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Site Suitability Analysis for Developing Wind Farms in Pakistan: A GIS-Based Multi-Criteria Modeling Approach

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Abstract: With a global scarcity of the fossil fuel resources and the eventual harm made to nature, a need for shifting to the renewable sources of energy has been given immense prominence. Developing countries, like Pakistan, have also been making a mark on this green evolution in their pursuit of enhancing the national grid capacity and reducing the energy deficit being faced by the country. Considering the case of Wind energy, research has shown a clear disparity in the amount of energy currently being tapped and the existing potential. Bearing in mind the substantial amount of resource investment needed to harness wind energy, meticulous planning becomes obligatory when choosing the potential site for a wind farm. Geographic Information Systems (GIS) have proven to be appropriate for this purpose. A multi-criteria approach modeled on the GIS software has been employed to establish the best-suited sites for wind energy development in Pakistan. Analysis indicated that the coastal areas of Sindh, northern parts of the country, the areas close to Bannu, Mardan, Sawabi, Islamabad and Mianwali as well as central-west of the country, including Sadiqabad in Punjab province and areas nearby Bolan Pass in Baluchistan were desirable for wind farm development. The GIS-based model can act as a guide for regional planners and policymakers in the energy sector for shaping future policies on wind energy and develop the optimum wind energy projects.

Keywords: Site/area suitability analysis, Wind energy, GIS; Multi-criteria, Wind farm, Pakistan.

INTRODUCTION

Pursuance of higher living standards coupled with increasing population pressure has resulted in further depletion of fossil fuels owing to increased consumption of energy. While the increased dependence on the depleting resource for energy demands portrays sustainability challenges, it also turns out to be environmentally demanding in terms of greenhouse gas emissions (IPCC, 2014). In order to counteract the negative insinuation posed by ecologically unwarranted exploitation of fossil fuels, countries around the globe have introduced renewable energy systems as a sustainable alternative to meet the ever increasing energy demands (Aydin *et al*., 2010). Renewable energy may be defined as any form of energy, that is either derived directly or indirectly from sun or from any source that replenishes itself naturally over a period of time (Twidell and Weir, 2015).

Essentially, being one of the most widely available renewable energy sources, wind withholds the potential to solve the issues of precipitous reliance on fossil fuels. It also has the ability to achieve such enterprising objectives with minimum effect on our environment (Panwar *et al*., 2011). The estimates state the perpetual availability of wind energy reserves up to 10 million megawatts (MW) (Herbert *et al*., 2007). Wind energy has become prominent due to its immense reserves and well-nigh nonexistent environmental impact. The advantages of wind energy over fossil fuels evidently outweigh the disadvantages such as bird collisions, noise, visual impact, and electromagnetic interferences. A few advantages such as tenuous production of carbon-based gases during operation and the possibility of local utilization with no requirement of transportation make wind energy the economical and ecological option (Miller and Li, 2014). A significant increase in the yield of wind energy has been recorded owing to technological advancements in wind power design and efficient wind turbines (Herbert *et al*., 2007). This furthers the adoption of wind energy as a sensible alternative.

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The process of suitable site selection of these potential wind farms is an imperative phase requiring integration and balancing the opinion of multiple stakeholders involved in the process (Lee *et al*., 2009; San Cristóbal, 2011). Moreover, various factors, particularly, economic, physical and ecological, are linked with the process of site selection, therefore, it is not always practical to consider wind potential as a core indicator when selecting a site (van Haaren and Fthenakis, 2011; Azizi *et al*., 2014). Therefore, in order to integrate the geo-spatial information in the decision-making process to help developers and planners, it is essential to use GIS for installation sites to ensure the economic gains of a wind farm (Siyal *et al*., 2015). GIS has the required functionalities for modeling multi-criteria analysis due to which it has been extensively used to assist in identifying the suitable sites for wind farms. For example, Azizi *et al*. (2014) used analytical network process (ANP) and decision making trial and evaluation laboratory methods (DEMATEL) in GIS environment to find suitable sites for wind farms in Iran. Similarly, GIS-based multi-criteria analysis was used for assessing the geospatial potential for wind farms by Janke (2010) in Colorado, van Haaren and Fthenakis (2011) in New York State, Sliz-Szkliniarz and Vogt (2011) in Poland, Miller and Li (2014) in Nebraska, Latinopoulos and Kechagia (2015) in Greece, and Siyal *et al*. (2015) in Sweden. The indicators used in the study were most common and slightly different depending on the socio-economic, physical and geographical features of the study areas. These studies provide useful insights to shape indicators to be used in developing countries as per their socio-geographical conditions where such studies are limited. In Pakistan, few studies are conducted to find suitable sites for renewable energy sources using multi-criteria analysis particularly when it comes to wind energy.

Pakistan, a developing country in South Asia, is a rich country in resources and its energy sector heavily depends on fossil fuels as a primary and secondary source. According to Ghafoor *et al*. (2016), oil and gas are the major sources of electricity in the country contributing 65% of total energy production, hydropower contribution is 12.5% and only 1% of total energy production is produced from renewable sources. Farooq and Kumar (2013) calculated the potential for renewable energies in Pakistan and indicated estimated solar power potential of 169 GW, biomass 15GW and wind 13GW in 2050.

Despite having such a large potential, Pakistan remained insufficient in energy production when considering the past records and it is now among the 10 countries facing the worst energy crisis (Siddique and Wazir, 2016). It is estimated that electricity is unavailable in rural areas for 16-18 hours and for 10-12 hours in urban areas (Khalil and Zaidi, 2014). The increasing prices of fossil fuels are a major cause of such drastic energy crisis (Ghafoor *et al*., 2016). Considering this scenario, recently, Pakistan has put a lot of efforts in renewable energy resources to deal with its prevailing energy supply deficit.

Besides solar energy, exploiting wind energy has gained much attention to strengthen the national grid capacity as an alternative source of renewable energy. In addition to its environmental benefits, the identification of potential wind reserves along coastal strip and northern Pakistan has augmented the investment in wind farms. The assessments conducted by the US National Renewable Energy Laboratory (NREL) and the US Agency for International Development (USAID) estimate a potential installed wind capacity of 158,000 MW (Elliot, 2011). Presently, the wind power capacity of the country is just 105.9 MW but considering various projects in the pipeline, the capacity is expected to rise to 1,530 MW, which, however, is still significantly lower than its potential capacity (Bhutto *et al*., 2013). This wide gap specifies the existence of huge potential to expand the development of wind energy projects in Pakistan and it is suggested that finding suitable sites are vital to harness the full potential for wind energy (Farooq and Kumar, 2013; Shaheen and Khan, 2016). Majority of studies have focused on a review of wind development (Siddique and Wazir, 2016), assessment of wind energy potential (Ghafoor *et al*., 2016; Farooq and Kumar, 2013) and its evaluation (Shami *et al*. 2016; Ullah *et al*., 2010). Research on the site suitability for wind farming is limited in Pakistan. Therefore, this study utilized the GIS-based multi-criteria modeling approach to identify the land parcels best suitable for wind farming in Pakistan.

METHODOLOGY

There are several indicators which need to be considered for selecting a suitable site for wind farms. Many studies have used different indicators considering their socio-economic, geographic and metrological conditions. This study has utilized the indicators defined by Shaheen and Khan (2016). The step by step process is given below:

Selection of modeling factors

Various criteria and indicators were available. In this study, six criteria were selected to find the most suitable locations for wind farms. These criteria comprised the potential of wind energy, slope/elevation (utilize digital elevation model (DEM)), land use, distance/closeness to transmission lines, distance to the major road network, and exclusionary areas comprising urban areas/towns, waterways, protected areas, airports, and railways. All these were taken as GIS layers for the whole area of Pakistan (Table 1) and were projected into GCS_WGS_1984 to change the structure of data from vector to raster. For modeling purpose, the raster dataset was resampled to common cell size. All the criteria, their justification for selection for analysis, data sources, structures, and feature type is presented in Table 1.

Table 1: Criteria and data description for conducting land suitability of wind farms in Pakistan.

Criteria	Reason for selection	Data source	Original data structure	Feature type
Potential of wind energy	Essential for wind energy production	NREL	Vector	Polygon
Slope/elevation	Influence construction and maintenance	NREL	Vector	Polygon
Land use	Reducing the environmental impact of development on coupled socio-ecological systems	NREL	Vector	Polygon
Distance/closeness to high voltage transmission line	Reductions of cost for transmission of energy to the grid	NREL	Vector	Polyline
Distance to major roads	Ease of access for logistics and construction	Geo-Fabric	Vector	Polyline
Exclusionary areas:				
Urban areas/towns	Reduction in visual and noise impact	NREL	Vector	Polygon
Waterways	To avoid the impacts on water bodies	Geo-Fabric	Vector	Polyline
Protected areas	Conflicting land use areas	Geo-Fabric	Vector	Polygon
Airports	Avoiding areas close to airports	NREL	Vector	Point
Railways	Avoiding areas close to railroads	NREL	Vector	Polyline

Data source: (Geofabrik, 2016; NREL, 2015; Shaheen and Khan, 2016).

Description of tools utilized

The following tools are used in the ArcMap environment to analyze the locational suitability of wind farms:

Geo-referencing: It is used to link the raster map to the spatial location. In this case, the image inputs, such as state map, were utilized to geo-reference.

Euclidean distance: The tool calculates the Euclidean distance to the closest source for each cell and, in this case, it is employed to identify the proximity of already available infrastructure.

Polygon to raster: It converts feature containing polygon, for example, shapefile or coverage, into a raster dataset. This tool was applied to analyze and classify the raster data resulting from vector data.

Buffer: It creates a buffer polygon to a particular distance around input features. No-go and exclusionary areas are defined using this tool in this analysis.

Reclassify: The tool reclassifies the raster with valid statistics and classifies them into defined intervals. In this analysis, it was exploited to evaluate the suitability of the site for all the input raster layers.

Merge: It integrates multiple same types of datasets into a single, new output dataset. It is also employed to merge polygon, line or point feature classes or tables. In order to combine all the input vector data for exclusionary areas, this tool was used.

Erase: This tool enables the user to create a feature class with the polygons of the Erase features by overlaying the input feature. Merged conflict – zone layer was used to erase the state boundaries vector data with the help of this tool.

Weighted overlay: This tool overlays multiple layers of raster data by utilizing a common measurement scale and weights as per the importance of layers. The tool is applied to produce a custom model for evaluating the suitability of the site.

Extract by mask: The tool extracts the raster cells that relate to the areas defined by a mask. This tool was applied to generate a final site suitability layer free from exclusionary parameters.

Modeling process

The available data (Table 1) was converted and reclassified for the selected criteria. Raster data structures with a resolution equivalent to the common cell size based on minimum cell size were obtained from all the essential data layers. A cell size of (X, Y) (6100, 6100) has been used for each raster file in the GIS ArcMap suitability model builder.

Based on the literature a rating scheme is developed (Miller and Li, 2014). The raster datasets are reclassified into the suitability ratings of 1-5, with 1 as the unsuitable and 5 being the most suitable. The reclassification of wind energy potential in 5 categories is done considering the wind power density at a 50m height from the surface (W/m^2). According to Elliot (2011), the wind power density of more than 645 W/m^2 is considered as most suitable, particularly in Pakistan (Fig. 1A).

In order to analyze the area based on elevation and slope, DEM was divided into 5 categories. The area having elevation less than 105 is considered most appropriate for the wind farms (Fig. 1B). Moreover, on the value scale, various land uses, like urban and built-up areas, are put as “restricted” and only barren, grassland and cropland are assigned with values for most suitable locations (Fig. 1C). Higher values are assigned to those sites which have higher proximity to major road networks, and high voltage transmission lines. The proximity parameters are taken as 20 kilometers for transmissions line and 10 kilometers for road networks and beyond these parameters (Miller and Li, 2014), the sites are considered as unsuitable (Fig. 1D and E).

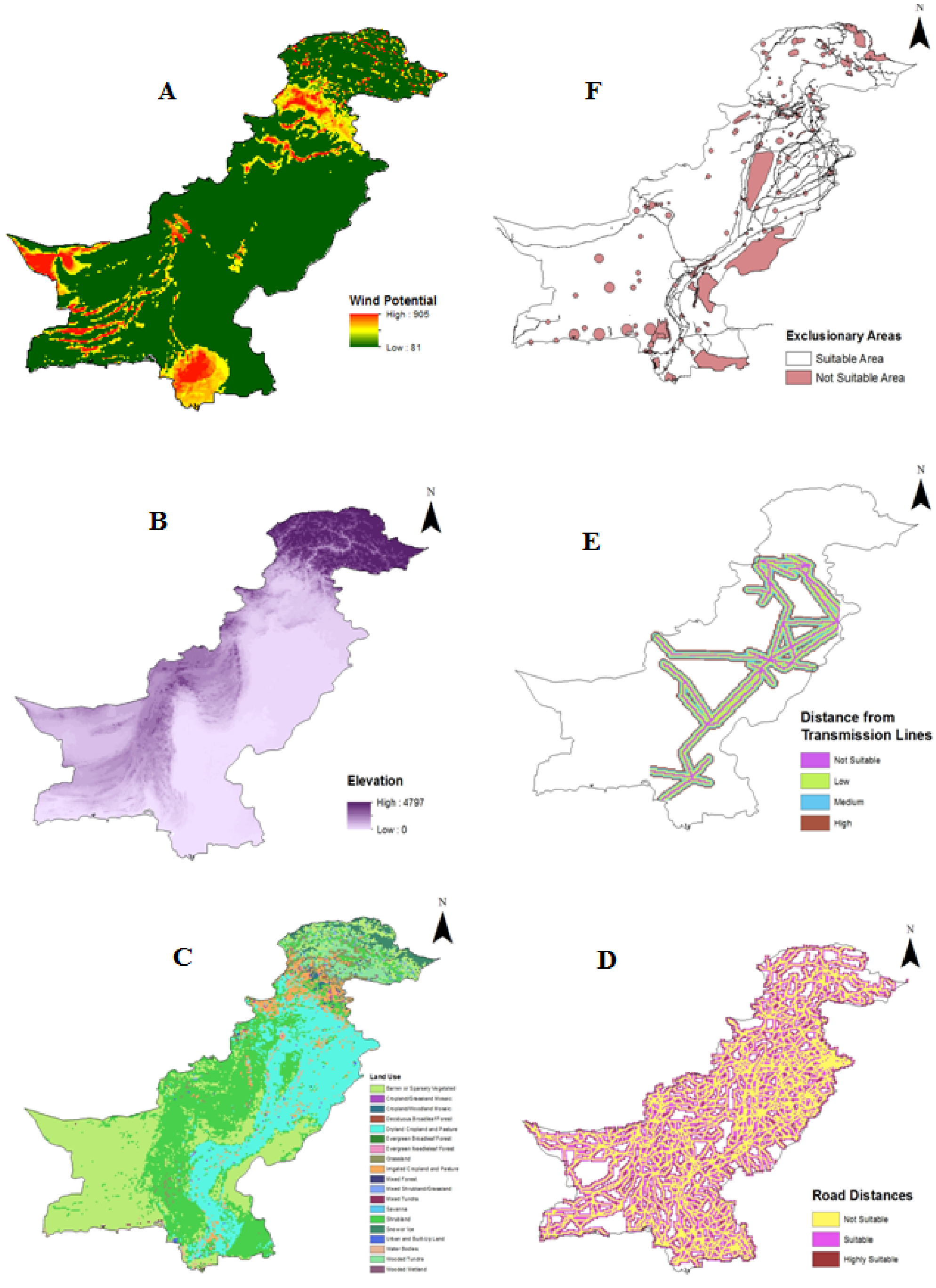

Fig. 1: Re-classification for land suitability criteria.

The weights are allocated to each layer in order to indicate the relative significance of individual modeling criteria mentioned in Table 1. Published literature guided the scales of weights, i.e., 5 to 1, with 5, indicating the most appropriate criteria for the location, while 1 shows the least. The potential for wind energy is given predilection since it is imperative in locating the suitable sites for wind farming as depicted in Table 2. The second important is the slope, followed by land use, transmission lines and distance to the existing road network. Areas with high population density are considered unsuitable for the development of wind farms and are given a scale of 'No Data'.

Table 2: Criteria with assigned weights.

Criteria	Weights %
Wind energy potential	40
Slope	20
Land Use	10
Distance to transmission lines	10
Distance to the major road network	10

Buffer analysis was carried out to create buffers for exclusionary areas with environmentally sensitive areas (e.g., forests, rivers, national parks, etc.) and areas with human interference, such as physical infrastructure facilities, e.g., airports, railroads, dams, military establishments, etc. (Fig. 1F). The buffer distance is taken from the literature and is presented in Table 3.

Table 3: Buffer distances for land uses.

Exclusionary area	Buffer (m)
Protected areas	300
Waterways	50
Airports	10,000
Railways	100

Source: (Miller and Li, 2014; van Haaren and Fthenakis, 2011).

The buffer distances are excluded from geospatial layers and various reclassified geospatial raster data layers were merged to calculate the final suitable score of the study, using the "Weighted Overlay" tool. The suitability score is classified into 5 classes as high, medium, low, very low and not suitable.

RESULTS AND DISCUSSION

The final map of suitable locations for wind farming in Pakistan is demonstrated in Fig. 2. The maps indicate 5 different areas as per classification from highly suitable to not suitable. According to the analysis, southern, northern and central-west parts of Pakistan are dominant and most feasible for the development of wind farms to generate energy. It is noticed that the areas in the southern parts of the Sindh province which are modeled as medium and highly suitable for this analysis, already have a few numbers of windmills for power generation.

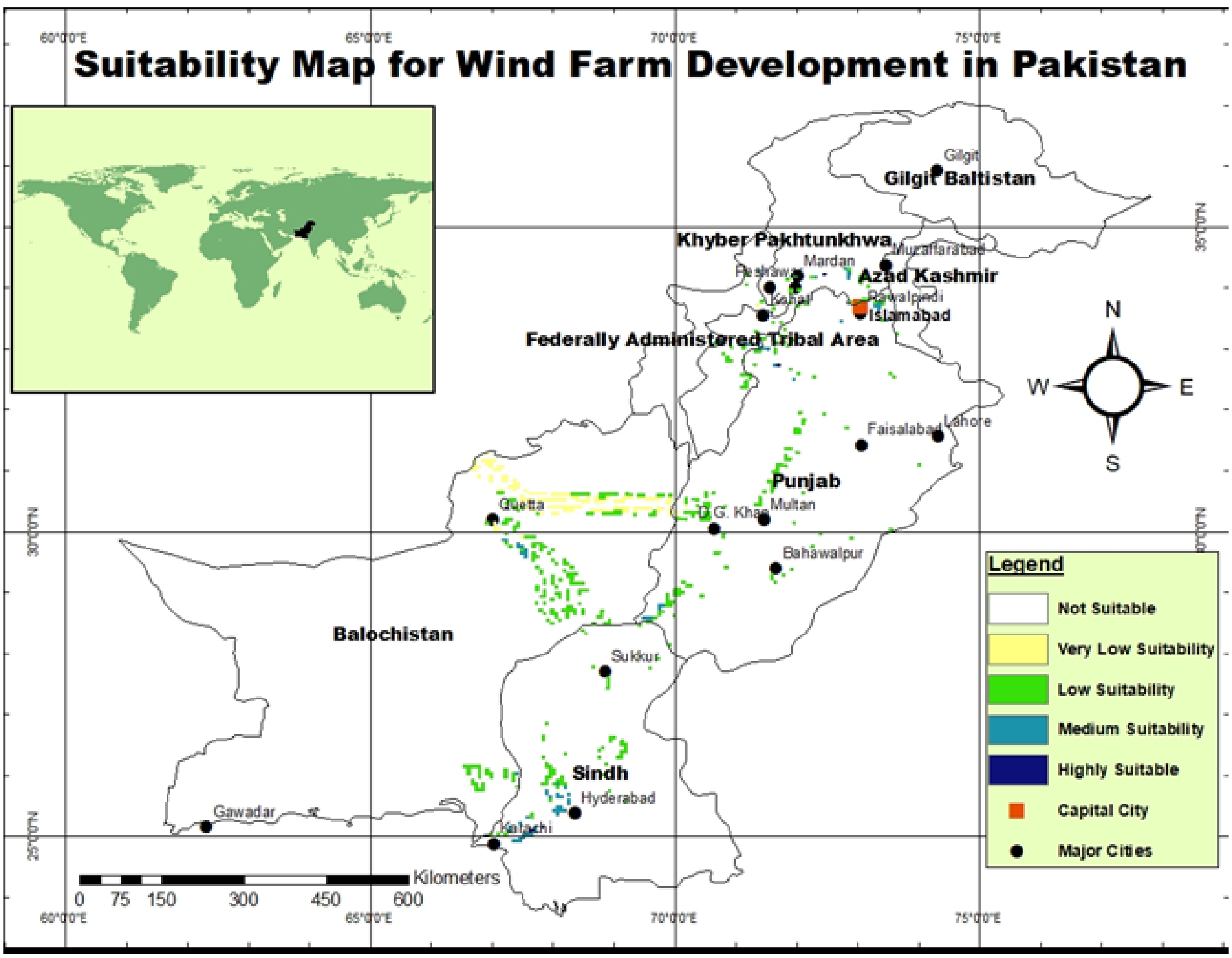

Fig. 2: Final site suitability map for wind energy development.

The final suitability map suggests the multiple sites with high suitability score which signifies the extensive potential for developing windmill projects in such resource cantered and logistically feasible regions. In the northern parts of the country, the areas close to Bannu, Mardan, Sawabi, Islamabad, and Mianwali, are the most appropriate ones for the wind farm development. Areas in the central-west side of the country include Sadiqabad in Punjab province, whereas Sibi and areas, nearby Bolan Pass in Baluchistan, are desirable for wind farm development. Moreover, it is noticed that Punjab province has a high density of physical infrastructure like road network (Kedir *et al*., 2016), but still, it is the least suitable province for wind energy development. This suggested that physical infrastructure cannot be the only prime factor rather various topographical and climatic factor can make wind power projects more feasible and economical. In order to gauge the reliability of the model, it was tested whether the current wind power projects are falling in the high suitability ranking zones of this model or not. Presently, development of wind power projects is concentrated in southern Pakistan at Keti Bandar, Jhimpir, and Gharo in Sindh province (Elliot, 2011). These locations fairly overlap with the sites determined in this model with high suitability. In this context, this model is valid and results acquired can provide the directions for future development of wind farm in Pakistan. For example, the specific selection of the site according to the required area for farm development can be easily made, using further analysis in GIS. Furthermore, the model can act as a guide for regional planners and policy-makers in the energy sector for shaping future policies on wind energy and develop the optimum wind energy projects.

CONCLUSION AND RECOMMENDATIONS

Wind energy, despite its momentous initial investment and planning, is one of the most viable forms of alternative energy due to its minor operation and maintenance cost coupled with environmental benefits. At present, renewable energy sources only hold the share of 1% in the total energy mix, where wind energy contributes insignificantly despite its large potential in the country. Thus, it is vital for the decision makers to engage and capitalize on the development of wind farms to minimize the vast gap between the actual production of wind energy and its potential. In this regard, GIS is a widely used tool to select the appropriate site concerning various socio-spatial and ecological factors and making the overall project cost-effective. A similar approach was developed that used a multicriteria to find suitable sites for wind farms in Pakistan. The resulted map indicated that the coastal areas of Sindh and central parts of Khyber Pakhtunkhwa province are most suitable for installing wind farms.. The sites found in the final suitability maps were compared with existing wind farms which suggested that the developed multi-criteria model was valid. The analysis presented in this article is done on the national level; however, this methodology may be used in further studies at the local level with more detailed and area-specific criteria and indicators having detailed data, to select individual sites for wind farms. Regarding governance, the government policies and other arrangements in this view should set ambitious energy and climate policy targets by reducing the use of fossil fuels and prioritizing the use of renewable energy sources. Moreover, keeping in view the successful policies of the developing and developed countries, the current national and local policies for wind power developments must be revised to provide a more comprehensive and concrete framework for wind power development in Pakistan.

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