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ORIGINAL PAPER

Optimization of power transmission line location at tropical forest area in avoiding endangered tree species

Zulkiflee Abd Latif[1,2] · Sofiya Zulaikha Ruslan[3] · Nurul Ain Mohd Zaki[1,3] · Mohd Nazip Suratman[1] · Hamdan Omar[4] · Tajul Rosli Razak[5] · Shukor Sanim Mohd Fauzi[5] · Ray Adderley GM Gining[5]

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Abstract

Due to social defiance, there was a controversial issue regarding the development of new high-voltage overhead power lines (HVOPL) in electricity companies. In developing the infrastructure of new power infrastructure design, the psychological aspects of the country culture need to be considered and accept its advancement as part of important components in the physical environment of the community. Species of the tropical tree such as *Aquilaria malaccensis* and *Dipterocarpus concavus* was listed as Critically Endangered by International Union for Conservation of Nature (IUCN) Red List. Therefore, this paper is to overcome the issues of transmission line siting to avoid endangered tree species. Due to the rising demand for power supply, site exploration and automated technology development have become necessary. One of the suitable sites to set up the transmission line is in the tropical forest area, resulting in forest clearing for transmission Right-Of-Way (ROW) that threatens endangered tree species. This study aims to propose the optimization power transmission line sitting using geospatial data at the tropical forest in avoiding the endangered tree species. Previously, the best route for transmission line siting in a particular location was determined based on expert opinion and drawn manually on paper. Geographic Information System (GIS) technologies with the optimize least-cost path (LCP) siting by considering the related multi-criteria features including endangered tree species, slope, average wind speed, and human mask was introduced. The transmission line siting optimization using the reclassification algorithm to weigh the relevant multi-criteria and LCP tools carried out data processing on the Model Builder platform. Finally, mapping suitable power transmission line siting development using geospatial data in avoided endangered tree species in tropical forest areas. The output will be the guideline or reference for any utility company for transmission line siting development at tropical forest area using GIS.

Keywords Optimize route · Least-cost path (LCP) · Reclassify algorithm · GIS

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✉ Zulkiflee Abd Latif
zulki721@salam.uitm.edu.my

1 Institute for Biodiversity & Sustainable Development (IBSD), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

2 Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

3 Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Cawangan Perlis, Kampus Arau, 02600 Arau, Perlis, Malaysia

4 Geoinformation Programme, Division of Forestry & Environment, Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor, Malaysia

5 Faculty of Computer and Mathematical Science, Universiti Teknologi MARA, Cawangan Perlis, Kampus Arau, 02600 Arau, Perlis, Malaysia

Introduction

The power line industry helps improve the national economy through massive construction and maintenance, creating power energy transmission corridors and loops around cities (Xu et al. 2016). Several parameters need to be considered in developing a new power transmission line, such as slope, urban growth, average wind speed, and distance which involve various risks and costs. The focus of the power transmission industry is to build a power transmission line within a short distance at the lowest cost with minimal environmental impact (Zipf et al. 2019). Aside from that, the meteorological condition is another critical parameter in siting transmission lines that determines their operation and limitation (Mo et al. 2017). According to Xu et al. (2016), several natural accidents caused by high voltage power lines like wildfires and icing had led to a power outage and tripping accidents in Hubei Province, China. These tragedies cause major losses in terms of the economy and human life. In 2013, about 30 tripping accidents caused wildfires, amounting to losses of more than 1.5 million US dollars in Hubei Province, China (Xu et al. 2016).

Electricity is an important device in these modern era societies that required effective monitoring and maintenance of power transmission lines with an electrical network included the nationwide networks, regional networks, and distribution networks (Matikainen et al. 2016). Power transmission line industry development of the national economy and consists of massive energy corridors and loops around cities (Xu et al. 2016). The tropical forest became the target area because of area suitability, while an endangered tree species occurs due to power transmission line siting development. Reported in an article written by Li and Lin (2019), forest fragmentation and degree impact on vegetation since 2014 in state grid of China caused by transmission line construction activities of cleared the forest area along transmission line within Right-of-Way (ROW) width with buffer zone about 50 to 100 m for every 2 or 3 years. Further studies were carried out to determine the solution for forest fragmentation issues in tropical forest areas by reducing the impact on wildlife and endangered tree species (Li and Lin 2019). The major environmental impact causes from the high-voltage transmission line (HVTL) is the land used land cover (Li and Lin 2019). The ROW result shows a permanent impact on the land cover as the trees cut for the cleaning process for avoiding any direct contact between trees and HVTL tower may cause disaster as stated by Xu et al. (2016) above.

The tropical forest keeps major carbon stock in aboveground living biomass of high density of trees (Mohd Zaki and Abd Latif 2017; Wassihun et al. 2019). Forest degradation caused by power transmission line development also makes a loss in carbon stock and above-ground forest biomass occur. Previously in Mohd Zaki et al. (2018), Southeast Asia is at the higher ranking for deforestation activity such as forest clearing increasing for the past decade especially happen in tropical forest areas. Moreover, Devices (2013) explicated how the transmission line development affected temporarily large-scale areas surrounding the actual ROW line area that permanently affected until it causes loss to the land benefits. The wildlife's habitat at tropical forest could temporarily be destroyed due to construction required a long duration to rebuild the habitats and shelter back into normal condition. In addition, transmission line siting is one of the forest development activities that endanger tree species. When a new path is created, all the trees that are in the way must be cleared (Devices 2013). Cutting off trees without replanting may lead to the extinction of the affected species. Furthermore, the power transmission line siting is also detrimental to the trees where some species cannot survive under high-voltage electrical power carried by the transmission line, while others succumbed to diseases (Devices 2013). Development of power transmission line siting at tropical forest areas could be part of causes lead to an issue regarding forests such as deforestation, forest degradation, and forest fragmentation increasing till occur loss in carbon stock. At this point, transmission line development has a temporary and permanent environmental impact; thus, there is a dire need for research to overcome these issues.

Data acquisition from airborne and spaceborne platforms provided high accuracy of data within a short period and fewer labors required to make this application usually applied nowadays (Azeez et al. 2021; Blackburn et al. 2014; Nordin et al. 2019; Saeidi et al. 2014; Sameen et al. 2018) Developing geospatial data is one way to optimize the power transmission line siting by processing and analyzing information of the relevant parameters. Light detection and ranging (LiDAR) provide the high accuracy for digital elevation model (DEM) land cover classification, while the meteorology data provided temperature and weather data to analyze wind speed and rain quantity in the selected area (Al-Najjar et al. 2019; Abd Rahman et al. 2017). Most remote sensing in forestry application was a collaboration with satellite images for high-accuracy data and algorithms in data 32 processing such as Random Forest (RF) learning algorithms machines applied for old growth forest identification (Calders et al. 2020; Rozali et al. 2020). Through data processing, the best location for power transmission line siting could be mapped and identified.

The studies carried out for future references in the improvement of power transmission line location in tropical forest areas in avoiding endangered tree species. The

Model Builder was a processing platform to optimize the line route for future research with similar characteristics with the type of forest, geospatial data, and size of the study area. The application of multicriteria decision as weight, reclassify algorithm application is assigned the weighted values for each criterion decision. The transmission line location determined for least-cost path (LCP) route from the start point to the endpoint using GIS technology tools which able to be used for future analysis and error detection. Previous applications in optimize transmission lines manually design that costly activity and time-consuming in acquired detailed information from terrain experts (Monteiro et al. 2005). The improvement in determining transmission line locations in tropical forest areas could give the environment a minimal degree of impact. Therefore, research was coming out to overcome the issues regarding transmission line siting avoided endangered tree species. This research was a new development and an initiative way to solve the problems. This study aimed to improvement of power transmission line location at tropical forest area in avoiding endangered tree species. There are three objectives that were prepared to achieve the aim of study: (1) to identify the parameters to establish power transmission line routing optimization at tropical forest area, (2) to examine the site suitability for power transmission line based on the parameter, and (3) to propose the power transmission line routing optimization at tropical forest area.

Materials and methods

Study location

Bukit Lagong Forest Reserve at FRIM Kepong, Selangor, is inhabited mainly by Dipterocarp arboretum and other trees from *Dipterocarpaceae* and non-*Dipterocarpaceae* species as shown Fig. 1.

FRIM has developed protection and control programs for threatened plant species, especially endangered tree species, where tree cutting or clearing activities are prohibited even for small tree branches since they are allowed to grow and die naturally. This location was selected as the research site because various tree species are present in the area.

Methodology framework

The methodology framework for the study is shown in Fig. 2. First, data collection is done using the field survey to create a tree inventory, purchasing of WorldView-2 satellite images, meteorology data collection, and an interview session with the utility expert regarding human mask related to Right-Of-Way (ROW) for transmission line siting at tropical forest area. Data processing was then conducted at stage 3 to obtain research parameters required using ArcGIS software, Microsoft Excel, and ERDAS IMAGINE software application to run the processing using the best procedure. After that, Model Builder, a platform designed to run data processing and digital mapping, was utilized for transmission line siting at the tropical forest area to represent the findings of this research.

Interview with an expert

An interview session was conducted with an expert in the utility industry, responsible for developing new, optimized transmission lines. Current issues related to endangered and critically endangered tree species due to transmission line development, especially in the forest area, were discussed. Previously, site criteria in optimized transmission line route involved heritage, terrain, urban and residential areas, access road, and other factors but did not include trees and wildlife habitats. Consequently, the number of tree species is rapidly decreasing due to large-scale forest exploration.

The utility industry has conducted research to prevent tree extinction from utility development as an activity that led to forest exploration. As a result, endangered and critically endangered tree species were identified, and prevention measures were taken to prevent their extinction to improve transmission line siting in the forest area. According to the expert, an optimized transmission line consists of 5 primary criteria: endangered species, slope, feature class, average wind speed, and human mask or ROW.

In terms of the transmission line ROW, its width depends on voltage power and location. When the voltage is 132 kV or 275 kV, the width should be 60 m, whereas, in places that require 500 kV like forest reserves, the width should be 70 m; 20 m wider than other locations. Consequently, 60 to 70 m of forest area along the transmission line route will be permanently cleared for safety purposes, thus destroying the natural flora and fauna without any rehabilitation program being conducted. In this research, the area inhabited by endangered and critically endangered tree species would be avoided from the transmission line ROW. However, when the situation is inevitable, other alternatives such as relocating and replanting trees might be more feasible.

Tree inventory

Tree inventory was constructed through a field survey to investigate and collect information about the desired trees positions, identity number, crown base height (CBH), diameter breast height (DBH), crown diameter (CD), height, species, and condition. The field survey covered a sample area of 2 ha within the study area. Approximately 326 trees were selected for the inventory, including all species with a height of more than 25 m which was visible from the top.

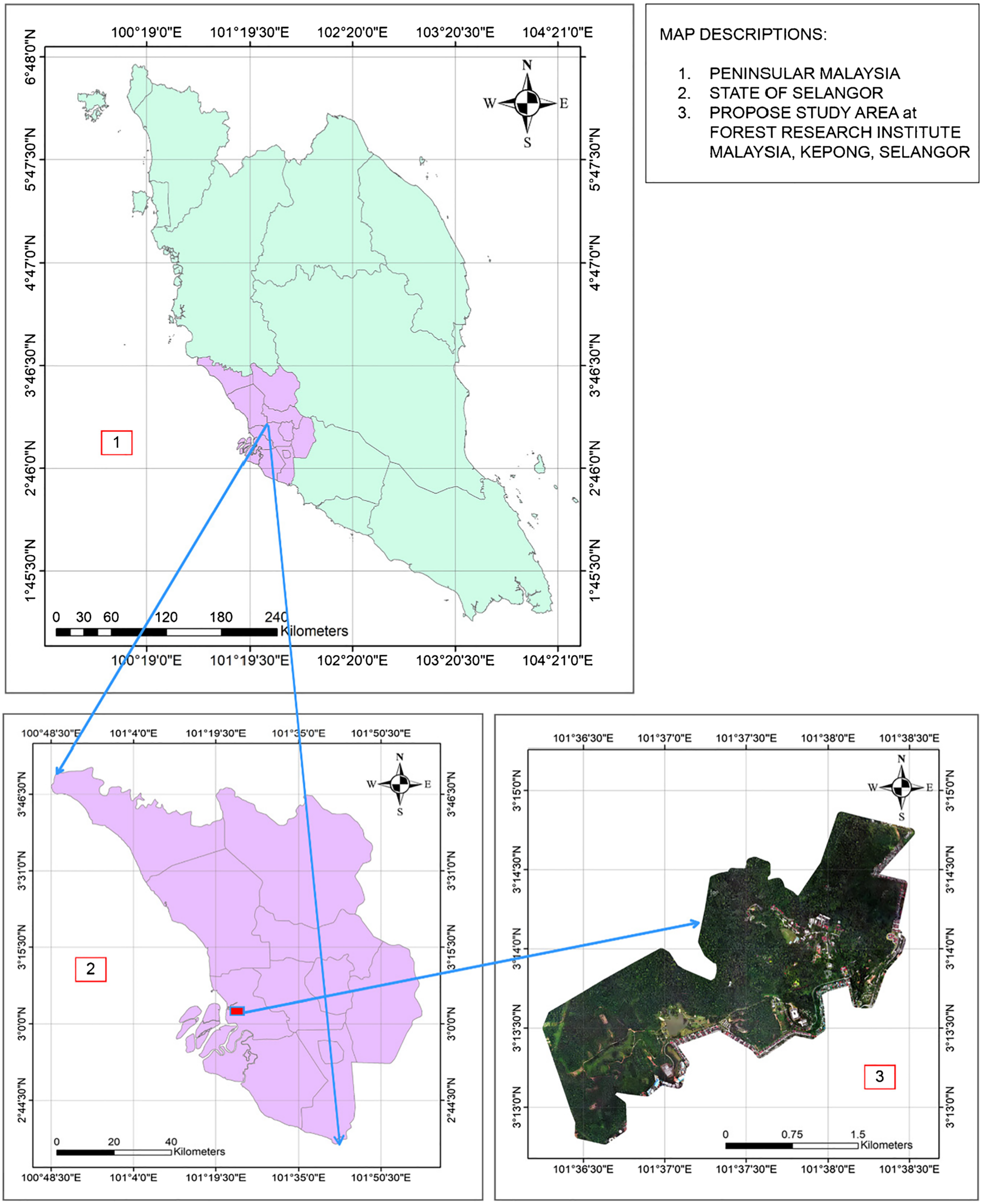

Fig. 1 Study area: Forest Research Institute Malaysia (FRIM), Kepong, Selangor

Trees that formed the canopy top were easily identified on satellite images for future processing. Furthermore, various trees species and their status were collected even though this research focused on endangered and critically endangered

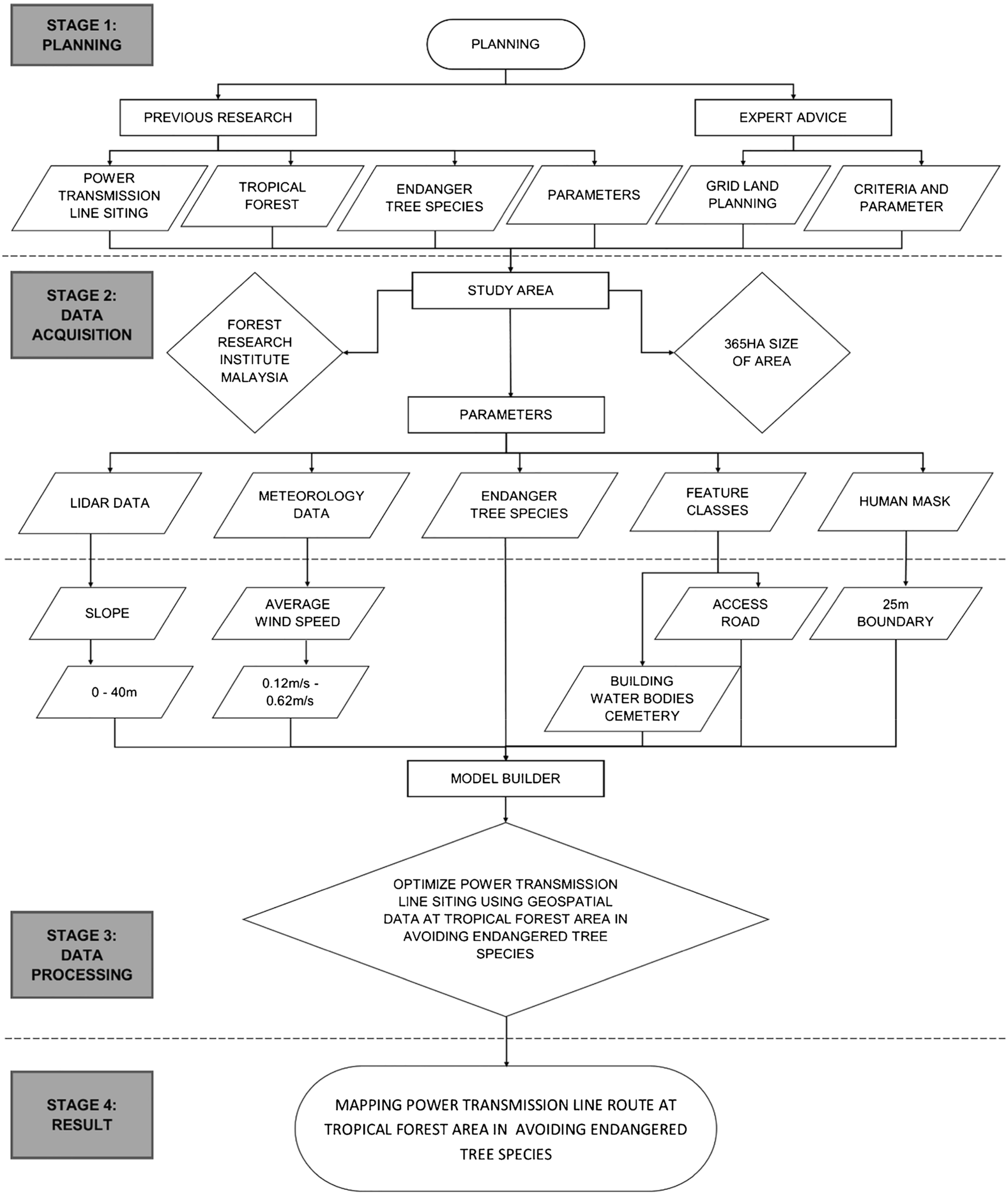

Fig. 2 Methodological flowchart for optimization of transmission line siting

species due to variations in data collection. The data will be filtered to obtain the desired tree classification for data processing.

Tree positions were measured using an open traverse method by referring to the base station with known coordinates that have been established in a nearby location. Static Global Positioning

System (GPS) was utilized in measuring coordinate for a base station with 2 h observation and tied with 3 nearest core stations: BENT, MERU, and UPMS. The open traverse was conducted to create a control network covering the sample study area and positioning measurement, consisting of 35 subplots (25 m × 25 m) and 48 network stations.

LiDAR and WorldView-2 image processing

The data used for this research were LiDAR point cloud, orthophoto image, meteorology data, and WorldView-2 satellite images with different datum and projection references. Since this research used GDM2000 datum references, datum transformation was required. LiDAR point cloud and orthophoto were referenced to Geocentric Kertau MRSO, while meteorology and WorldView-2 satellite images datum referenced to Geocentric WGS 1984. The transformation was carried out using projection and coordinate system tools available in ArcGIS software for all 3 images except for meteorology data due to the format difference. Upon the completion of changing the datum reference, a subset image of the research study area (365 ha) of the FRIM forest was produced.

Slope

The slope was one of the research parameters obtained using LiDAR point cloud data processing. The geometry of X, Y, and Z values was calculated using the LAS dataset. Then, the LAS dataset was converted to a raster to produce DEM that can develop slope data. The layers present were selected according to the DEM required. Layer properties of the LAS dataset consisted of filter tabs specifying information regarding classification codes and returns in the filtered LiDAR data. Meanwhile, classification codes used ground, while the return selected for all to create DEM. Therefore, all the signals returned from the ground to the LiDAR sensors were used in the data processing.

Interpolation to determine the cell values for the output raster can be procured via the binning or triangulation method. In this study, the binning interpolation method was applied with an average cell assignment approach using only the average values found in the pointed pixel. Meanwhile, the linear void fill function was utilized to allow linear triangulation on the triangulated value to determine cell values. Besides, the float data type was used to produce raster output with floating points. Apart from that, the cell size sampling type was used to define the cell size of the output raster.

Feature classes

The study area also contained features other than forest areas such as building, road, water bodies, sensitive area, residential area, commercial and industry area, school, and other facilities. Based on the investigation by Eroglu and Aydin (2015), features could be classified into 4 categories: access road, building, water bodies, and a sensitive area involving cemeteries. Orthophoto image was used as a reference for feature digitizing operation using ArcGIS software. The digitizing operation used the editor tool to trace the orthophoto image feature into a vector data type. All the features used polygon type except access road, where line type was selected to present a more realistic feature shape.

Average wind speed

The average wind speed data were obtained from the Department of Meteorology of Selangor, Malaysia, in an excel file detailing the average daily data for the whole year at three (3) stations in Selangor: Sepang Petaling Jaya, and Kepong. Following the pre-processing procedure for average wind speed data that has been transferred into point feature in ArcGIS software, interpolation was carried out in the next step.

Tree species classification

Resume operation with trees segmentation procedure conducted for delineating individual tree crown using eCognition software. The procedure began with a subset desired study area and carried out a convolution filter for removing noise and increasing the distinction to NIR and red band. The segmentation procedure carried out using the WorldView-2 satellite image consists of multi-band for presenting feature ground color band. The segmentation algorithm applied in this processing was a multiresolution segmentation useful for satellite image. The segmentation file was created using algorithm execute child processes with domain execute. Later, insert child for segmentation operation with algorithm multiresolution segmentation and domain pixel level. The image layer weights were change with 1 for the red band layer while 4 for the NIR band layer for the band to be more influential in the segmentation process. The composition of the homogeneity criterion for the shape set with 0.8 and the compactness to 0.5 for this segmentation of tree operation with scale parameter 25. Each feature has its own segmentation included the shadow on images. This segmentation helps in tree species classification processing. The normalized difference vegetation index (NDVI) algorithm conducted with the Eq. 1 for classified vegetation and non-vegetation area.

$$([Mean\ NIR] - [Mean\ Red])/[Mean\ NIR] + [Mean\ Red] \tag{1}$$

Tree species found within the study area about 45 different species with ten (10) species publish to be endangered species by IUCN Red List (Chua et al. 2008), based on NDVI processing, merging segmented image for merged vegetation and non-vegetation area. Based on area classification, species classification could be conducted by the focus on vegetation area only. The main purpose of the segmentation process is to create a segmentation of trees crown individually by referred to the WorldView-2 satellite image. However, the image shows only the crown visible from the top. This means the tree located below neighbored trees with a wide crown which invisible from the top view will not be segmented. Therefore, to solve these issues, refining the segmentation procedure applied for separating individual trees based on their crown size and shape (Hashim et al. 2019). The morphology was created and insert child for processing of refining tree segmentation. In this operation, the watershed transformation algorithm used and the image object level as input for image object level. The length factor must be the largest size of tree crowns available in this study area. Execute the processing for separating tree crowns. The processing was beginning with creating species classes at the class hierarchy window. Species was assigned classes according to individual species and combined species within the same family into the same group of class. The classes of species were assigned to segmentation by append new and assigned name of the process according to species class such as *Shorea leprosula*. Inside *Shorea leprosula* class, insert child with assign class as process algorithm, and image object level for image object domain. In the threshold condition parameter, editing by changing the setting for feature brightness values to be specified for certain feature class to be assigning species classes to image segmentation. Merge region algorithm was applied in creating species family classes such as the *Dipterocarpaceae* family. The purpose of the merge region procedure to merge all tree species classes within the same family within the same group family class. The process much faster and organized compared to classes only based on tree species. The rule set more systematic with this algorithm and easier for the detection of tree species for analysis purposes by focusing on species family classes and summary which family species available more in the study area. For this research, only endangered species classes were extracted and applied in optimize the power transmission line route as a research parameter.

Model Builder

All the research parameters were transferred into a model builder with feature classes in the vector layer, including Inverse Distance Weighting (IDW) average wind speed, slope, and endangered tree species (refer to Fig. 3). Notably, the raster data type is easier to optimize transmission line location than the vector data type for future processing. Thus, the IDW average wind speed and feature classes were converted into a raster layer.

Then, the reclassify algorithm was used to weigh the multi-criteria decision. All criteria were assigned with 1 and 0 as a new value. The value 1 represented weight for criteria close to the transmission line, while 0 indicated the weight for criteria to be avoided. The criteria with value 1 were access road, terrain slope of less than 40°, and area with average wind speed less than 0.5 m/s. Meanwhile, criteria labels with 0 value were building, sensitive area, water bodies, endangered and critically endangered tree species, terrain slope of more than 40°, and areas with average wind speed exceeding 0.5 m/s.

Results

It is important to know and understand procedures and guidelines being used in power transmission line siting in Malaysia before future action was taken. Transmission division was a second division after generating division and before distribution division. Transmission division consists of land planning which is responsible for optimizing route development of transmission lines for new development. Land planning will determine the selected location for a new tower in developing routes by gazette the area and apply it to the land authority. Land acquisition is responsible for gazette, the proposed route area to land authority, and discusses with a purpose to obtain the gazette area for transmission line routing development. Constructor was responsible for developing the idea of transmission line routing such as build and setup tower on the proposed area for the final touch. Maintenance was responsible for maintaining transmission tower and route for security and safety purposes such as trim or clean any trees or features that may touch the power cable for a certain duration by following to their schedule.

Optimizing power transmission line siting was handling by land planning unit. Before optimizing the route, the voltage to be carried needs to be identified for a future procedure. Power voltage under the grid land planning unit available in three sizes is voltage with 500 kV, 275 kV, and 132 kV. The other voltage less than 132 kV such as 32 kV was used and handled by the distribution unit for supply to their end-user. The power station was available in each state in Malaysia, however the number of towers depending on demand from the end-user.

According to the utility expert, new technologies and innovations were applied in transmission line routing. The current technologies were applied in transmission line routing purposes such as involvement of unmanned aerial vehicle (UAV) flight along the alignment for feature detection procedure and ArcGIS software used in the analysis procedure, while engineers units applied TLS-CNDB software to optimize the number of towers needs to propose new route

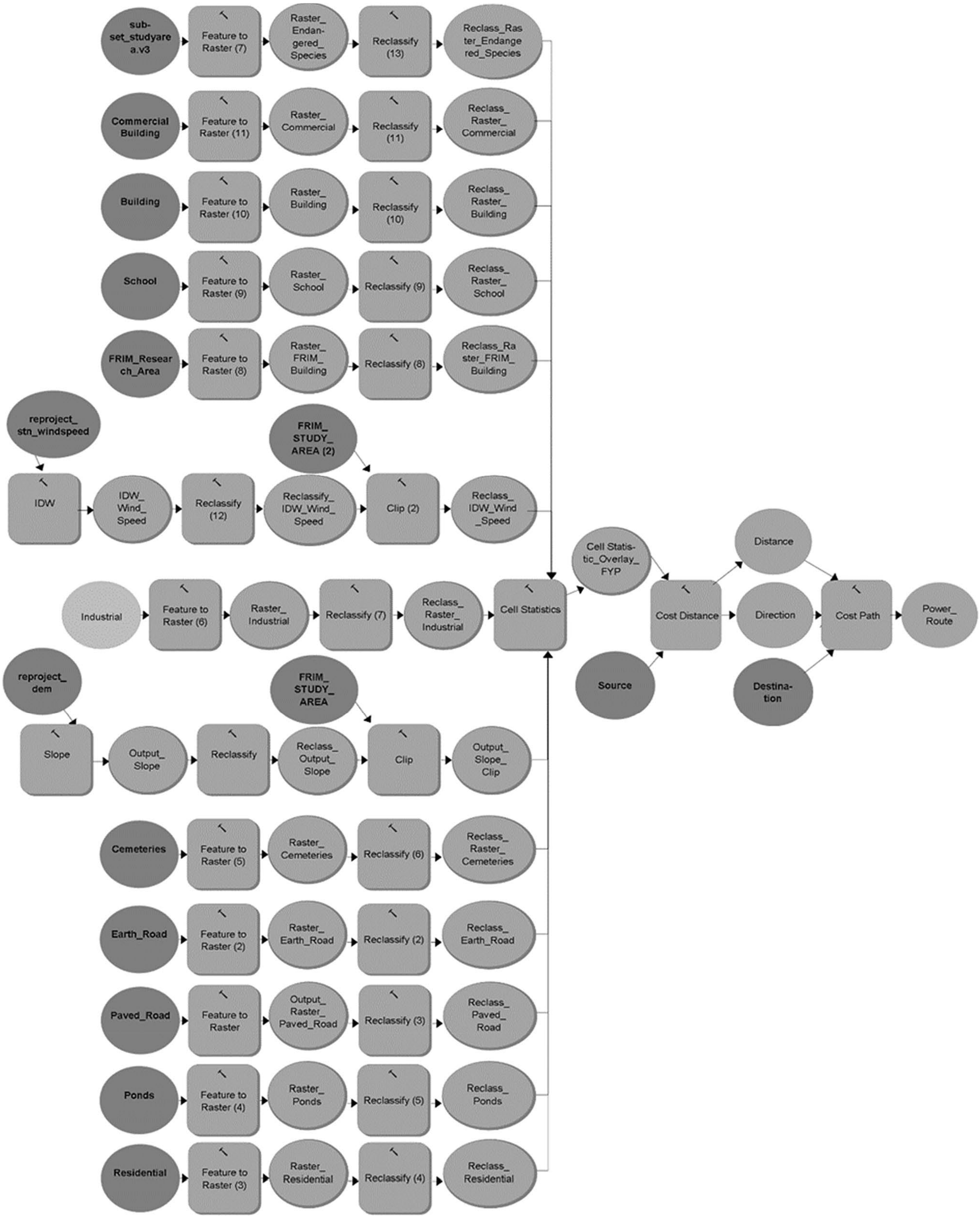

Fig. 3 Overall ArcGIS modeler for optimizing power line transmission

Table 1 Endangered and critically endangered tree species based on IUCN Red List

Species	Status (tear)	Tree(s)
Aquilaria malaccensis	Critically endangered (2018)	4
Shorea bracteolata	Endangered (2017)	19
Shorea sumatrana	Endangered (2017)	2
Neobalanocarpus heimii	Endangered (2017)	3
Hopea helferi	Endangered (2017)	3
Dipterocarpus hasseltii	Endangered (2017)	2
Dipterocarpus kerrii	Endangered (2017)	1

development. Besides, innovation in power tower design improved a normal lattice power tower to a monopole power tower. However, the monopole power tower has the same buffer area according to their voltage which only establishes in urban areas or sensitive areas and complicated for maintenance purposes compared to the lattice power tower type.

The procedure being applied is carried out as a premium study to identify the issues, causes, and effects faced by these endangered species. Data acquisition was carried out and analyzes the data using desktop analysis such as ArcGIS and portal. Aerial mapping procedure was applied for topography mapping at the selected area with current condition and features. Route finalization was produced after conclusion and analysis were made by concern about parameters. The report was submitted to land authority or urban and rural planning department for application and approval for land acquisition for power line routing purposes. The Right-Of-Way for transmission line by referred to guideline used by utility industry found out 60 m Right-Of-Way was the most suitable size for this research area. In utility industry, parameters for line siting at the forest with endangered species still ongoing discussion and research to solve extinct species issues and protection alternatives.

Tree inventory

The tree inventory survey identified 24 families within the sample study area. Most trees belonged to the *Dipterocarpaceae* family (185) due to the forest conditions, which were primarily covered with the *Dipterocarpaceae* family and some non-*Dipterocarpaceae* families (Table 1). Besides, tree conditions and situations were recorded under a remark column for identified any dead tree or tree with an overlapping branch with neighbors.

Slope

The higher slope values indicated a steeper terrain surface, while the lower slope value represented a flat terrain surface. The slope of the terrain surface at the proposed study area where steeper terrain surface was to be avoided because of the higher cost incurred for the cut-and-fill procedure or less avoided the area to develop the transmission line. However, a steeper terrain surface could be selected for the power transmission line route in areas without an established tower. Nonetheless, the flatter the terrain surface, the better condition with less cost and lower risk for transmission line development.

Slope ranges were classified into 6, which is <10°, 10–20°, 20–30°, 30–40°, 40–50°, 50–60°, and >60° (Eroglu and Aydin 2015). Based on the mapping done in the FRIM study area, the slopes ranged from 0 to 40° in most areas, while only a small area comprised slopes exceeding 41°. Therefore, the selected study area is suitable to be used for the power transmission line route. According to Eroglu and Aydin (2015), a terrain slope less than 40° is suitable for optimum power transmission line siting at tropical forest area since the cut-and-fill cost could be avoided entirely. Moreover, the optimized site could pass through any route within the forest area. Besides, the potential location for developing a power tower can be accessible at any location without concerns about the ground position since most of the study area has a flat surface.

Average wind speed

The average wind speed data were obtained from three (3) stations in Sepang, Petaling Jaya, and Kepong for research analysis (Fig. 4). Even though the study area is located at Kepong, data from other stations were collected for analysis purposes. Based on a study by Mo et al. (2017), the average wind speed limit is 0.5 m/s for power lines. Based on the data collected, the average wind speed for Sepang, Petaling Jaya, and Kepong stations ranged from 0.12 to 1.62 m/s, indicating that some areas have higher wind speed than the average limit.

Feature classes

The existing access road consisted of paved and earth roads. Earth roads were mostly found in the FRIM forest area, which is beneficial in power transmission line development. However, the FRIM Research area does not have a residential and commercial building in its vicinity. Consequently, the line route needs to avoid building features to prevent land acquisition and building extermination operations, which involve complex procedures related to land ownership, land transaction, loss reparation, and legal documentation. These operations will increase the cost of power transmission line siting development.

Human mask

This human mask parameter is a ROW for a power transmission line designed based on voltage size and location

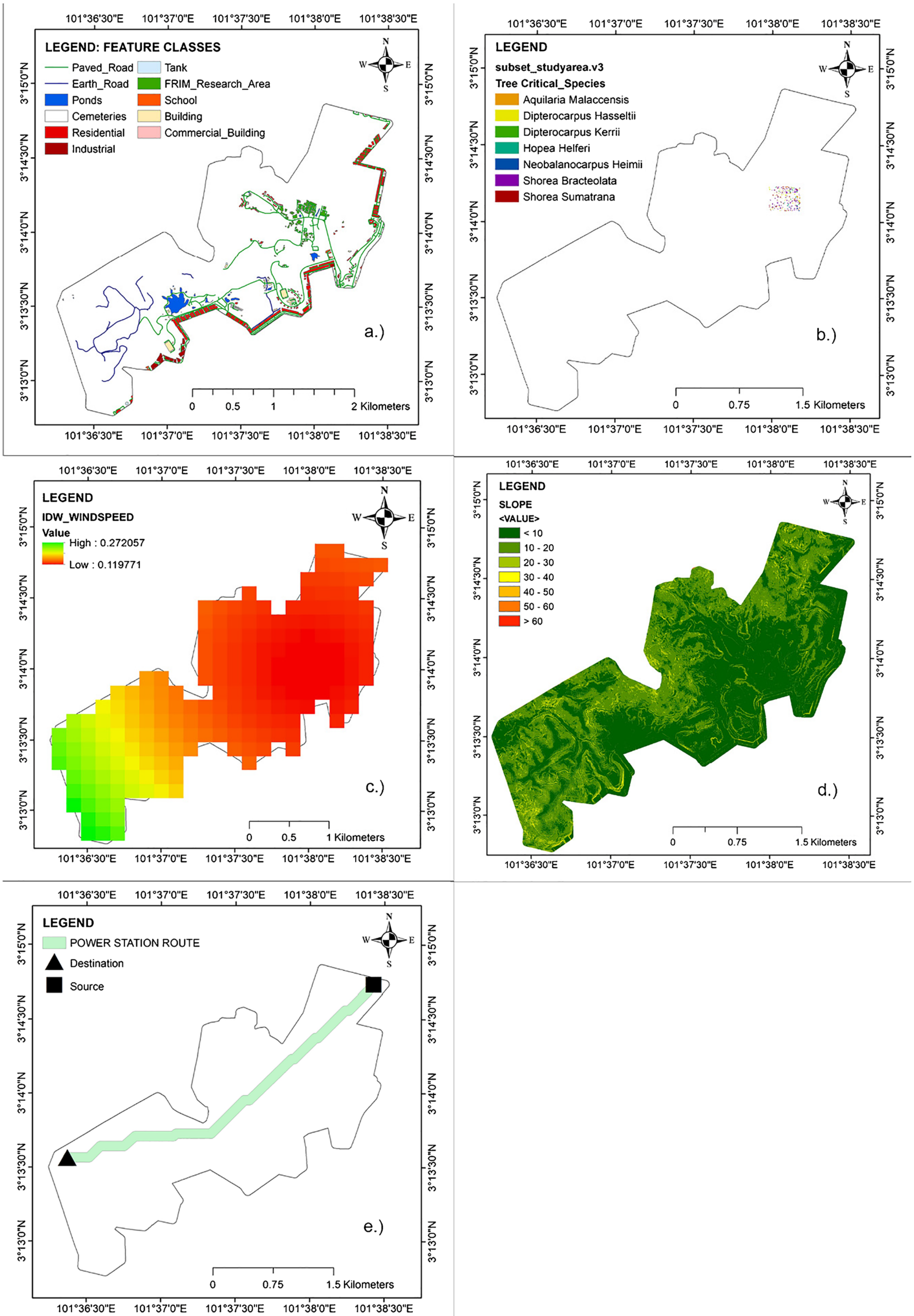

Fig. 4 Overall output result for the analysis: **a** feature class, **b** endangered tree species, **c** average wind speed, **d** slope, and **e** power line route

(Fig. 4). ROW for transmission line varies depending on the voltage size and type of land used for development by the utility company. The proposed voltage size for this power transmission was 132 to 275 kV to be carried through the transmission line in the tropical forest area. Furthermore, the ROW for power transmission line routing was prepared by considering the potential risk and mitigation measures to minimize risks calculated by the utility company. The size of the voltage for the transmission tower consists of 132 kV, 275 kV, and the higher with 500 kV and the size location divided into normal condition site and forest reserve site location. Due to circumstances of the reserve forest, the Right-Of-Way must longer ten (10)m more than the common condition site location.

Endangered tree species

The endangered trees were positioned randomly in the FRIM forest. Two tree species, Aquilaria malaccensis and *Dipterocarpus concavus*, were included in the IUCN Red Lists as critically endangered species, whereas the other 8 species, classified as endangered species, were *Shorea bracteolata*, *Shorea sumatrana*, *Neobalanocarpus heimii*, *Hopea helferi*, *Dipterocarpus hasseltii*, *Dipterocarpus indicus*, *Dipterocarpus kerrii*, and *Dipterocarpus chartaceus* (Chua et al. 2008). The layer for endangered tree species had been added in the Model Builder.

Overlaying parameter

The research parameters in this study consisted of 5 criteria which were feature classes, endangered and critically endangered tree species, average wind speed, slope, and human mask from different datasets (Fig. 4). All the parameter processing to optimize power transmission line siting in the study area was conducted using a model builder platform as shown in Fig. 3. The transmission line siting in a tropical forest area was optimized based on the parameters' weight in this research: (a) represented feature classes, (b) represented endangered and critically endangered tree species, (c) represented average wind speed obtained through IDW interpolation, (d) represented slope acquired from digital elevation model (DEM) of LiDAR dataset, and (e) represented human mask which was ROW of transmission line at forest area.

Power transmission line location

The optimized transmission line route runs across an area with slopes of less than 40° and an average wind speed of less than 0.5 m/s at the flat ground surface. Areas that experienced wind speed exceeding 0.5 m/s were avoided. According to Mo et al. (2017), wind speed at 0.5 m/s or less is suitable for power transmission line establishment to reduce electricity cables' movement in the wind direction. Furthermore, the movement of electricity cables could lead to tripping and outage accidents (Xu et al. 2016).

Transmission line development over forest areas required stricter control and maintenance due to trees near the power tower and electricity cables that may initiate a fire caused by high voltage electricity. Therefore, this research was carried out to identify the environmental condition at the FRIM forest area and research parameters to introduce risk control measures. The line siting in tropical forest areas should avoid endangered tree species, buildings, sensitive areas, and water bodies. In contrast, line siting should be close to the access road available in the study area.

Aside from that, the transmission line was not arranged in a straight line to avoid undesired features along the study area. The critical aspect of optimizing line siting using LCP is to minimize development cost because a shorter path is equivalent to a lower cost. Nevertheless, undesired parameters should be avoided in preventing issues for future development. For example, the current issue regarding the harmful effects of transmission line siting caused endangered tree species population to decrease due to forest clearing operations by the utility industry. Therefore, this research investigated types of endangered tree species at the FRIM forest and identified their respective locations. Fig. 5 exhibits the random pattern of endangered tree species location because FRIM forest was a planted forest. About 8 species were found to be endangered tree species according to IUCN Red List: which are *Shorea bracteolata*, *Shorea sumatrana*, *Neobalanocarpus heimii*, *Hopea helferi*, *Dipterocarpus hasseltii*, *Dipterocarpus indicus*, *Dipterocarpus kerrii*, and *Dipterocarpus chartaceus* belong to were majorly from *Dipterocarpaceae* family.

Discussion

The research was carried out in identifying the criteria needs for protecting endangered species purposes. The types and locations of endangered species need to be identified before the future procedure was carried out for gazette purposes. The area needs to be avoided totally or other alternative needs to figure out before the development of power transmission line siting at forest could be done. Required data such as current topography map, the population of endangered species, and weight of growth were parameters used for routing development in forest.

The experiment provided a new insight into the relationship between several parameters which is average wind speed, critically endangered tree species, human mask, slope aspect, and the feature class to propose the optimization route for locating transmission line. Procedure in

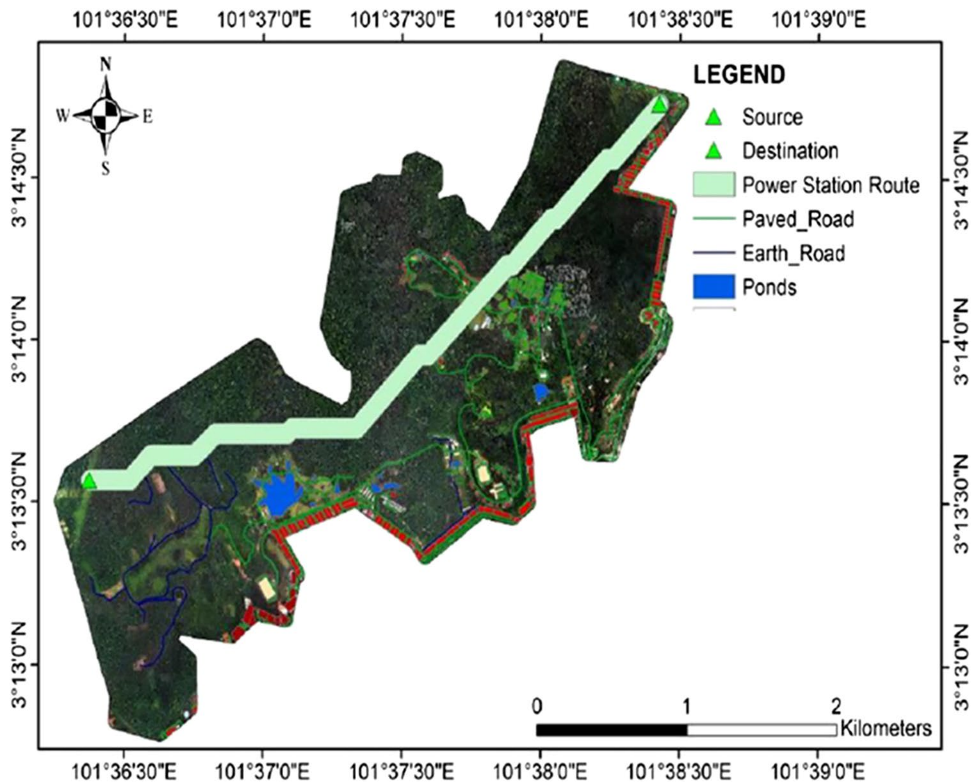

Fig. 5 Optimization line for power transmission line map over study area

identified and classified features laid within the study area make by making a reference to orthophoto images obtained by LiDAR sensors in purpose to get an overall view of features. Based on the investigation, features could be classified into four (4) classes which are access road, building, water bodies, and sensitive area which is cemeteries area. Access road class consists of paved road and earth road features laid within the study area, and building class consists of FRIM research building, school, residential, commercial, and industrial. In addition, human mask was applied to this research which set the voltage size 132 kV or 275 kV, the 20 m for both side in common condition site while 30 m for the reserve forest area.

Overall research had found that feature class parameter that was in the vector layer was through conversion to raster layer. Afterward, all the research parameter dataset through classification operation with a purpose to assign a new value for each data with 1 value represented data to be included inline routing and 0 value for data exclude in line routing. The average wind speed for Kepong station was classified with 1 value which same goes with endangered tree species, while the slope data, 0 to 40°, was assigned as 1 value, while the 41° and above was assigned as 0 value (Eroglu and Aydin 2015). For the feature classes, only the access road features were classified as 1, while the other features such as building, water bodies, and sensitive area were classified as 0 value.

Based on the classify output of all datasets, the cell statistic tool that was developed in processing to overlay all the multi-layer of research parameters within single layers contains all the information of datasets. The cost distance operation was carried out using cell statistics output and source location as the input for distance and direction measurement from the start point location. Optimizing the line route was conducted by developed cost path operation. Cost path operation is a tool used in optimizing line routing based on direction and distance output from start to endpoint.

Conclusion

In summary, this research aimed to overcome issues regarding power transmission line siting at the tropical forest area by considering five (5) research parameters, slope, average wind speed, feature classes, endangered tree species, and human mask. Data processing was carried out using the model builder platform due to the different data formats used in this study, which was critical in optimizing power transmission lines in tropical areas. The final map produced shows the optimized route of power transmission line at the tropical forest in an area where slopes were less than 40°, average wind speed below 0.5 m/s, and avoided endangered tree species.

The endangered tree species were classified using object-based image analysis (OBIA) technique referring to tree inventory data samples of ground survey. We found the endangered tree species majorly from *Dipterocarpaceae*'s family located in random pattern location instead of grouping pattern. May due to the type of FRIM forest was planted forest which the trees manually planted not from growing naturally. Therefore, analysis over the location of the trees was required before optimizing the transmission line. The endangered species located at the study area needs to be avoided in optimize line routing to prevented cleaning operation for the ROW transmission line across the area where the endangered tree species was located. This research was carried out as an alternative in controlling and protecting endangered tree species going extinction due to large-scale trees cleaning for transmission development.

The final map production shows line route of power transmission at tropical forest with slope value less than 40°, average wind speed below than 0.5 m/s, and avoided endangered tree species. Besides, the route also avoided building, sensitive areas, and water bodies while close by to existing access road. The ROW with 60 m was required by rules and regulation from utility company in developing power transmission line at forest area. The search parameters applied consist of five (5) data for weighting in optimize power transmission line siting. According to Eroglu and Aydin (2015), multicriteria decision making (MCDMs) were the most preferred method in optimize line siting. The greater number of parameters involved as weighting, the more accurate result for line siting optimize could be gained. The environmental aspect should be concerned as the transmission line carried and transfer high voltage that produces a frequency effect on the environment and living things health.

The model builder was conducted using similar dataset within the selected study area without future evaluation due to time constraints. The evaluation should be carried out to investigate the performance of the model builders at different areas with similar forest characteristics such as Lowland *Dipterocarpaceae* using the same parameters dataset. Besides, the application of fuzzy analytical hierarchy process (FAHP) algorithm in decision-making for any problem related to the transmission line could produce results with accuracy assessment analysis in future research (Eroglu and Aydin 2015).

Based on the finding, further research is required to establish the optimization for transmission line also needed to identify more parameter such as adding the cost of the routing path, which considers the shortest path of the route using algorithm, MCDM and LCP analysis (Hemalatha and Valsalal 2012; Monteiro et al. 2005; Schito et al. 2021). In addition, the additional parameter which combines statistical analysis with the selection path for transmission line can produce several alternatives for path selection.

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Declarations

Competing interests The authors declare no competing interests.

References

*Abd Rahman MZ, Abu Bakar MA, Razak KA, Rasib AW, Kanniah KD, Wan Kadir WH, Omar H, Faidi A, Kassim AR, Abd Latif Z (2017) Non-destructive, laser-based individual tree aboveground biomass estimation in a tropical rainforest. Forests 8(3):86. https://doi.org/10.3390/f8030086

*Al-Najjar HAH, Kalantar B, Pradhan B, Saeidi V, Halin AA, Ueda N, Mansor S (2019) Land cover classification from fused DSM and UAV images using convolutional neural networks. Remote Sens 11(12):1461. https://doi.org/10.3390/rs11121461

*Azeez OS, Pradhan B, Jena R (2021) Urban tree classification using discrete-return LiDAR and an object-level local binary pattern algorithm. Geocarto Int 36(16):1785–1803. https://doi.org/10.1080/10106049.2019.1678675

*Blackburn GA, Abd Latif Z, Boyd DS (2014) Forest disturbance and regeneration: a mosaic of discrete gap dynamics and open matrix regimes? J Veg Sci 25(6):1341–1354. https://doi.org/10.1111/jvs.12201

Calders K, Jonckheere I, Nightingale J, Vastaranta M (2020) Remote sensing technology applications in forestry and REDD+. Forests 11(2):10–13. https://doi.org/10.3390/f11020188

Chua LSL, Suhaida M, Hamidah M, Saw LG (2008) Malaysia plant red list. Peninsular Malaysian Dipterocarpaceae. Research Pamphlet 29:230 ISBN 978-967-5221-34-7

Devices IM (2013) Measuring and identifying environmental impacts quantifying potential impacts identifying the duration of potential impacts. Public Service Commission of Wisconsin, pp 1–32. https://psc.wi.gov/Documents/Brochures/EnviromentalImpactsTL.pdf

Eroglu H, Aydin M (2015) Optimization of electrical power transmission lines' routing using AHP, fuzzy AHP, and GIS. Turk J Electr Eng Comput Sci 23(5):1418–1430. https://doi.org/10.3906/elk-1211-59

*Hashim H, Abd Latif Z, Adnan NA (2019) Land use land cover analysis with pixel-based classification approach. Indones J Electr Eng Comput Sci 16(3):1327–1333

Hemalatha S, Valsalal P (2012) Identification of optimal path in power system network using bellman ford algorithm. Model Simul Eng 2012

Li X, Lin Y (2019) Do high-voltage power transmission lines affect forest landscape and vegetation growth: Evidence from a case for southeastern of China. Forests 10(2):1–13. https://doi.org/10.3390/f10020162

Matikainen L, Lehtomäki M, Ahokas E, Hyyppä J, Karjalainen M, Jaakkola A, Kukko A, Heinonen T (2016) Remote sensing methods for power line corridor surveys. ISPRS J Photogramm Remote Sens 119:10–31. https://doi.org/10.1016/j.isprsjprs.2016.04.011

Mo Y, Zhou X, Wang Y, Liang L (2017) Study on operating status of overhead transmission lines based on wind speed variation. Progress In Electromagnetics Research M 60(September):111–120. https://doi.org/10.2528/PIERM17072605

Mohd Zaki NA, Abd Latif Z (2017) Carbon sinks and tropical forest biomass estimation: a review on role of remote sensing in aboveground-biomass modelling. Geocarto Int 32(7):701–716. https://doi.org/10.1080/10106049.2016.1178814

Mohd Zaki NA, Abd Latif Z, Suratman MN (2018) Modelling aboveground live trees biomass and carbon stock estimation of tropical lowland Dipterocarp forest: integration of field-based and remotely sensed estimates. Int J Remote Sens 39(8):2312–2340. https://doi.org/10.1080/01431161.2017.1421793

Monteiro C, Ramírez-Rosado IJ, Miranda V, Zorzano-Santamaría PJ, GarcíaGarrido E, Fernández-Jiménez LA (2005) GIS spatial analysis applied to electric line routing optimization. IEEE Trans Power Deliv 20(2 I):934–942. https://doi.org/10.1109/TPWRD.2004.839724

*Nordin SA, Abd Latif Z, Omar H (2019) Individual tree crown segmentation in tropical peat swamp forest using airborne hyperspectral data. Geocarto Int 34(11):1218–1236. https://doi.org/10.1080/10106049.2018.1475511

*Rozali S, Abd Latif Z, Adnan NA, Hussin Y, Blackburn GA, Pradhan B (2020) Estimating feature extraction changes of Berkelah Forest, Malaysia from multisensor remote sensing data using and object-based technique. Geocarto Int. https://doi.org/10.1080/10106049.2020.1852610

*Saeidi V, Pradhan B, Idrees MO, Abd Latif Z (2014) Fusion of airborne lidar with multispectral SPOT 5 image for enhancement of feature extraction using Dempster-Shafer theory. IEEE Trans Geosci Remote Sens 52(10):6017–6025. https://doi.org/10.1109/TGRS.2013.2294398

*Sameen MI, Pradhan B, Aziz OS (2018) Classification of very high resolution aerial photos using spectral-spatial convolutional neural networks. J Sensors 2018(7195432):1–12. https://doi.org/10.1155/2018/7195432

*Wassihun AN, Hussin YA, Van Leeuwen LM et al (2019) Effect of forest stand density on the estimation of above ground biomass/carbon stock using airborne and terrestrial LIDAR derived tree parameters in tropical rain forest, Malaysia. Environ Syst Res 8:27. https://doi.org/10.1186/s40068-019-0155-z

Xu K, Zhang X, Chen Z, Wu W, Li T (2016) Risk assessment for wildfire occurrence in high-voltage power line corridors using remote-sensing techniques: a case study in Hubei Province, China. Int J Remote Sens 37(20):4818–4837. https://doi.org/10.1080/01431161.2016.1220032

Zipf M, Kumar S, Scharf H, Zöphel C, Dierstein C, Möst D (2019) Multicriteria high voltage power line routing—an open source GIS-based approach. ISPRS Int J Geo Inf 8(8):316. https://doi.org/10.3390/ijgi8080316