting plant in Gambella Region?
3. How do I select optimal site for solar powered non-wooden biomass briquetting plant in Gambella Region.

1.5.Rationale

Different NGOs and Governmental organization in Ethiopia are working towards realization of clean cooking technologies. Particularly, Development Response to Displacement Impacts Project (DRDIP), Mothers and Children Multi-sectorial Development Organization (MCMDO), GiZ and regional Mine and Energy agency are promoting the commercialization of briquette and improved cook stove to transform cooking sector in sustainable way but coming short with the site condition as no research has been done related to the suitability of the site. Therefore, the finding of this research will confidentially guide the regional decision makers in energy sector to achieve their goal.

1.6.Scope

This study is limited to the site suitability analysis of solar powered non-wooden biomass briquetting plant in Gambella Region with focus on direct densification of biomass using binders. The resources here will be limited to non-wooden biomass with exclusion of wooden biomass. The finding will be in area and geographical location

2. Literature Review

2.1.Introduction

Numerous research on the site selection for solar farm installation have been carried out in the past ten years. Geographic Information Systems (GIS) have been frequently employed for that purpose. In order to assess both qualitative and quantitative spatial criteria at the same time, multi-criteria decision-making (MCDM) techniques are frequently used with GIS. The MCDM methodologies have garnered interest in the context of GIS-based decision-making because of their practical application in addressing problems involving a large number of variables over vast, occasionally unreachable regions (Prieto-ampar et al. 2021).

Developing a sustainable energy and climate action plan (SECAP) is a decision-making problem. Local authorities have to identify the best set of actions for reaching their long-term CO2 reduction targets and related environmental impacts. This decision-making process involves some uncertainty and multiple stakeholders, encompassing individual perspectives and contexts; thus, it must be guided by a structured approach. Multiple criteria decision aid (MCDA) methods can be important supportive tools in policy making, making it possible to estimate which impacts various alternative scenarios have in terms of environmental, economic, and social sustainability.

Among the multi-criteria decision-making methods, the AHP method developed by Thomas L. Saaty in the late 1970s allows a set of alternatives to be prioritized with respect to their contributions to achieving a goal, considering several criteria and sub-criteria.

A peculiarity of the AHP method is the hierarchical structure based on several levels: the highest level represents the main objective to be achieved, the intermediate levels are the criteria with which decisions regarding the different options are made, and the lowest level is the list of alternatives, which must be compared with each other by means of the criteria and sub-criteria. The AHP method developed by Saaty involves the pairwise comparison of the elements at each level of the hierarchy with those of the upper level using the Saaty Scale.

The purpose of this study is to use a combination of GIS and the AHP to map the most suitable sites for the installation of solar powered non-wooden biomass and agricultural waste briquetting plant in Gambella. Gambella has enormous biomass resources that can potentially be used to strengthen its energy security, and meet its global climate commitments. To make use of these abundant resource its necessary to locate best candidate sites for the installation of solar powered non-wooden biomass and agricultural waste briquetting plant using a large national-scale GIS database with determinant criteria and their relative weightings calculated using the AHP (Munkhbat and Choi 2021).

2.2.Multi-Criteria Decision Making (MCDM)

Decision making problems are important in all aspect of life. Multi-Criteria Decision Making (MCDM) or also known as Multi-Criteria Decision Analysis (MCDA) became widely used in the last decades. The technique Multi-Criteria Decision Making (MCDM) is a branch of decision making which basically deals with the process of making decisions in the presence of multiple objectives (D'Orso et al. 2023).

Priority based, out- ranking, distance based and mixed methods are also applied to various problems. Each method has its own characteristics and the methods can also be classified as deterministic, stochastic and fuzzy methods. There may be combinations of the above methods. Depending upon the number of decision makers, the methods can be classified as single or group decision making methods. Decision making under uncertainty and decision support systems are also prominent decision making techniques.

These methodologies share common characteristics of conflict among criteria, incomparable units, and difficulties in selection of alternatives. In multiple objective decision making, the alternatives are not predetermined but instead a set of objective functions is optimized subject to a set of constraints. The most satisfactory and efficient solution is sought. In this identified efficient solution it is not possible to improve the performance of any objective without degrading the performance of at least one other objective. In multiple attribute decision making, a small number of alternatives are to be evaluated against a set of attributes which are often hard to quantify. The best alternative is usually selected by making comparisons between alternatives with respect to each attribute.

2.2.1. Weighted sum method (WSM)

The weight sum method (WSM) is the most commonly used approach, especially in single dimensional problems. If there are M alternatives and N criteria then the best alternative is the one that satisfies the following expression:

$$A^{*}_{WSM} = Max \sum_{i}^{j} a_{ij} w_j \quad \text{for} \quad i = 1, 2, 3, \ldots M$$

Where $A^{*}{}_{WSM}$ is the WSM score of the best alternative, N is the number of decision criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion. The total value of each alternative is equal to the sum of products. Difficulty with this method emerges when it is applied to multi-dimensional decision-making problems. In combining different dimensions, and consequently different units, the additive utility assumption is violated(Akyol et al. 2018).

2.2.2. Weighted product method (WPM)

The weight product method (WPM) is very similar to WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. In general, in order to compare the alternatives A_K and A_L the following product is obtained:

$$R(A_K/A_L) = \sum_{j=1}^{N} (a_{kj}/a_{Lj})^{w_j}$$

Where N is the number of criteria, a_{ij} is the actual value of thei^{th} alternative in terms of the j^{th}criterion, and w_j is the weight of importance of the jth criterion. If R (A_K/A_L) is greater than one, then alternative A_K is more desirable than alternative A_L (in the maximization case). The best alternative is the one that is better than or at least equal to all the other alternatives (Silva and Caiado 2021)

2.2.3. Analytic Hierarchy Process (AHP) for Criteria Evaluation.

The analytic hierarchy process (AHP) is one of the multi-criteria decision-making methods. It was used to make complex decision problems. The pair- wise comparison method is used to evaluate the weights of the criteria. First, the weights of criteria analysis were done to examine important criteria in finding suitable location. Thus, ArcGIS can prioritize the sites according to the weights of the criteria. The input can be obtained from subjective opinion like satisfaction feelings and preference. The pairwise comparison of the attributes makes it easy for complex problems decision. It compares the importance of two attributes at one time.

Pohekar and Ramachandran conducted a review on GIS-MCDM methods and Concluded that the Analytical Hierarchy Process (AHP) was the most widely used in sustainable energy location studies. The AHP was first presented by (Saaty 1987) as a method of pair-wise criteria comparison, where a specific weight of relative importance is assigned to each considered criterion. The AHP offers the opportunity of integrating the points of view of experts and decision-makers in pair-wise comparisons, which can then be represented in a GIS environment to achieve specific objectives. In addition, the simulation of scenarios under MCDM can be used to develop supportive decision-making processes based on hypotheses of interest (Prieto-ampar et al. 2021)

Table 1: Fundamental scale for pairwise comparison (Saaty 1987)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

2.2.4. Preference ranking organization method for enrichment evaluation (PROMETHEE)

This method uses the outranking principle to rank the alternatives, combined with the ease of use and decreased complexity. It performs a pair-wise comparison of alternatives in order to rank them with respect to a number of criteria. (Brans, Vincke, and Mareschal 1986) have offered six generalized criteria functions for reference namely, usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and Gaussian criterion.

The method uses preference function P_j(a, b) which is a function of the difference d_j between two alternatives for any criterion j, i.e. d_j= f (a, j)-f (b, j), where f (a, j) and f (b, j) are values of two alternatives a and b for criterion j. The indifference and preference thresholds q'and p' are also defined depending upon the type of criterion function. Two alternatives are indifferent for criterion j as long as d_j does not exceed the indifference threshold q'. If d_j becomes greater than p', there is a strict preference. Multi-criteria preference index, π (a, b) a weighted average of the preference functions P_j (a, b) for all the criteria is defined as:

$$\pi(a,b) = \frac{\sum_{j=1}^{J} w_j P_j(a,b)}{\sum_{j=1}^{J} w_j}$$

$$\phi^+(a) = \sum_A \pi(a,b)$$

$$\phi^-(a) = \sum_A \pi(b,a)$$

$$\phi(a) = \phi^+(a) - \phi^-(a)$$

Where w_j is the weight assigned tothe criterion j; $\phi^+(a)$ is the outranking index of a in the alternative set A; $\phi^-(a)$ is the outranked index of a in the alternative set A; $\phi(a)$ is the net ranking of a in the alternative set A. The value having maximum $\phi(a)$ is considered as the best.

a outranks b iff φ (a) > φ (b) ; a is indifferent to b iff φ (a) = φ (b)

2.2.5. The elimination and choice translating reality (ELECTRE)

This method is capable of handling discrete criteria of both quantitative and qualitative in nature and provides complete ordering of the alternatives. The problem is to be so formulated that it chooses alternatives that are preferred over most of the criteria and that do not cause an unacceptable level of discontent for any of the criteria. The concordance, discordance indices and threshold values are used in this technique. Based on these indices, graphs for strong and weak relationships are developed. These graphs are used in an iterative procedure to obtain the ranking of alternatives (Capros, Papathanassiou, and Samouilidis 1988). This index is defined in the range (0–1), provides a judgment on degree of credibility of each outranking relation and represents a test to verify the performance of each alternative. The index of global concordance C_{ik} represents the amount of evidence to support the concordance among all criteria, under the hypothesis that A_i outranksA_k. It is defined as follows.

$$C_{ik} = \sum_{i-1}^{m} W_j c_j(A_i A_k) / \sum_{i-1}^{m} W_j$$

Where W_j is the weight associated with j^{th} criteria. Finally, the ELECTRE method yields a whole system of binary outranking relations between the alternatives. Because the system is not necessarily complete, the ELECTRE method is some- times unable to identify the preferred alternative. It only produces a core of leading alternatives. This method has a clearer view of alternatives by eliminating less favorable ones, especially convenient while encountering a few criteria with a large number of alternatives in a decision making problem

2.2.6. The technique for order preference by similarity to ideal solutions (TOPSIS)

This method is developed by (Olson 2004) as an alternative to ELEC-TRE. The basic concept of this method is that the selected alternative should have the shortest distance from the negative ideal solution in geometrical sense. The method assumes that each attribute has a monotonically increasing or decreasing utility. This makes it easy to locate the ideal and negative ideal solutions. Thus, the preference order of alternatives is yielded through comparing the Euclidean distances. A decision matrix of M alternatives and N criteria is formulated firstly. The normalized decision matrix and construction of the weighted decision matrix is carried out. This is followed by the ideal and negative-ideal solutions. For benefit criteria the decision maker wants to have maximum value among the alternatives and for cost criteria he wants minimum values amongst alternatives. This is followed by separation measure and calculating relative closeness to the ideal solution. The best alternative is one which has the shortest distance to the ideal solution and longest distance to negative ideal solution.

2.2.7. Compromise programming (CP)

Compromise Programming defines the best solution as the one in the set of efficient solutions whose point is the least distance from an ideal point (Rehman and Romero 1984).The aim is to obtain a solution that is as close as possible to ideal. The distance measure used in CP is the family of L_p-metrics and is given as:

$$L_p(a) = \sum_{j=1}^{j} w_j^p \left| f_j^* - f(a) \right| / \left| M_j - m_j \right|$$

where L_p (a) is the L_p metric for alternative a, f (a) is the value of criterion j for alternative a, M_j is the maximum (ideal) value of criterion j in set A, m_j is the minimum (anti ideal) value of criterion j in set A, fj is the ideal value of criterion j, w_j is the weight of the criterion j, p is the parameter reflecting the attitude of the decision maker with respect to compensation between deviations. For p =1, all deviations from $f_j^*$are taken into account in direct proportion to their magnitudes meaning that there is full (weighted) compensation between deviations.

2.2.8. Multi-attribute utility theory (MAUT)

Multi-attribute Utility Theory takes into consideration the decision maker's preferences in the form of the utility function which is defined over a set of attributes The utility value can be determined by determination of single attribute utility functions followed by verification of preferential and utility independent conditions and derivation of multi-attribute utility functions. The utility functions can be either additively separable or multiplicatively separable with respect to single attribute utility. The multiplicative form of equation for then utility value is defined as follows.

$$1 + ku(x_1, x_2, \ldots x_n) = \prod_{i-1}^{n} (1 + kk_j u_j(x_j))$$

Here j is the index of attribute, k is overall scaling constant (greater than or equal to -1), $k_j$is the scaling constant for attribute j, u (.) is the overall utility function operator, u (.) is the utility function operator for each attribute j.

2.3.Multi-criteria decision making applications in energy planning

The application areas of MCDM in energy planning presented in this section are renewable energy planning, energy resource allocation, building energy management, transportation energy management, planning for energy projects, electric utility planning and other miscellaneous areas. The comparison of MCDM methods applicable to energy planning are discussed in the literature. (Hobbs 1995) compared the methods with respect to simplicity of applications and feasible expected outcomes, (Pohekar and Ramachandran 2004) discussed the methods used in energy and environmental modeling under uncertainties, Lahdelma et al. discussed these methods for environmental planning and management. The commonly applied MCDM methods out of the above are multi-objective optimization, AHP, PRO- METHEE, ELECTRE, MAUT, fuzzy methods and decision support systems (DSS). More than one MCDM method is also applied in many application areas to validate the results.

A review of the published literature is presented here with a view to highlighting the applications areas and trends. A classification of published literature before 1990 and beyond 1990 is also presented to highlight suitability of the methods in changed global scenario. Six generalized application areas and a miscellaneous area presented here have common features of minimization of cost benefit ratios, high degrees of uncertainties in formulating the problems, incommensurable units and the need to handle socio-economic aspects in planning. Renewable energy planning and energy resource allocation refers to compilation of feasible energy plan and dissemination of various renewable energy options. The key factors applicable are investment planning, energy capacity expansion planning and evaluation of alter- native energies. Building energy management refers to design, selection, installation and building energy management options in a multi-criteria environment.

The application normally deals with quantitative issues. Transportation system applications include evaluation of alternative strategies for pollution control, elimination of old polluting vehicles, choosing between private and public transport etc. The key features of transportation applications are of a high concern for socio- economic reasons. Project planning refers to site selection, technology selection and decision support in renewable energy harnessing projects. The objectives are arriving at a Pareto optimal solution for technology selection, sizing, execution, investment planning. Optimal electrical dispatch scheduling, deciding power generation mix, optimum electricity supply planning are the applications of electric utility planning using MCDM. Miscellaneous applications include desalination plant selection, solid waste management. It can be observed from the surveyed literature that AHP is the most popular method for prioritizing the alternatives, followed by PROMETHEE and ELEC- TRE. Multi-objective programming is also very widely used to formulate alternative plans. Fuzzy MCDM methods are also adopted for considering the uncertainties in energy planning. Decision support systems are becoming popular in energy planning and resource allocation with the advent of the latest computational aids (Pohekar and Ramachandran 2004).

2.4. Related studies

In the work of (Anon 2021)selection of suitable solar farm sites was conducted by using spatial multi criteria evaluation method in Kewet Woreda . Different spatial and non-spatial data such as solar radiation, slope, aspect, LULC, proximity distance to road, proximity distance to sub-station site, proximity distance to river, proximity distance to railway and proximity distance to town have been used to identify and map area. Some parameter data are taken from 30 meter resolution of DEM such as solar radiation, slope, aspect and river streams. Analytical Hierarchy process (AHP) was used for calculation of the criteria weighted overlay to produce a suitable solar farm site map. The result shows that solar radiation has the highest weight and distance to river has the lowest weight with 36.6% and 3.4%, respectively. In addition, optimal solar farm sites were identified and highly suitable area found in the south, southeast and northeast part of the study area and covers 35988.71 hectare area (Anon 2021).

After reviewing GIS-MCDM techniques, (Prieto-ampar et al., 2021) came to the conclusion that the Analytical Hierarchy Process (AHP) was the most often utilized technique in studies on sustainable energy location. (Saaty 1987) introduced the AHP, it was as a technique for comparing criteria pairwise, with each criterion being given a certain weight indicating its relative relevance. In order to accomplish particular goals, the AHP provides the chance to integrate expert and decision-maker perspectives through pairwise comparisons that can subsequently be represented in a GIS setting. Furthermore, by simulating scenarios under MCDM, one might create helpful decision-making procedures based on intriguing theories. Research was conducted to provide a framework for determining best locations for US Department of Defense (DOD) Humanitarian Assistance (HA) projects as well as proposing a method to selecting and optimal portfolio of DOD projects for an area of operation through data-driven analyses and an understanding of priorities and tradeoffs. To identify optimal locations for HA projects a Multi-Criteria Decision Analysis (MCDA) approach to site suitability analysis is presented along with a case-study using data from El Salvador to demonstrate the utility of the approach(Curran, Bates, and Bell 2014).

Geographic Information System (GIS) and the Analytical Hierarchy Process (AHP) were utilized to select the most suitable sites for landfill in Paveh, which the current landfill in this county does not follow environmental laws. In the process of zoning sites for landfill in Paveh, twelve various criteria were mapped and join for cover analyses within GIS application to construct the last suitability index map for the site. Group number one was environmental criteria that involve soil type, Distance from fault, Distance from the river, Land use type, Rainfall, Wind direction, Distance from protected areas, Evaporation rate. Group number two was economic criteria included slope and distance from road sub-criteria, and group number three criteria was the social factor, which is included distance from residential areas and distance from religious areas. The weightings of criteria were done with the help of AHP, and the weightings of the criteria were identified based on various factors (Rostampoor, Zamani, and Vaighan 2020).

GIS was used to find the most suitable sites in the South Gondar Zone for generating power from solar PV. The suitability of the study area for a solar PV power plant is 86.5%. Eighty-six (86%) of the criteria considered in the study area were found to be suitable for optimal location of solar PV power plant. Most of the suitable areas were found in the western part of the zone. The nature of topography is a key factor in generating solar energy; it affects the solar irradiance coming to the solar PV panel surface (Nebey, Taye, and Workineh 2020). Another study employed a geographic information system (GIS)-based approach to identify sites suitable for large-scale solar photovoltaic (PV) power plant installations in Mongolia. Accordingly, cells of 30 × 30 m were used, and data based on seven criteria, including annual global horizontal radiation, annual average temperature, elevation, slope, slope direction (aspect), and distances from main roads and major power lines, were collected for each cell. GIS layers for these seven criteria were then converted into rated value layers using four grades. The weightings applied to the seven criteria were determined, using an analytical hierarchy process, by ten solar field experts. By combining the seven rating value layers with the weightings, a site suitability map was developed, using good, fair, low, and poor suitability grades. The results showed that sites graded as good, fair, low, and poor accounted for 3.27%, 53.06%, 42.59%, and 1.08% of the total surface area, respectively. Good sites were predominantly located in the southern and central regions of Mongolia (Munkhbat and Choi 2021).

Table 2: Summary of site suitability literatures

S.no	Tittle	Place	Method used
1	Site suitability analysis for generating power from solar PV	South Gondar Zone	GIS/AHP

2	sites suitable for large-scale solar photovoltaic (PV) power plant installations in Mongolia	Mongolia	GIS/AHP
3	Determining best locations for US Department of Defense (DOD) Humanitarian Assistance (HA)	America	GIS/AHP
4	suitable solar farm sites	Kewer woreda, Ethiopia	GIS/AHP

2.5. GIS-based multi-criteria methods

GIS is a computer-based system that offers a convenient and powerful platform for performing land suitability analysis and allocation. As pointed out earlier, the integration of multi-criteria methods of suitability assessments and allocation methods into a GIS system offers both the spatial capabilities of GIS and the analytical power of formal multi-criteria decision making tools. The proposed integrated GIS-based model can provide more than site-specific and spatially explicit map of site suitability. The integrated model can also use these site suitability to serve as a guide to subsequent allocation of land to potential uses. This allocation process is performed and implemented under a raster GIS environment.

2.6. Biomass Densification process

The major reason for biomass residue briquetting is in most cases to increase the bulk density of a given material. A more general term for this process is thus densification. Under such a heading, one could include a vast variety of processes, from baling of straw, through a string of processes using increasing pressure and/or binding agents, to the high pressure processes such as piston briquettors and pellet machines. Briquetting is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. The densification of the biomass can be achieved by any one of the following methods (Agency, Development, and Hood 2010):

(i) Pyrolysed densification using a binder,
(ii) Direct densification of biomass using binders and
(iii) Binder-less briquetting.

As far as environment is cross-cutting issue and the resources in use here are mostly soft non-wooden, this paper will consider direct densification of biomass using just binder to ensure sustainability of the briquetting plant.

2.6.1. Accumulation of scattered Biomass residues

The collection of raw materials, mostly non-wooden biomass which is ready to use directly as a fuel for domestic (cocking or heating) purposes in the inconvenient size and shape is first carried out.

2.6.2. Preparation of biomass

The various processes of preparing the biomass include but not limited to compaction. Drying, decrease in size, mixing of different biomass residues in suitable ratios and mixing of binder with biomass residues etc. are some preparing process. There are various types of binders used to improve the quality of briquettes. Bio solids, Cassava, corn, gelatin, microalgae, Molasses and starch are some examples of binders. The binders are used for increased the compressive strength and mechanical durability of biomass briquettes.

2.6.3. Compaction of biomass residues

The process in which raw biomass converted into dense form (briquettes & pellets) known as densification or compaction. Figure 1 shows Biomass solid fuels (Briquettes/pellets) manufacturing process. Generally, biomass pellets/briquettes machine are required for compaction process. The process depends on the type of densification technology is employed. Three different compacting pressures are considered for briquettes compaction process and the higher compaction pressure (150 kPa) is better for to improve the quality of briquettes by using cassava as a binder.

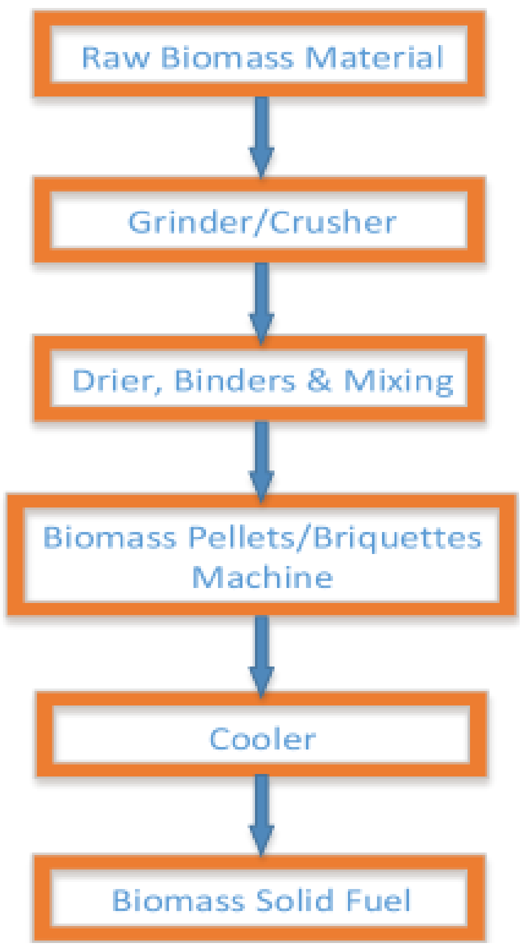

Figure 1: Briquetting process (Vaish, Sharma, and Kaur 2022)

3. Methodology

3.1. Study area

The Gambella Regional State is one of the nine member states of the Federal Democratic Republic of Ethiopia (FDRE). It is located in the south-western Ethiopian lowlands bordering the Republic of South Sudan from the west, the Oromia Regional State from the north-east and the Southern Nations Nationalities and Peoples Regional State (SNNPRS) from the south-east. According to the latest national census results, Gambella region has a population of 435,999 (2017) people distributed on 25,802 km^2 land. The Gambella Regional State is predominantly inhabited by five indigenous ethnic groups, namely the ‘Anywa’, ‘Nuer’, ‘Majang’, ‘Opo’ and ‘Kumo’. In addition to these five indigenous ethnic groups, there are other Ethiopians of different ethnic origins in the region who are collectively referred to as “highlanders”. The identity boundary between the ‘indigenous peoples’ vs. ‘highlanders’ is constructed along: linguistic origins (the highlanders being mainly from ‘Semitic and Cushitic’ linguistic group, while the indigenous groups are from the ‘Nilo-Saharan’ linguistic group) and ethnic background.

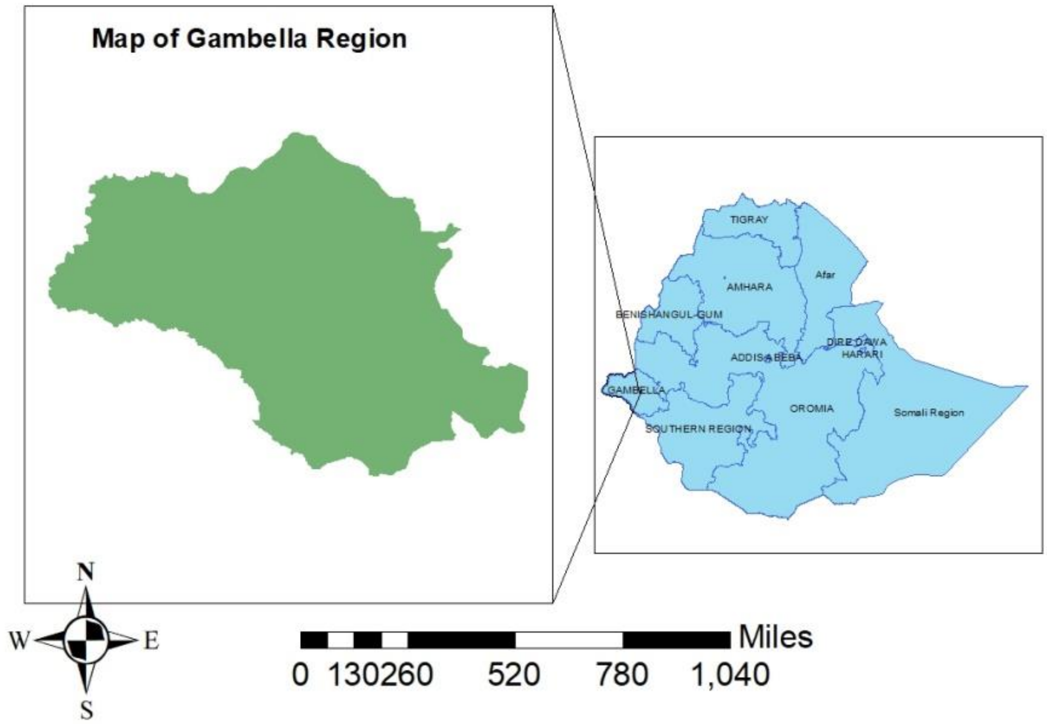

Figure 2: Map of the study area (Degife, Zabel, and Mauser 2018)

3.2. Data Description

Different data were gathered from different organizations and field observation. GPS data is one of the primary data which collected from field and SRTM data, landsat8 satellite data, road network data, boundary shape files data, and recorded meteorological data are secondary data.

3.2.1. Slope

Satellite image (DEM) downloaded at a resolution of 30m is used in this study to generate the slope pattern of the study area as one of the most important criteria for selecting suitable site for solar powered non-wooden biomass briquetting plant as long as construction and installation of solar PV system is concerned.

Nearly spaced lines symbolize sharper slopes and scarce contours display gentle slope while in the altitude output raster each cell has a slope value. In general lower slope indicate the flatter terrain and higher slope shows the steepness of the terrain. The altitude of the earth affects the receiving radiation of the sun, and hardens the construction. Most of the radiation receives by the flat earth's surface and can produce high energy from the solar (Umer et al., 2019).

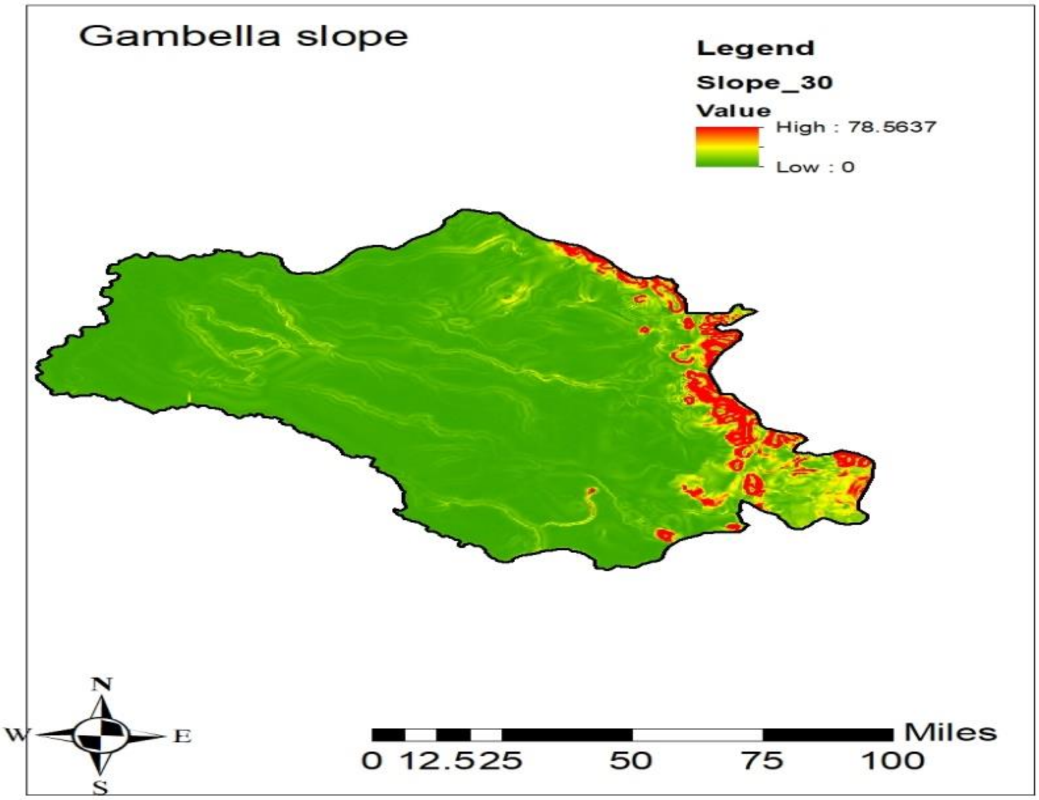

Figure 3: Slope map of the study area

3.2.2. Solar radiation

Solar radiation can be measured with a pyranometer. However, here in the study area there are no instruments used to measure solar irradiance. In this case, satellite data (DEM) are used to estimate the amount of solar radiation in the study area. The ESRI Toolset Solar Analyst Extension for ArcGIS is used to calculate solar radiation for this thesis. The main entrance of this work is a DEM with a resolution of 30m.

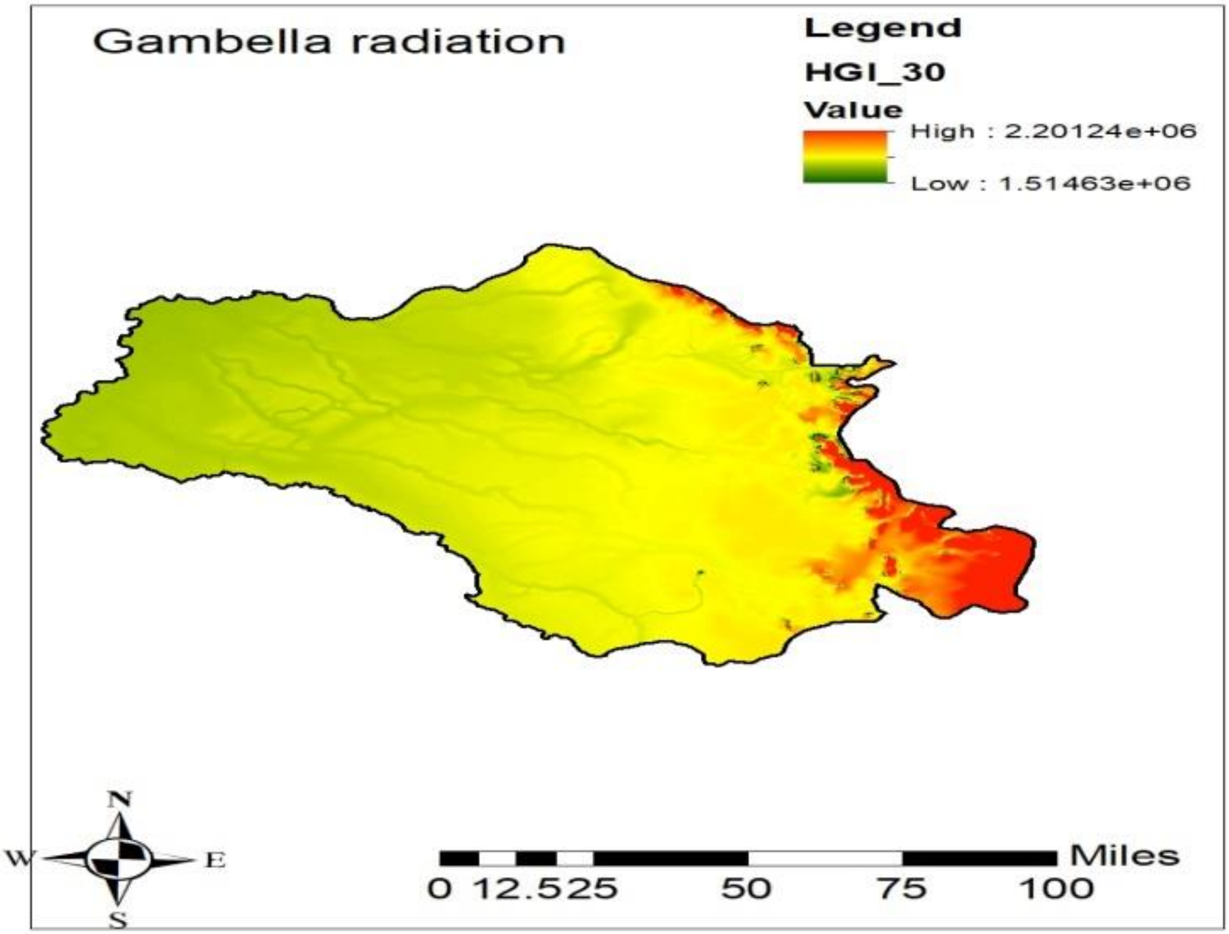

Figure 4: Solar radiation map of the study area

3.2.3. Land Use /Land Cover of the Study Area

The MODIS Land Cover Type Product (MCD12Q1) was downloaded from earth explorer and specific to Gambella was clipped using Geoprocessing toolbox of ArcGIS. The Product (MCD12Q1) provides a suite of science data sets (SDSs) that map global land cover at 500 meter spatial resolution at annual time step for six different land cover legends. The maps were created from classifications of spectro-temporal features derived of data from the Moderate Resolution Imaging Spectroradiometer (MODIS). With the help of resample toolbox under data management toolbox of ArcGIS, raster data is approximated to the nearest resolution of 30m with minimal error.

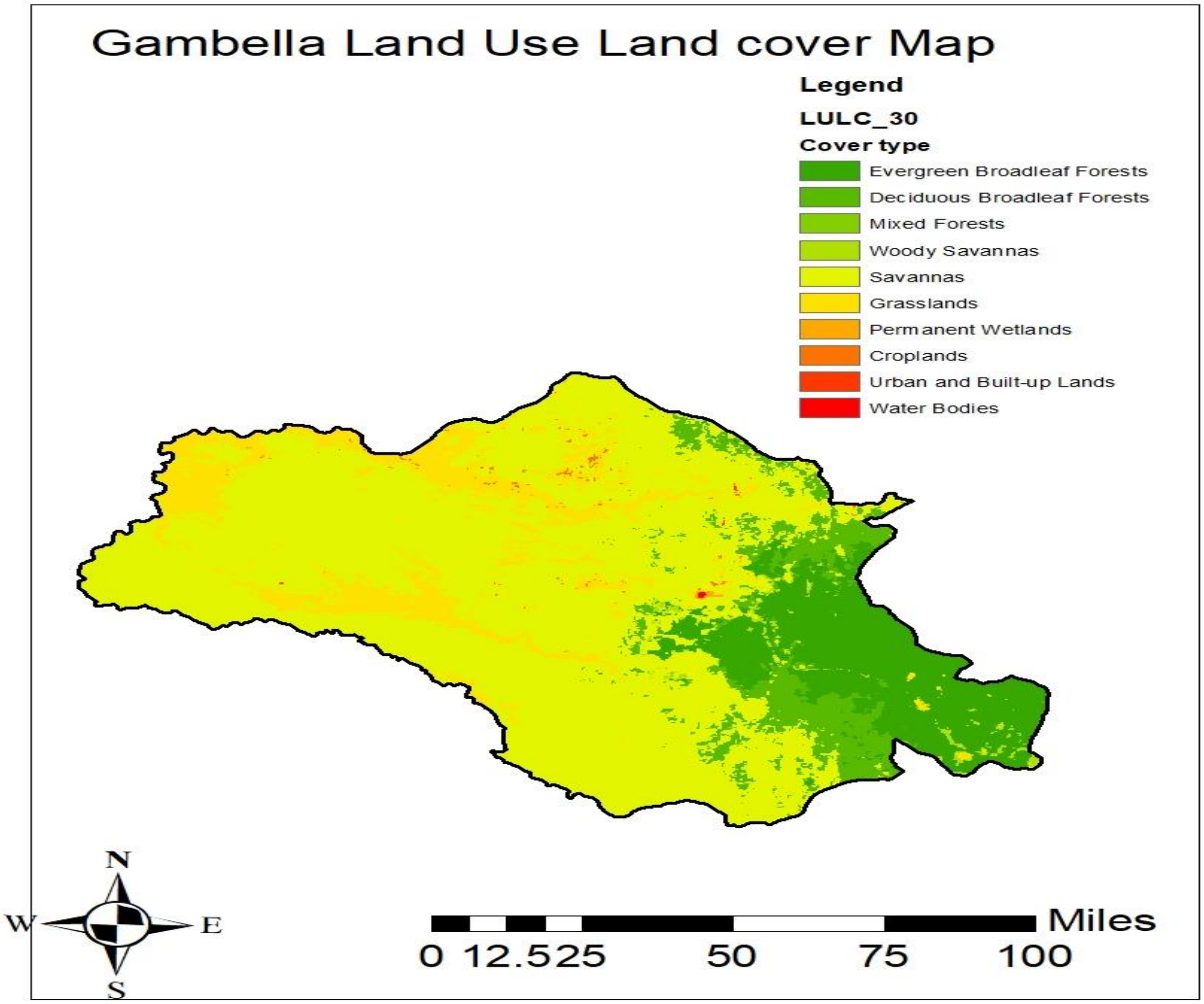

Figure 5: Land use land cover map of the study area

Name	Value	Description
Evergreen needle leaf forest	1	Dominated by evergreen conifer trees (canopy >2m). Tree cover >60%.
Evergreen broadleaf forest	2	Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%.
Deciduous Needle leaf Forests	3	Dominated by deciduous needle leaf (larch) trees (canopy >2m). Tree cover >60%.
Deciduous Broadleaf Forests	4	Dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%.

Mixed Forests	5	Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%.
Closed shrub lands	6	Dominated by woody perennials (1-2m height) >60% cover.
Open Shrub lands	7	Dominated by woody perennials (1-2m height) 10-60% cover.
Woody Savannas	8	Tree cover 30-60% (canopy >2m).
Savannas	9	Tree cover 10-30% (canopy >2m).
Grasslands	10	Dominated by herbaceous annuals (<2m).
Permanent Wetlands	11	Permanently inundated lands with 30-60% water cover and >10% vegetated cover.
Croplands	12	At least 60% of area is cultivated cropland.
Urban and Built-up Lands	13	At least 30% impervious surface area including building materials, asphalt, and vehicles.
Cropland/Natural Vegetation Mosaics	14	Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation.
Permanent Snow and Ice	15	At least 60% of area is covered by snow and ice for at least 10 months of the year.
Barren	16	At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation.
Water Bodies	17	At least 60% of area is covered by permanent water bodies.
Water Bodies U	255	Has not received a map label because of missing inputs.

Table 3: MCD12Q1 International Geosphere-Biosphere Program (IGBP) legend and class descriptions

3.2.4. Road data

Road shape file was downloaded from EthioGIS map server and clipped with the help of Geoproccessing toolbox in ArcGIS to the extent of the study area to find detailed road network for Gambella region.

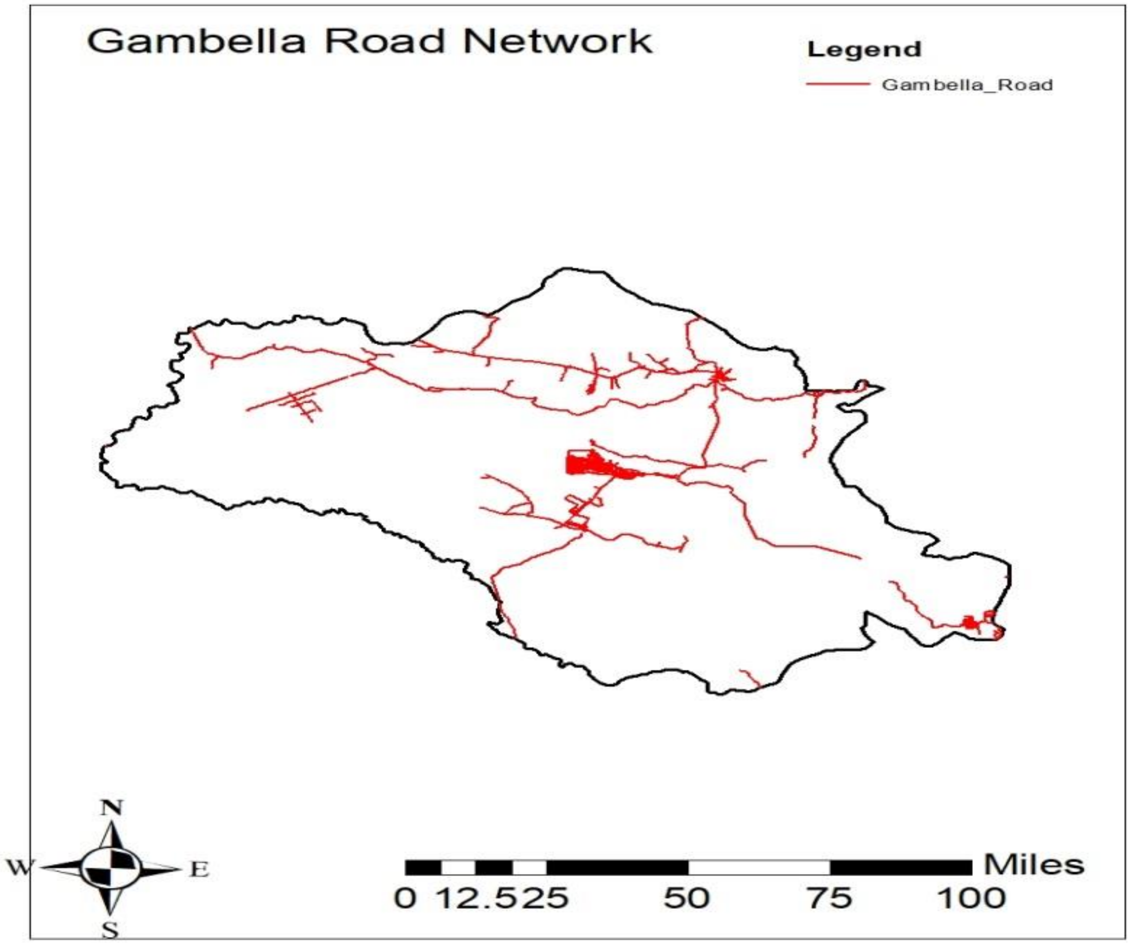

Figure 6: Road network of the study area

3.2.5. River data

In case of the flood availability and water need of the plant, generating and knowing river streams in study area is mandatory for locating optimal location of solar powered non-wooden briquetting plant. The river /stream networks were delineated from DEM using ArcGIS spatial analysis hydrology tools. Then the flow direction was derived from DEM, which was used to calculate the flow accumulation. Finally, the stream network was extracted from flow accumulation.

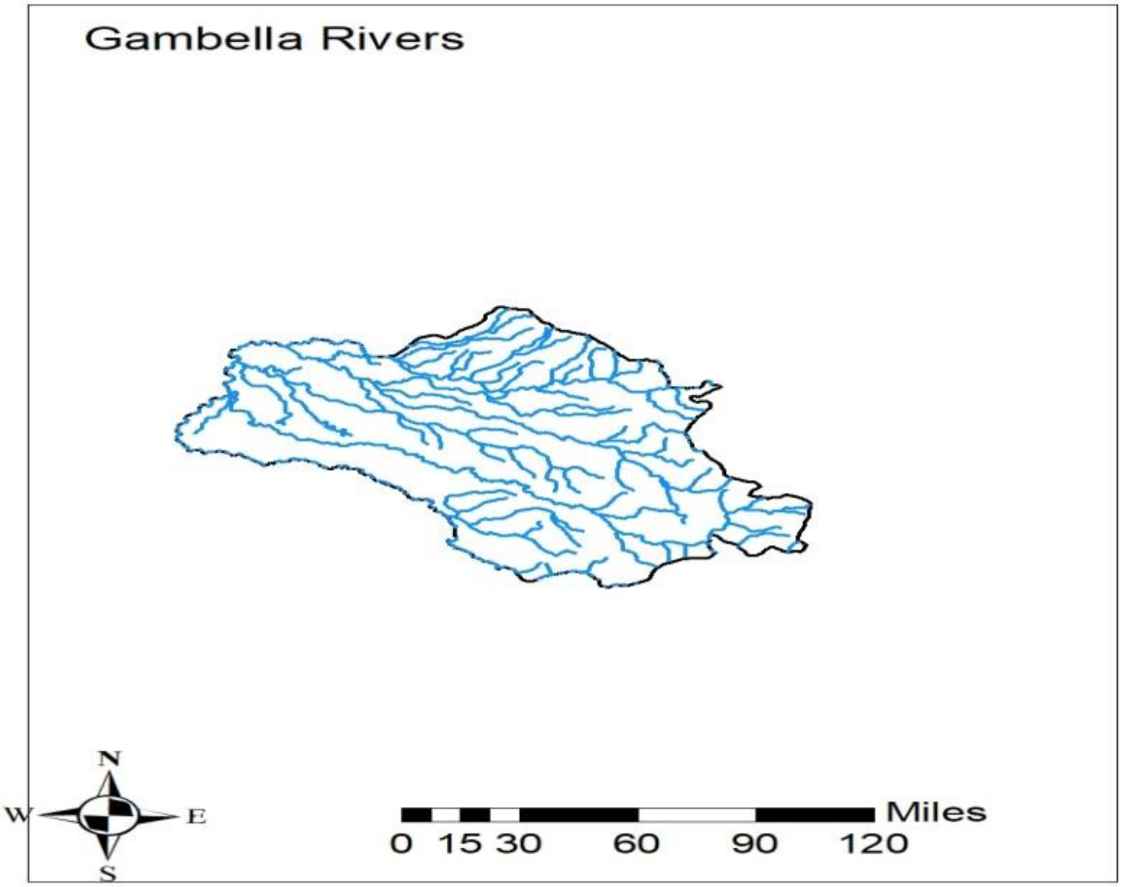

Figure 7: River network of the study area

3.2.6. Towns' data

Boundary shape file and Ethio-town were taken from the FDRE Geospatial Information institute and used to generate map of the study area that was later used as an extend to clip map of major towns in Gambella region using Geoproccessing toolbox in ArcGIS 10.6 as show in the figure below.

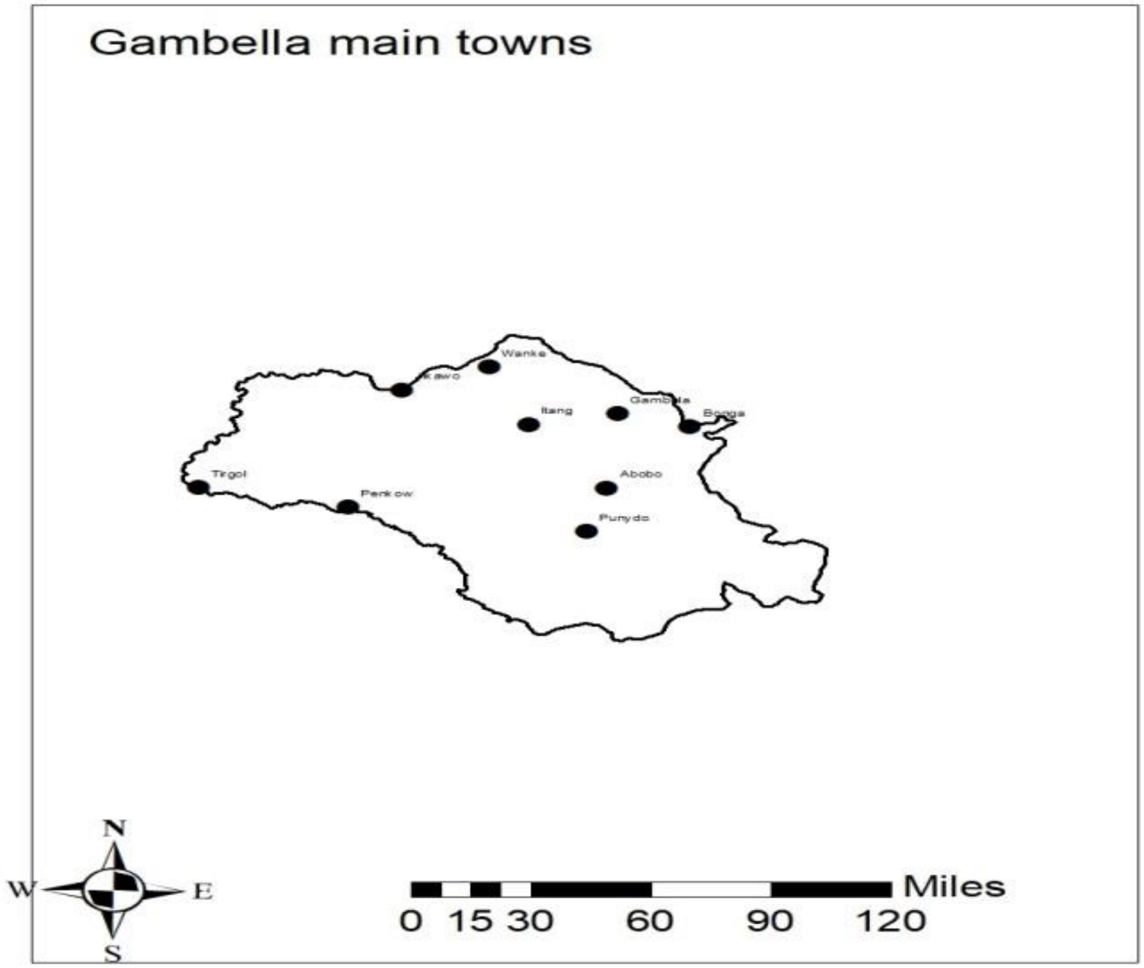

Figure 8: Major town in the study area

3.3. Software to be used

Table 4: Soft wares to be used

S.no		
1	ARCGIS10.5	To prepare all map layouts, to calculate weight using AHP and overlay spatial data.
2	AHP	Pair-wise comparison of all criteria

3.4. Methodology

This study deployed ArcGIS and AHP to select most suitable site for the installation of solar powered non-wooden biomass briquetting plant using spatial multi-criteria evaluation method. ArcGIS played key role in preparation and transformation of raw data as collected from difference sources. The analysis was done with six selected criteria like LULC, solar radiation,, slope, proximity to roads, proximity distance to town, proximity to river and any other relevant criteria depending on the view of experts. Other more related data such as proximity to existing power grid was left as the plant is solely to be powered by solar.

3.4.1. Spatial multi criteria evaluation method

This method can be thought of as a process that combines and transforms a number of geospatial data (input) into a resulting decision (Malczewski, 2004). This method provide us a set of tools for spatial decision making processes in order to help to find the solutions for multiple choice alternatives. Since this deals with evaluating locational choice alternatives on the beginning of suitability criteria much effort has been made in integrating spatial multi criteria evaluation method with GIS software (Eldrandaly, Eldin, Sui, Shouman, & Nawara, 2005).

3.4.2. GIS-AHP based approach for suitable solar farm site selection

Nowadays, analysis of land-use suitability requires consideration of different criteria including not only the natural/physical capacity of a land unit but also socio-economic and environmental effects (Noorollahi et al., 2016). AHP has specific application in group decision making, and was used all over the world in different decision situations, in fields such as, industry area, government sector, healthcare sector, business area, shipbuilding, site suitability selection and Education (T. L. Saaty, 2013). Somewhat recommending a "precise" judgment, AHP aids for decision makers delivering best generation for their goals and their understanding of the problem (Madurika & Hemakumara, 2017). The essentials of the order are able to join to any feature of the conclusion difficult touchable or intangible, wisely dignified or approximately expected, fit or unwell assumed everything at totally that applies to the choice (Kim et al., 2018).

3.4.3. The Criteria on Weighting

Weights of criteria used for suitability evaluation were obtained using professional experiences of local experts and supported by different scientific literatures through pairwise comparisons method following AHP (R. W. Saaty, 1987) a widely accepted decision making method. This method is a mathematical and a flexible for evaluating and making complex decisions to decompose into specific elements by using pairwise comparison (Kim et al., 2018). The relative importance of each criteria against each other was collective view of expert in focal group discussion reasonable weight generated by AHP template using analytical approach in section 3.4.5.

3.4.4. Pairwise comparison matrix

It is a method which has commonly used to challenge the individual and unbiased decisions around qualitative and quantitative measures in multi-criteria decision making, especially in the Analytical Hierarchy Process (AHP) denoted as pairwise comparison matrices (Kou, Ergu, Lin, & Chen, 2016).

3.4.5. Evaluation of Matrix Consistency

For weighting each criterion, the matrix (A) is standardized by dividing the elements in each column by the sum of the elements in that same column. The rows average in the new matrix defines the required relative weights of the criteria. Some inconsistencies may arise once a certain number of pairwise comparisons are performed. The AHP includes the consistency ratio (CR), which is a parameter to evaluate the weights' consistency. To calculate the CR, the consistency index (CI) must be first calculated (Saaty 1987)

$$CI = \frac{(\lambda\text{-n})}{(n-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where: λ denotes the eigenvalue of the pairwise comparison matrix, n is the number of the criteria. In the end, the CR is calculated by dividing the CI by the random consistency index (RI). The RI values for the appropriate n values were reported by Saaty. To obtain the value of CR

$$CR = \frac{CI}{RI} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

CR means constancy ration and Random index (RI) the CI of a randomly created pairwise comparison matrix of order 1 to 10 obtained by approximating random indices using a sample size of 500 (R. W. Saaty, 1987), table below shows the value of RI sorted by the order of the matrix.

Table 5: Random index (Ammarapala et al. 2018)

Order Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.5. Methodological skeleton

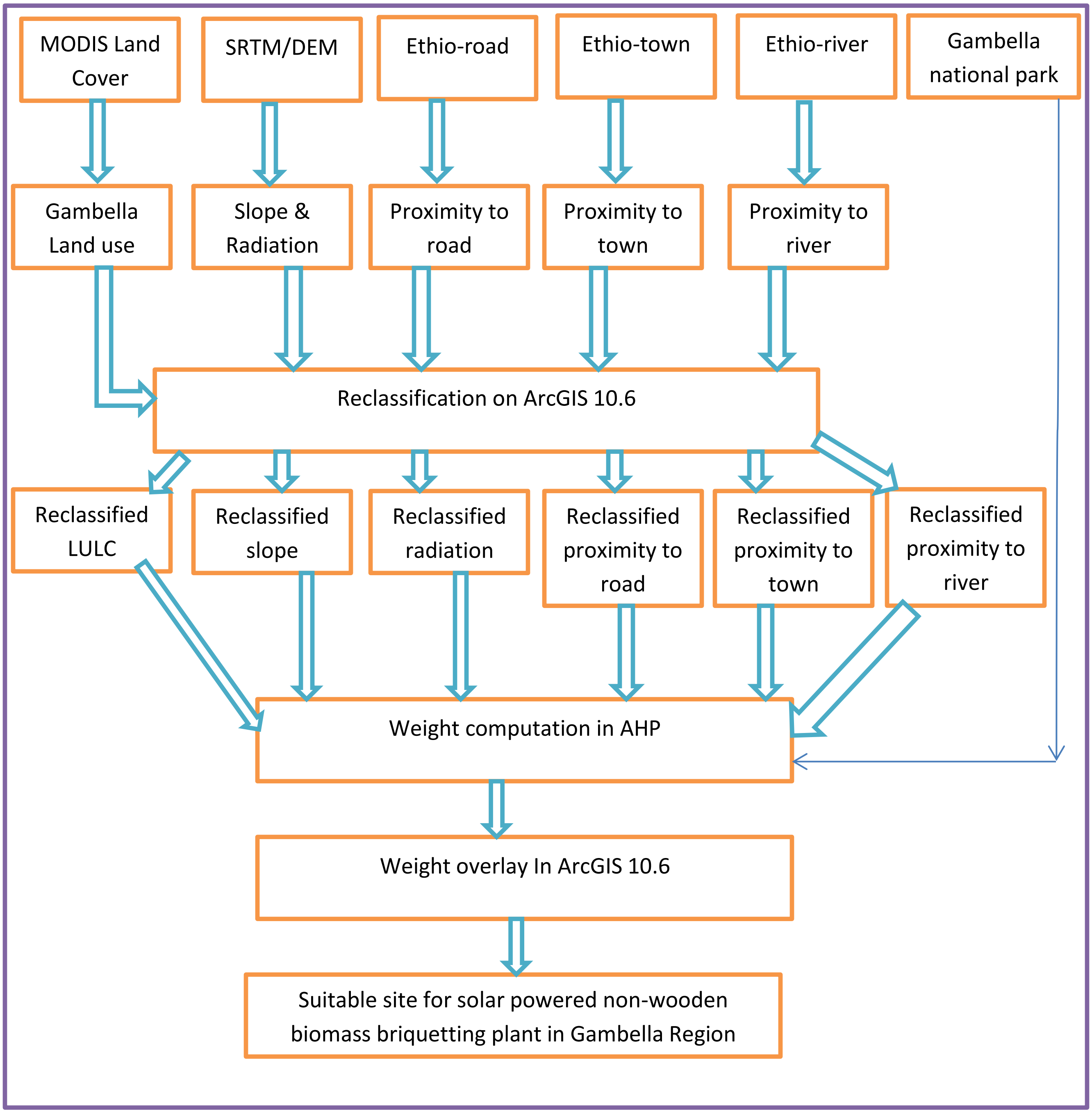

Figure 9: Methodological skeleton of the study

4. Result

4.1. Land use land/land cover classification

The land use/land cover of Gambella region is consisting of Evergreen broadleaf forest 14.50%, deciduous broadleaf forest 7.76%, mixed forest 0.01%, woody savanna 0.91%, Savanna 65.16%, grass land 11.34%, permanent wet land 0.05%, crop land 0.24%, urban and build up land 0.01% and water body 0.02%.

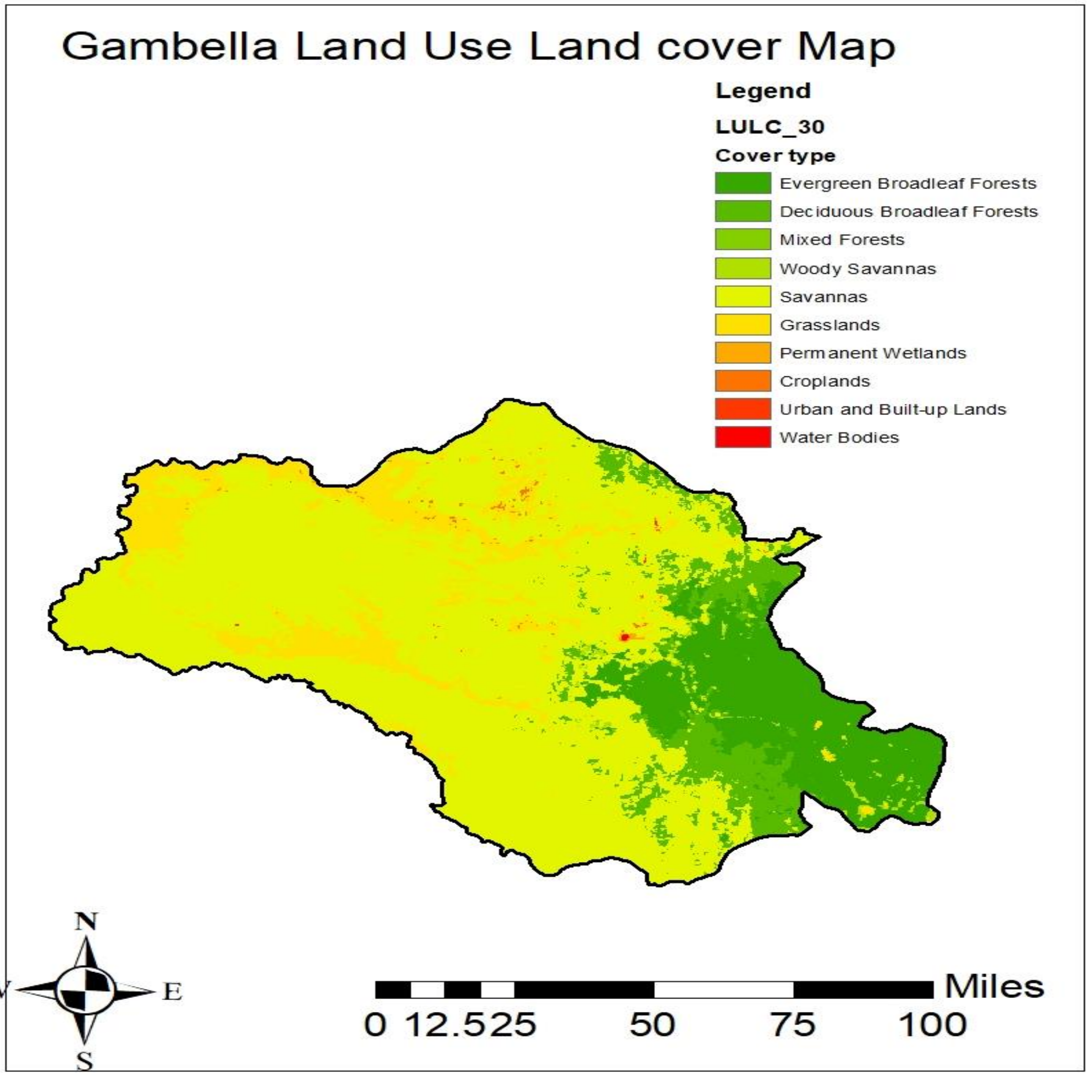

Figure 10: Classified LULC of the study area

Rowid	VALUE	COVER_TYPE	COUNT	AREA_PERCENT
0	2	Evergreen Broadleaf Forest	4095112	14.50
1	4	Deciduous Broadleaf Forest	2193284	7.76
2	5	Mixed Forest	3318	0.01
3	8	Woody savanna	256025	0.91
4	9	Savanna	18410848	65.16
5	10	Grass Land	3202695	11.34
6	11	Permanent Wetland	15391	0.05
7	12	Crop land	67151	0.24
8	13	Urban and build up land	4085	0.01
9	17	Water body	4488	0.02

Table 6: LULC value by percent

4.2. Solar radiation

According to the International Energy Agency (2010), every surface with a variety of climatic conditions and estimated solar radiation of more than 1300 kWh/m2 has the capacity to generate solar energy(Anon 2021). The solar radiation in the research region was calculated using DEM, and its value ranged from 1,514 to 2,201 KWh/m2, as shown in the figure below 11.

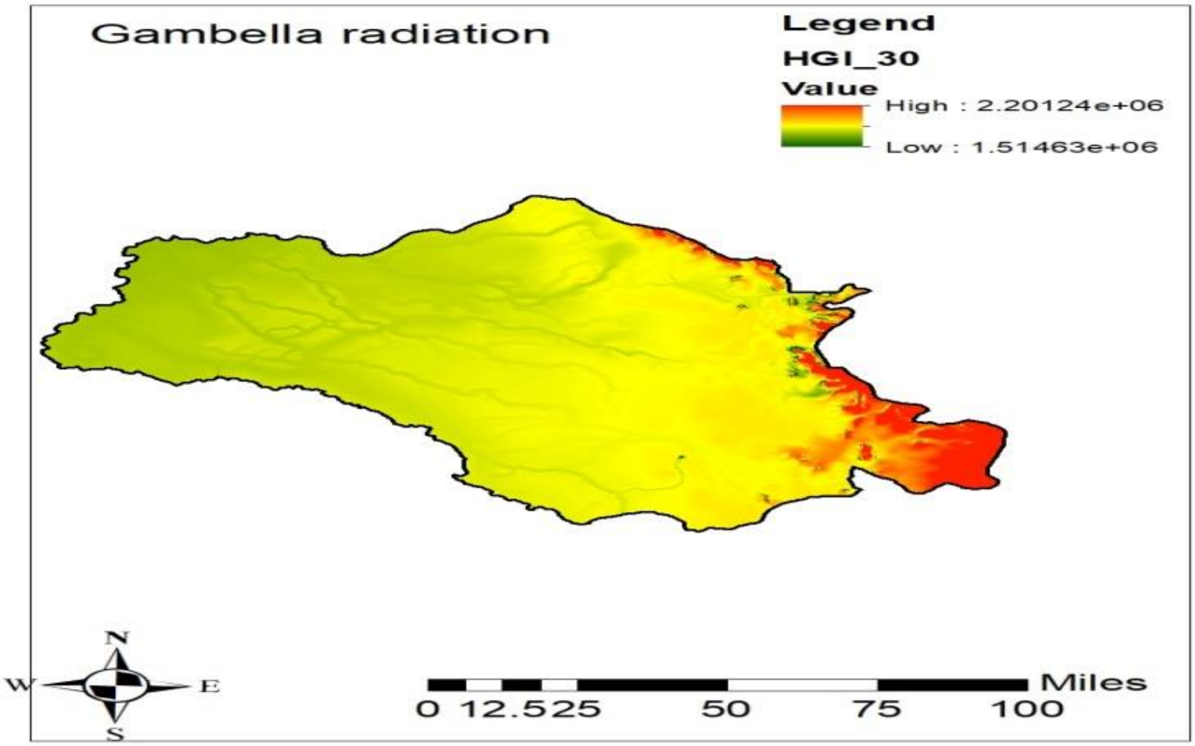

Figure 11: Ranged solar data of the study area

4.3. Parameters of non-wooden biomass briquetting plant suitability

4.3.1. Reclassified Slope

The slope is one of the criteria for choosing the best location for a solar-powered non-wooden biomass briquetting plant because it has a direct impact on the plant's overall efficiency and construction costs. According to Nebey et al. (2020), there are strong correlations between slope and solar farm site selection, indicating that slopes less than 10% were good, with slopes of 3% or less being highly suitable, 3% to 7% being suitable, and 10% or more being unsuitable due to economic considerations. Less than 3% of gradient was used to reclassify study sites as very acceptable, whereas more than 10% was used to classify them as unsuitable.

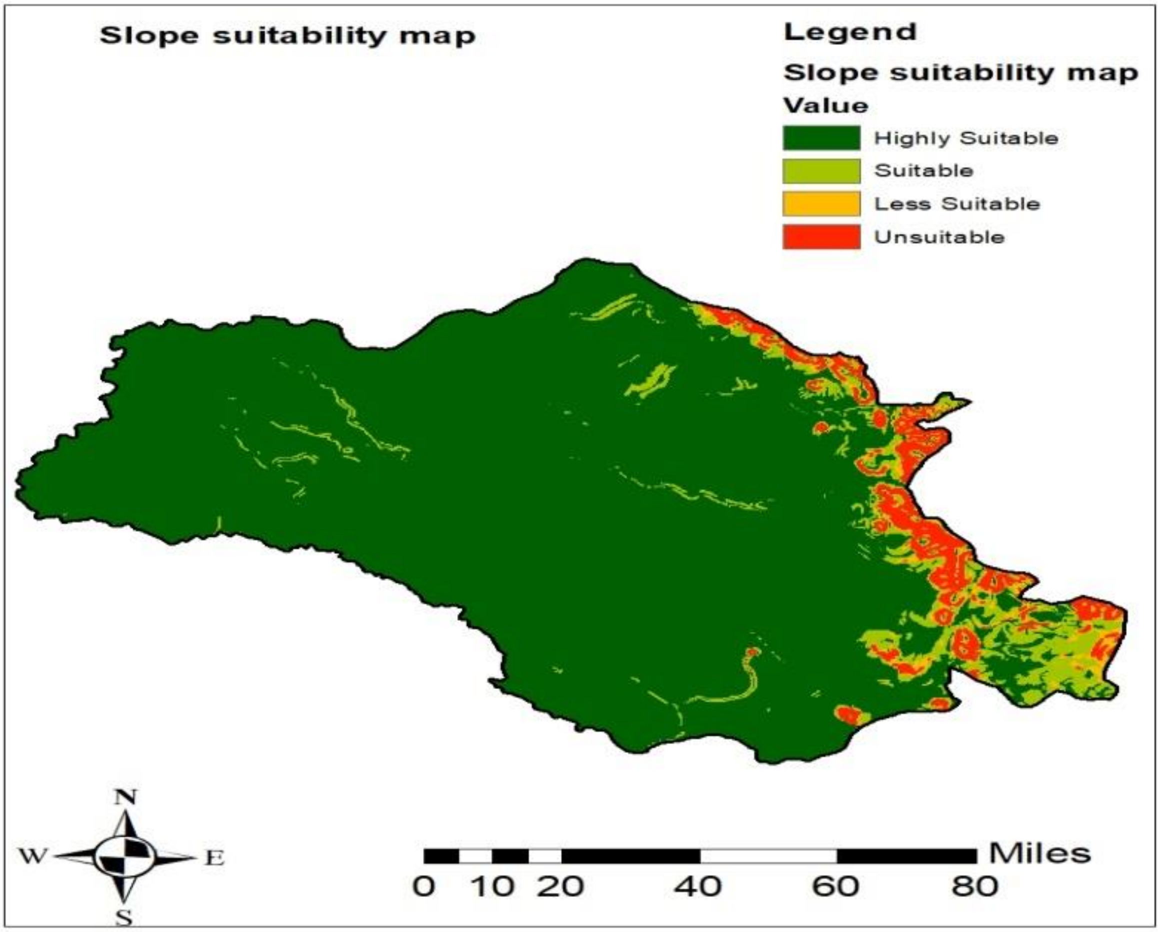

Figure 12: Reclassified slope

OBJECTID *	Value	Range	Count	Suitability	Suitability by Percent
1	1	0-3%	24957146	Highly suitable	88%
2	2	3-7%	1779946	Suitable	6%
3	3	7-10%	449096	Less suitable	2%
4	4	>10%	1122388	Unsuitable	4%

Table 7: Slope suitability by percent

As in the table 7, 88% of the study area is highly suitable, 6% suitable, 2% less suitable and 4% unsuitable in term of slope. Unsuitability can be observed around east and south eastern part of Gambella region as in the figure 12.

4.3.2. Reclassified distance to Road

The road proximity to the solar powered briquetting site is divided based on its economical factor as the mean of transport for the products and the access to the market, so within 1000 meter was taken as highly suitable, 1000-3000m taken as suitable, 3000-10,000m taken as less suitable and >10,000 meter taken as unsuitable defending on the view of the experts.

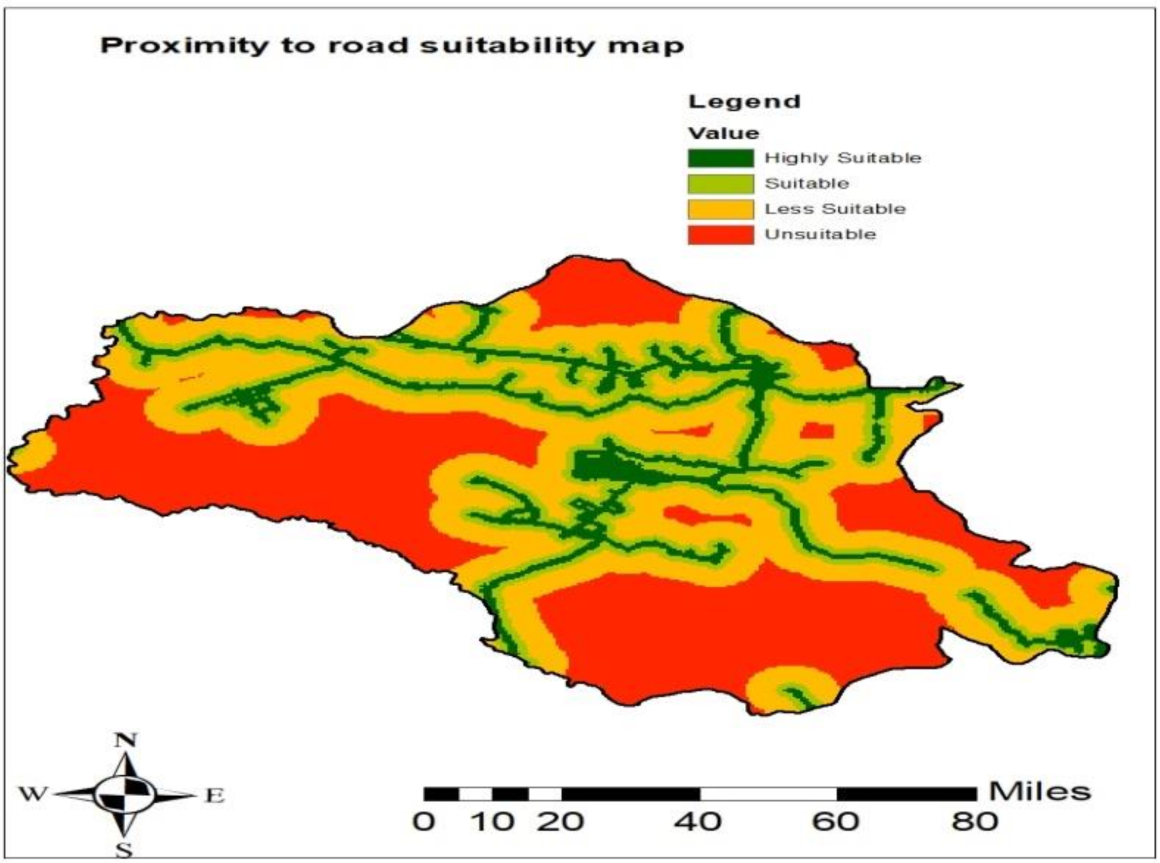

Figure 13: Reclassified proximity to the road of the study area

OBJECTID *	Value	Range	Count	Road suitability by percent	Suitability
1	1	0-1000	2883854	10%	Highly suitable
2	2	1000-3000	4383965	15%	Suitable
3	3	3000-10000	10032796	35%	Less suitable
4	4	>10000	11203693	39%	Unsuitable

Table 8: Proximity to road suitability in percent area

As in the table 8, only 10% of land is highly suitable for the solar powered non-wooden biomass briquetting plant which is primarily attributed to the lack of road infrastructure visibly shown of the figure 13.

4.3.3. Reclassified distance to River

The proximity to the river is considered in this study as an auxiliary facility of the plant for water demand of the plant personnel and security of the plant in case of any accidental fire blow up but not as the raw material for this research is dealing with direct densification as in section 2.5. The reclassification is determined based on the view of the experts as follow: <500m taken as a highly suitable, from 500-1000m taken as suitable, 1000-2000m less suitable and less than 2000m taken as unsuitable.

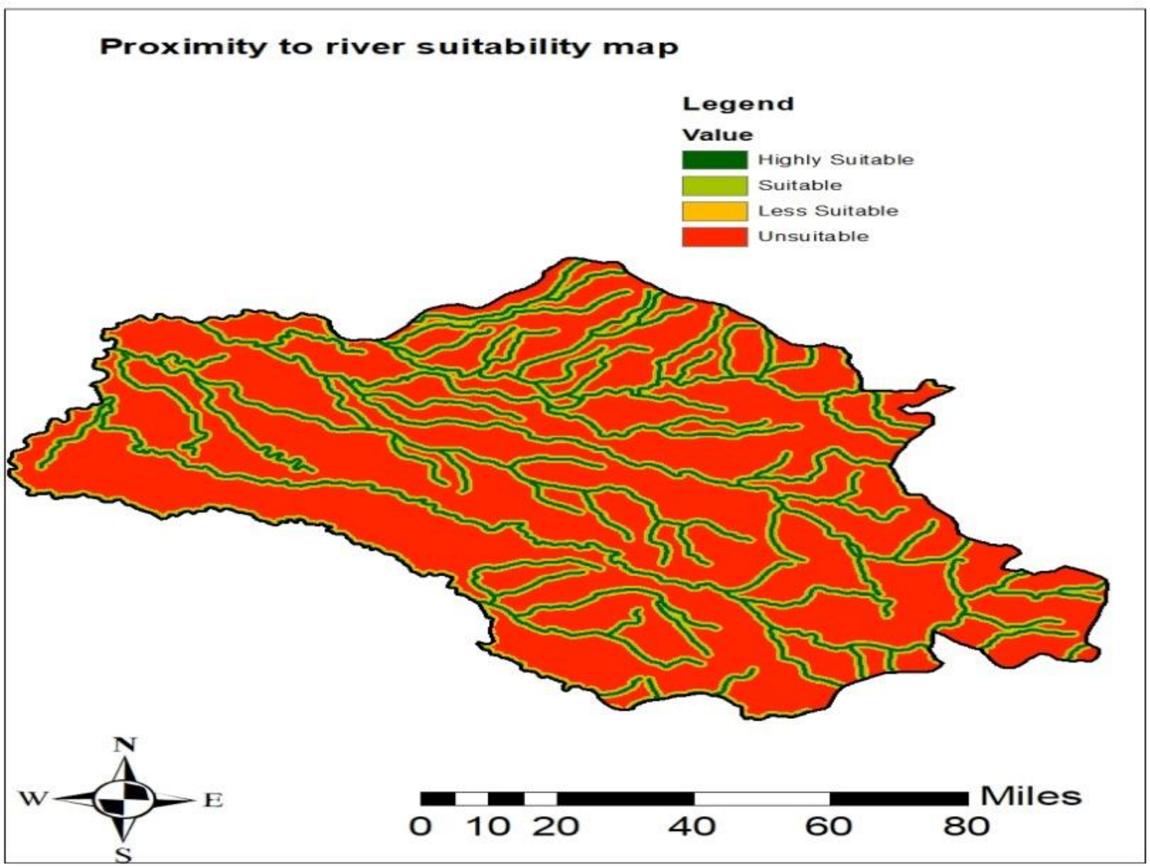

Figure 14: Reclassified proximity to the river of the study area

OBJECTID *	Value	Range	Count	River suitability by percent	Suitability
1	1	0-500	3509733	12%	Highly suitable
2	2	500-1000	3559197	12%	Suitable
3	3	1000-2000	2812779	10%	Less suitable
4	4	>2000	18618459	65%	Unsuitable

Table 9: Proximity to river suitability in percent

The study area; Gambella region is blessed with network of rivers as can be seen in figure but the issue of the plant security can come up with total destruction of the entire plant leads to the narrow range of suitability as of the experts. Hence, just 12% of the region is considered highly suitable, 12% suitable, 10% less suitable and 65% unsuitable as illustrated in table 9.

4.3.4. Reclassified distance to Town

Distance to town was the main necessary factor to select suitable site for the establishment of solar powered non-wooden biomass briquetting plant for the town was considered the potential market of the product. In this particular study, the nearest plant is considered highly suitable and the farthest one was unsuitable accounting the cost of transportation. The distance within 10,000m was taken highly suitable, between 10,000 and 15,000, suitable, between 15,000 to 25,000m.

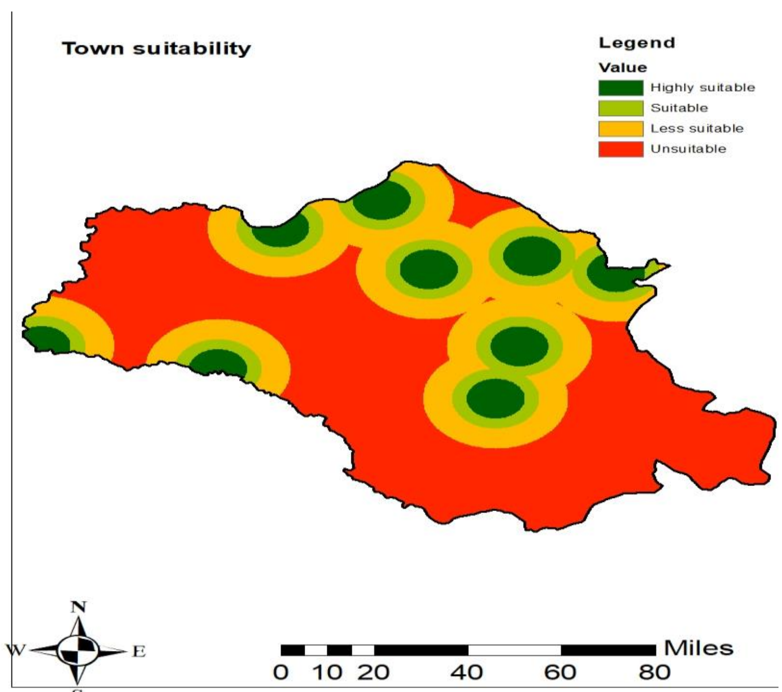

Figure 15: Reclassified proximity to town of the study area

OBJECTID *	Value	Range	Count	Town suitability by percent	Suitability
1	1	0-10000	2597305	9%	Highly suitable
2	2	10000-15000	3041477	11%	Suitable
3	3	15000-25000	6986565	25%	Less suitable
4	4	>25000	15874821	56%	Unsuitable

Table 10: Proximity to town suitability in percent area

It can be observed from Table 10 that only 9% of the study area is highly suitable showing the scattered residents in the region visibly on Figure15 with 11% suitable, 25% less suitable and majority of 56% unsuitable; difficult to access the main markets.

4.3.5. Reclassified Solar Radiation

The strength of solar radiation is the main factor to consider while choosing the ideal location for a non-wooden biomass briquetting facility driven by solar energy. Higher than 1850 kWh/m2/year solar radiation is now categorized as highly suitable, suitable (1650–1850 KWh/m2/year), less suitable (1500–1650 KWh/m2/year), and unsuitable (less than 1300 kWh/m2/year) (Nebey et al. 2020).

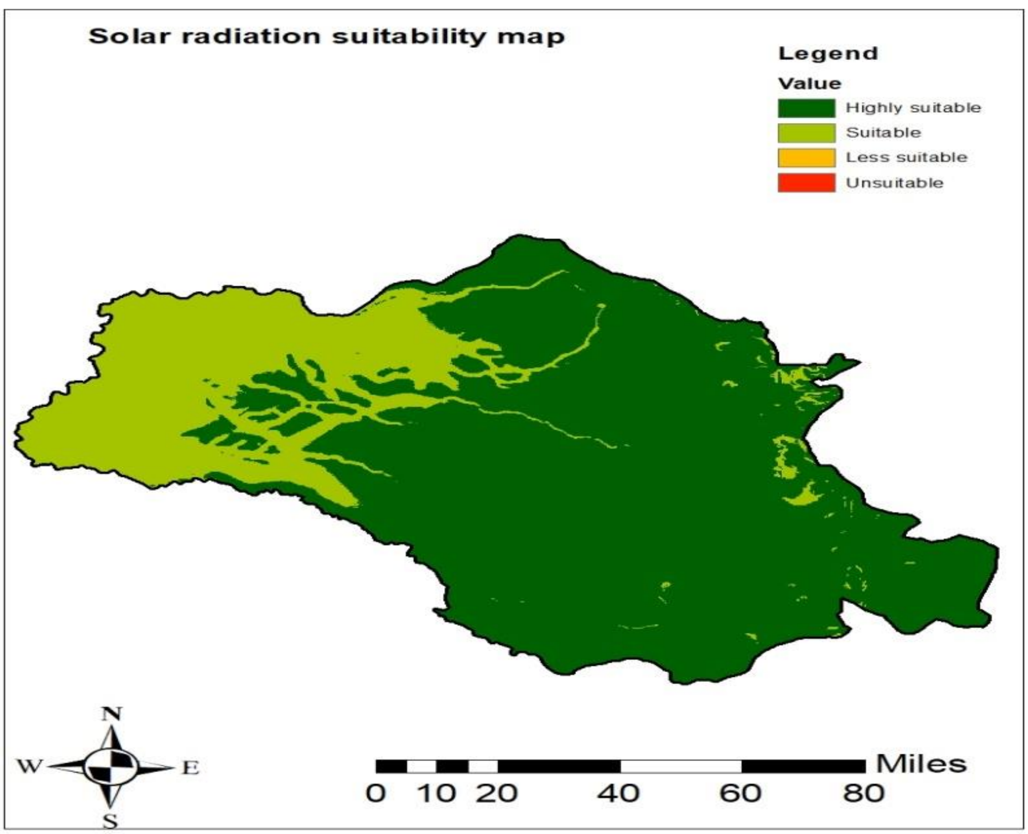

Figure 16: Reclassified solar radiation of the study area

OBJECTID *	Value	Range	Count	Solar suitability by percent	Suitability
1	1	0-1500	21288909	75%	Unsuitable
2	2	1500-1650	7207740	25%	Less suitable
3	3	1650-1850	1612	0%	Suitable
4	4	>1850	218	0%	Highly suitable

Table 11: Solar radiation suitability in percent area

Table 11 illustrates that the study area; Gambella region is blessed with strong solar radiation giving 75% of the total area highly suitable and the remaining 25% suitable with no unsuitability.

4.3.6. Re-classified Land use land cover

The land use land cover of this study areas suitability range was reclassified into four depending of the view of the experts on each cover type and environmental aspect as highly suitable, suitable, less suitable and unsuitable. Savanna and grass land were considered highly suitable as highly dominated by non-wooden biomass making up 77% of the total area, Woody savanna (1%) was considered suitable, mixed forest and crop land (almost 0%) were considered less suitable, and Evergreen broad leaf forest, Deciduous broad leaf forest, Permanent wetland and water body (22%) was considered unsuitable as detailed in table 12 and table 13. The values from 1 to 4 were assigned to each cover type by the focal group discussion of team of expert with 1 considered highly suitable; 2 suitable; 3 less suitable and 4 unsuitable.

Rowid *	**VALUE**	**COVER_TYPE**	**Value**	**Suitability**
0	2	Evergreen Broadleaf Forest	4	Unsuitable
1	4	Deciduous Broadleaf Forest	4	Unsuitable
2	5	Mixed Forest	3	Less suitable
3	8	Woody savanna	2	Suitable
4	9	savanna	1	Highly suitable
5	10	Grass Land	1	Highly suitable
6	11	Permanent Wetland	4	Unsuitable
7	12	Crop land	3	Less suitable
8	13	Urban and build up land	4	Unsuitable
9	17	Water body	4	Unsuitable

Table 12: Reclassification of LULC

OBJECTID *	Value	Cover type	Suitability	Count	LULC suitability by percent
1	1	savanna and grass land	Highly suitable	21613543	77%
2	2	Woody savanna	Suitable	256025	1%
3	3	Mixed forest and crop land	Less suitable	70469	0%
4	4	Evergreen broad leaf forest, Deciduous broad leaf forest, Permanent wetland and water body	Unsuitable	6312360	22%

Table 13: LULC suitability in percent area

Unsuitability can be seen east and south east of the study area which known to be the home of UNESCO registered forest in Majang zone of Gambella region.

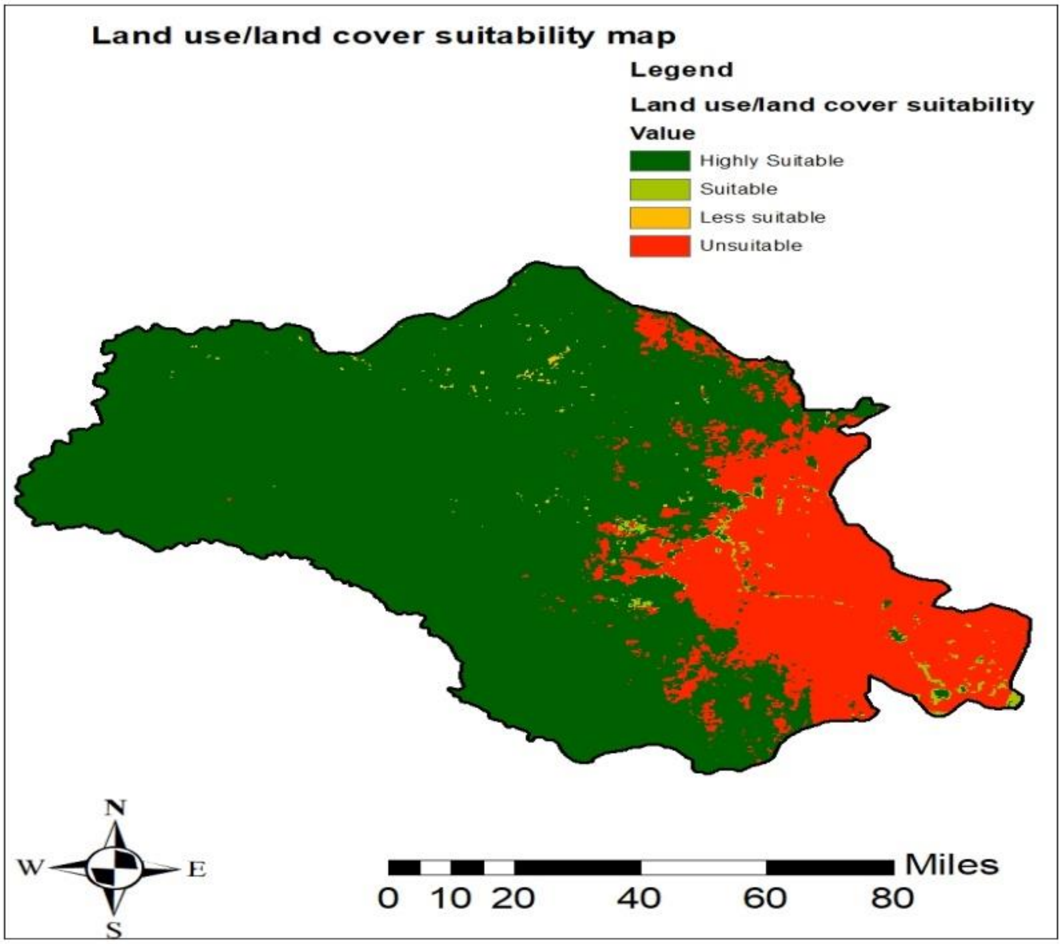

Figure 17: Reclassified LULC of the study area

4.4. Suitable site for the establishment of solar powered non-wooden biomass briquetting plant

In the study area, an optimal site for solar powered non-wooden biomass briquetting plant was derived from each influencing parameters and calculating their weight using pair wise comparison in AHP then doing weighted overlay in Arc GIS 10.6.

4.4.1. Criteria weighting

The six criteria such as solar radiation, slope, road, land use land cover, town and river were used in the analysis of this study with need illustrated in Table 14. These six criteria pairwise comparisons calculate priorities using Analytic Hierarchy Process. The constancy ration of this pairwise comparison result is 9.6%, which is less than 10% and acceptable so we can use this driving weight for next step software work (Saaty 1987).

	Criterion	Comment	Weights
1	Distance from road	To transport the product to the market and accessibility	8.3%
2	Distance from river	For the safety of the site in case of any fire (direct densification)	5.5%
3	Distance from town	Potential customers (access)	3.8%
4	Strength of solar radiation	To power the machineries during production	20.4%
5	Slope	Plate area is easy for construction and installation	15.5%
6	Land use land cover	Availability of raw materials (input)	46.6%

Result	**Eigenvalue**			Lambda:	6.609		MRE:	48.3%
	Consistency Ratio	0.37	GCI:	0.35	Psi:	6.7%	CR:	9.7%

Table 14: Criteria description and weight

Matrix		Distance from road	Distance from river	Distance from town	Strength of solar radiation	Slope	Land use land cover	normalized principal Eigenvector
		1	2	3	4	5	6	
Distance from road	1	1	3	3	1/3	1/3	1/7	8.26%
Distance from river	2	1/3	1	3	1/3	1/5	1/7	5.46%
Distance from town	3	1/3	1/3	1	1/3	1/5	1/7	3.77%
Strength of solar radiation	4	3	3	3	1	3	1/3	20.42%
Slope	5	3	5	5	1/3	1	1/5	15.52%
Land use land cover	6	7	7	7	3	5	1	46.58%

Table 15: AHP criteria weighting

4.4.2. Weighted overlay analysis

The weighted overly analysis was done by using ArcGIS 10.6 Spatial analyst tool. The final step was aggregate all reclassified raster datasets that include solar radiation, slope, road, river, land use land cover and town. All these raster data sets were aggregate based on their weighted level. The below table 16 generalized the weights of all criteria, all factor value and assigned in the weight overlay tool.

S.no	Criteria	Range	Suitability	Weight
1	LULC	savanna and grass land	Highly suitable	46.58%
		Woody savanna	Suitable	
		Mixed forest and crop land	Less suitable	
		Evergreen broad leaf forest, Deciduous broad leaf forest, Permanent wetland and water body	Unsuitable	
2	Radiation	0-1500	Unsuitable	20.42%
		1500-1650	Less suitable	
		1650-1850	Suitable	
		>1850	Highly suitable	
3	Proximity to town	0-10000	Highly suitable	3.77%
		10000-15000	Suitable	
		15000-25000	Less suitable	
		>25000	Unsuitable	
4	Proximity to river	0-500	Highly suitable	5.46%
		500-1000	Suitable	
		1000-2000	Less suitable	
		>2000	Unsuitable	
5	Proximity to road	0-1000	Highly suitable	8.26%
		1000-3000	Suitable	
		3000-10000	Less suitable	
		>10000	Unsuitable	
6	Slope	0-3%	Highly suitable	15.52%
		3-7%	Suitable	
		7-10%	Less suitable	
		>10%	Unsuitable	

Table 16: Criteria, factor values and weight in use

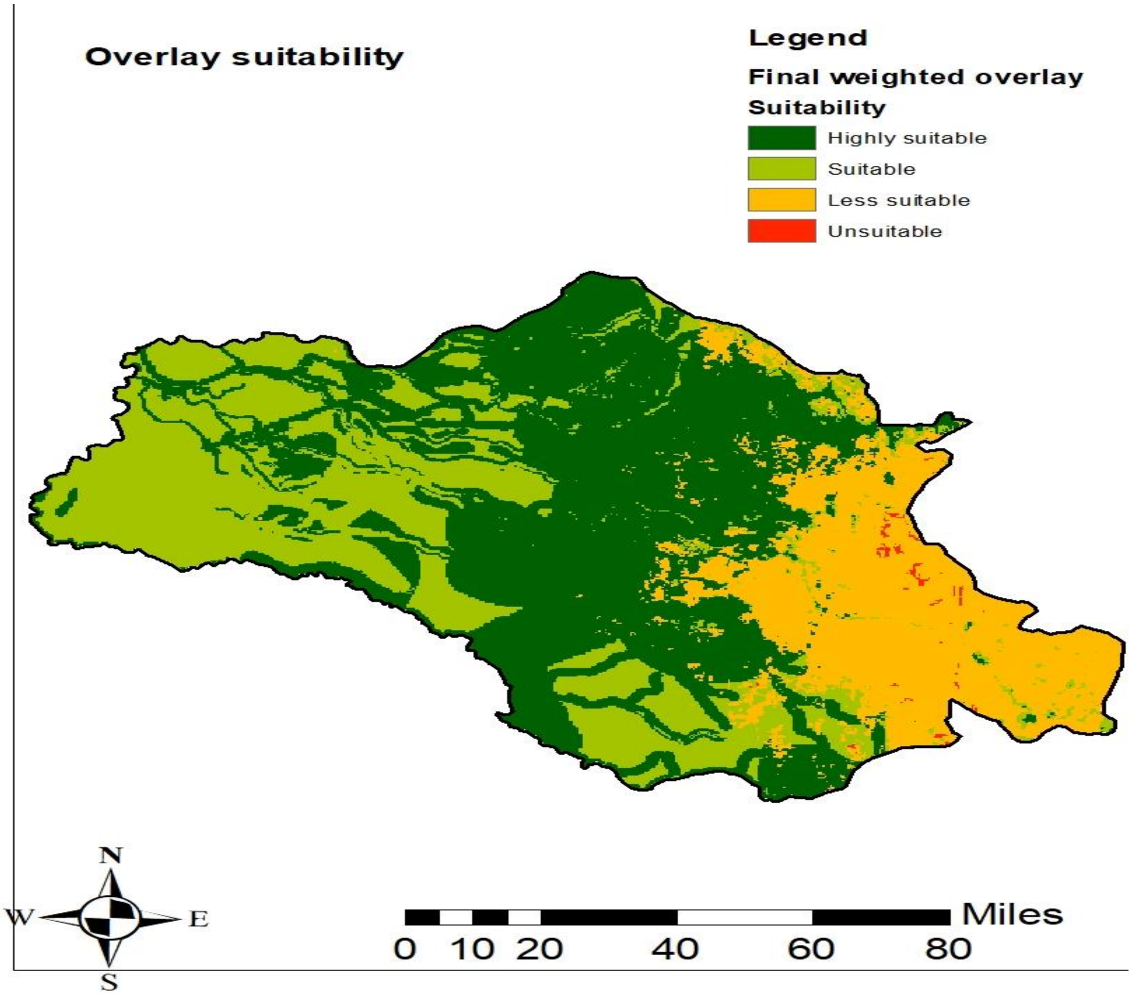

Figure 18: Area suitability map for the establishment of solar powered non-wooden biomass briquetting plant in Gambella Region

OBJECTID *	Value	Suitability	Count	AreaSq.km	Area percent
1	1	Highly suitable	55808	12094.49183	47%
2	2	Suitable	36241	7854.008001	31%
3	3	Less suitable	26013	5637.435781	22%
4	4	Unsuitable	291	63.06438367	0%

Table 17: Land suitability in percent area

5. Discussion

GIS and different geospatial technology are used for analysis and combination of different features that are used to indicate suitable solar powered non-wooden biomass briquetting plant in Ganbella Region. In doing this study, we have used different vector and raster data format such as MODIS Land Cover Type Product (MCD12Q1), road, rivers, towns and digital elevation model. DEM has great factor in this study to estimate the study areas solar radiation and almost all the environmental factors are drive from it, such as slope, solar radiation and river network. The estimated solar radiation depended on the resolution of DEM as well as the parameters such as time interval and sky size resolution. Higher resolution with smaller time interval and bigger sky size results more accurate output, but also increases considerable calculation time.

GIS-based spatial multi criteria evolution method was applied to select the ideal location for suitable solar powered non-wooden biomass briquetting plant in Gambella Region. Various topographic, economic and environmental factors were taken into consideration in the site selection process which include but not limited to Proximity to road, Proximity to river network, proximity to major town, strength of solar radiation, slope of the study area, land use land cover.

The nine criteria such as solar radiation, aspect, slope, sub-station site, road, railway, land use land cover, town and river were used to select optimal solar farm in kewet wereda using GIS-based spatial multi criteria evolution method. Some of the criteria but in different context were used in this analysis as no research directly related to the briquetting site selection has been conducted in Ethiopia with the rest omitted by the team of expert on their importance.

This research differs from both studies in context, geographical coverage and data usage, the primary aim of this research was to enhance productive of the briquetting plants by proper site selection while addressing economic and environmental issues. Strength of solar radiation, proximity to town, proximity to road, and proximity to river, slope, and LULC were the six criteria used to select suitable site for the establishment of solar powered non-wooden biomass briquetting plant in Gambella in map image to serve as the baseline for all implementing partners and policy maker.

According to ((Saaty 1987)), AHP pairwise comparison with CR value less than 0.1 is considered acceptable and further analysis can be made. So, this study weight was derived from the AHP pairwise comparison method its CR value was 0.097 which is less than 0.1 and the weight was acceptable. A team of expert through careful evaluation and review of criteria has finally ran the AHP resulting the lead of land use/land cover (46.58%) as the main input to the plant followed by the solar radiation (20.42%) the sole energy source of the plant with slope (15.52%), proximity to road (8.26%), proximity to river (5.46%) and lastly proximity to town (3.77%).

In resource assessment, this research managed to categorize the whole area of the study area in to highly suitable (77%, savanna and grass land), suitable (1%, Woody savanna), less suitable (0%, mixed forest and crop land) and non-suitable (22%, Evergreen broad leaf forest, Deciduous broad leaf forest, Permanent wetland and water body) which indicates high potential of non-wooden biomass resources.

The plant suitability analysis result after weight overlay tells that, the most suitable area found north-south line through the center of the study area covers 12,094.49 km^2area which is approximately 47% of the total study area is highly suitable, 7854.01km^2 (31%) of the area is suitable, 5637.43 km^2 (22%) of the study area is less suitable and just 63.06 km^2 (approximately 0%) of the area is unsuitable. Figure 18 clearly reveal that most criterion are met central region of the study area basically due to poor road network and less number of residential towns along the road. South eastern tip of the study area is part of Ethiopia high land that is too sloppy whereas Western tip is most of the time wet land leading to low suitability index.

6. Conclusion and recommendation

6.1. Conclusions

This study assesses suitable sites for the establishment of solar powered non-wooden biomass briquetting plant in Gambella Region based on spatial multi criteria evaluation methods by ArcGIS software using different type of spatial and non-spatial data. The obtained results show that there was high potential area for the briquetting plants throughout the region with minor limitation mainly due to poor road network and scattered settlement as can be observed in figure 18.

The 12,094.49 km^2area was selected as highly suitable site for solar powered non-wooden biomass briquetting plant followed by suitable (7854.01km^2), less suitable (5637.43km^2) and unsuitable (63.06km^2). The analysis was done with the account of various topographic, economic, social and environmental factors such as solar radiation, slope, and land use/land cover, proximity distance to road, proximity distance to river and proximity distance to town.

The result indicates the availability of raw materials which is land use land cover in this context is most influential factor with weight of 46.58% followed by strength of solar radiation (20.42%), slope (15.52%), proximity to road (8.26%), proximity to river (5.46%) and proximity to town (3.77%). Highly suitable or the most optimal site is found along North-South line through the central part of the study area mostly influenced by the road network and the major towns distribution. This highly suitable area if effectively used can respond to the dire need of cooking energy in the region whereby slow down the common deforestation and resource depletion looming in the region in sustainable way.

6.2. Recommendations

Majority of the local residence that live in study area are in dire need of clean cooking energy resorting to tradition cooking fuel in risky and hazardous manner as different modern cooking technologies are not well preached throughout the community. Traditional charcoal producers are inflicting accelerated depletion of forest resource as the mean of income and to meet the energy demand of high settlement of refugee and host community in the region. The government of Ethiopia through numerous stakeholders is initiating the development of briquetting technology to make use of forest and agricultural waste for cooking in form of briquette to ensure renewable and sustainable cooking energy supply but the distribution of these forest and agricultural waste (non-wooden biomass) is not in hand.

I am therefore recommending the Ethiopian government, Gambella regional government and implementing partners to make use of resource distribution and other influencing factors in establishment of briquetting plant which can be powered any source but in the sustainability view in this specific research, a solar. Considering the renewability of the resources, I am recommending the use of non-wooden component such as: shrub, grass, leaf and agricultural waste as can be regenerated any time. In addition, I recommended for Ethiopian space science and technology institute to carefully organize and archive all geospatial information data and deliver high resolution data for the user for better analysis throughout the country.

For further research, I am recommending careful resources quantification and successive modeling of the plant production against the cooking energy demand to bring solution to the health, economic, social and environmental concerns of the residents in the study area.

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