Suitability Modeling of Energy Zones for the Eastern Interconnection*

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Abstract

The Eastern Interconnection States' Planning Council is partnering with three U.S. Department of Energy National Laboratories to develop a web-based tool to help define energy zones suitable for clean energy development in the eastern United States. Using suitability modeling, the raster component of the tool uses resource layers and multiple screening layers (e.g., environmental, land use, and infrastructure) to arrive at an image showing a suitability gradient. Energy planners using this tool have the flexibility of choosing layers to include in the model and assigning their importance. Considerable effort was put into developing environmental screening layers. Development of composite protected lands, habitat, and imperiled species occurrence layers was guided by a diverse team of subject matter experts from federal and state agencies, environmental non-governmental organizations, and industry. This paper presents background about the project, describes the data and modeling process, and presents hypothetical results for various clean energy technologies.

1. Introduction

The Eastern Interconnection States' Planning Council (EISPC) is a collaboration of 39 eastern states, the District of Columbia, the City of New Orleans, and 8 Canadian Provinces located within the Eastern Interconnection electric transmission grid. EISPC partnered with three U.S. Department of Energy (DOE) National Laboratories to conduct a clean energy study that was mandated by DOE's Funding Opportunity Announcement. The goal of the clean energy study was to use a collaborative approach to facilitate coordination and consensus-building around interconnection-wide transmission planning. Argonne National Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National Laboratory supported EISPC's goal by developing a geographic information system (GIS) database of energy resource, screening, and other data layers coupled with a web-based energy zones mapping tool.

The EISPC Energy Zones Mapping Tool (EZMT) allows users to locate areas with high suitability for clean energy generation in the U.S. portion of the Eastern Interconnection. The mapping tool includes nine clean energy resource categories: (1) biomass, (2) coal with carbon sequestration, (3) geothermal, (4) natural gas, (5) nuclear, (6) solar, (7) storage, (8) water, and (9) wind. For each of these categories, energy resource data and information have been compiled, reviewed, and assembled into a GIS database. This tool contains an extensive mapping library, including energy resource, electrical transmission, oil and gas pipelines, protected lands, habitat, and related information. It also includes interactive suitability models, a variety of reports that can be run and customized for user-specified regions, and a searchable policy and incentives database. The EZMT is a multi-criteria decision support system (MCDSS) with a set of operation options to guide the analysis. The analytical process involves a number of steps that may also be customized by the user depending on the type of clean energy resource being analyzed, the area of interest, and other user-specified parameters. EISPC stakeholders can use this tool to identify areas with a high concentration of clean energy resources that could provide significant new power generation from a diverse set of electricity generating technologies. The MCDSS methodology and the EZMT are not intended to provide the means for a detailed siting analysis of any specific clean energy project. Rather, the intention is to enable users to identify clean energy resource areas that could have the potential to be developed as energy zones.

2. Data

The EZMT contains an extensive library of data layers, including energy resource, energy infrastructure, environmental, and other categories of data. Most spatial data on low and no carbon energy sources can be freely obtained from federal agencies; however, universities and private organizations have also made substantial data contributions. In addition, high-quality, purchased commercial mapping data are available and have become a standard for certain technologies.

Some datasets in the EZMT are informational layers the user can view, such as the locations of hospitals, county boundaries, and ferry routes. In addition to informational layers, the mapping tool also contains a catalog of model input layers. These layers can be used as screening layers to determine the overall suitability of the EISPC region for the various clean energy technologies. For example, the enhanced geothermal system (EGS) model uses resource data to determine areas of high resource availability (Figure 2-1) and other screening layers such as distance to transmission lines greater than 220 kV to determine areas that are more economically feasible for development. Some model input layers are composites made from many individual datasets. In the EZMT, environmental screening factors related to energy development were grouped into the following composite model input layers: protected lands, habitat, and imperiled species.

3. Methods

Two main methodologies are discussed in this paper: (1) development of three environmental screening layers and (2) modeling. The unique approach to create three composite environmental layers is discussed in detail in Section 3.1. Section 3.2 explains the methodology for creating the suitability models of 21 clean energy types.

3.1 Environmental Screening Layers

Including environmental screening layers in the EZMT allows environmental factors to be incorporated at the beginning of the planning process to reduce the risk of public opposition, regulatory intervention, and litigation later in the planning or development process. The three environmental screening layers, (protected lands, habitat, and imperiled species) were included in models for all nine clean energy resource types. Each environmental screening layer is a composite made up of several datasets. More than 70 individual datasets were used to develop the habitat screening layer.

An Environmental Focus Group (EFG) was created to determine the appropriate environmental spatial data to include in each composite screening layer. The EFG included subject matter experts from federal and state agencies, environmental non-governmental organizations (NGOs), and industry stakeholders (Table 3-1).

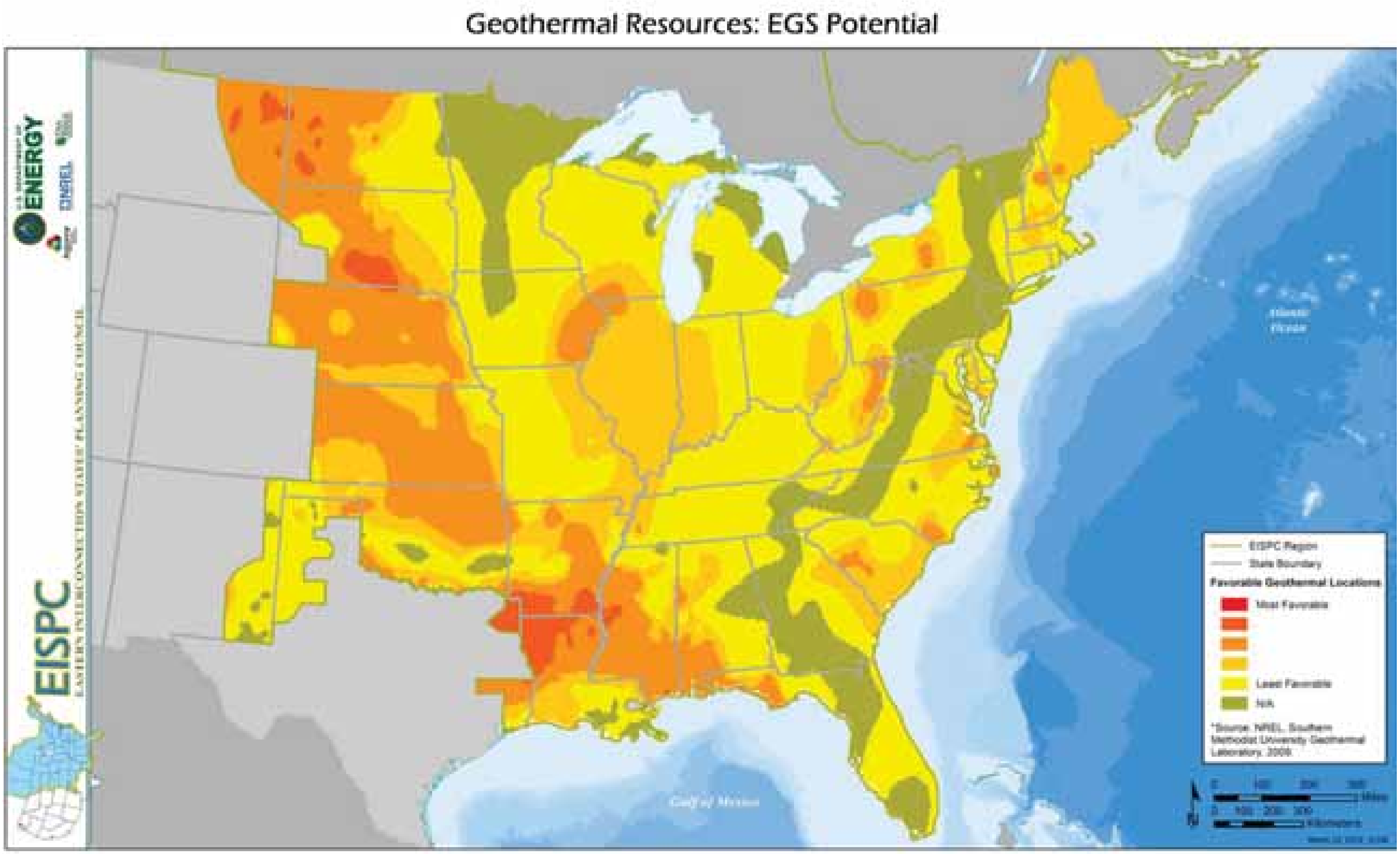

Figure 2-1: Geothermal resource potential for enhanced geothermal systems model.

Table 3-1: Environmental Focus Group Member Organizations.

American Transmission Company
Argonne National Laboratory
Association of Fish and Wildlife Agencies
Bureau of Ocean Energy Management
The Conservation Fund
Defenders of Wildlife
Eastern Interconnection States' Planning Council
Eastern Interstate Planning Council
U.S. Environmental Protection Agency Region 4
Exelon Corporation
Michigan Public Service Commission
National Audubon Society
The Nature Conservancy
NatureServe
New York Independent System Operator
Oak Ridge National Laboratory
Southern Regional Energy and Environmental Office
Western Governors' Association
The Wilderness Society
Xcel Energy

In order to create composite environmental screening layers, a four-tier sensitivity categorization was applied to each dataset. The sensitivity categorization levels for clean energy resource development were defined as:

- Red (exclude from development): Areas where development is already precluded by statute or regulation (federal, state, or local).
- Orange (develop with extreme caution): Areas where development would likely pose a high risk to natural resources but development is not precluded, or where development would likely pose a high risk to important habitat or imperiled species (G1, G2, T1, T2, S1, ESA-E, ESA-T, ESA-C, ESA-P, State-E, and State-T) (abbreviations described in Table 3-2).
- Yellow (develop with caution): Areas where development would likely pose a moderate risk to protected lands (development has not already been precluded) or where development would likely pose a moderate risk to important habitat or imperiled species (G3, T3, ESA-SAT, ESA-SC, and S2).
- Background (likely low conflict area): Areas where development would have the lowest impact on habitat, imperiled species, and protected lands based on the included data. Additional data may provide information to increase the sensitivity in these areas. Further research at the project level would provide a more comprehensive categorization of sensitivity in these areas.

Each sensitivity categorization level was assigned a different default suitability value for the default model runs ranging from 0 (unsuitable) to 100 (most suitable): red = 0, orange = 20, yellow = 40, and background = 95. In the EZMT, the default suitability values can be adjusted. Data creators or managers for each dataset were contacted, asked for feedback about the categorization of their data, and their advice was incorporated. The EFG conducted webinars to discuss data needs as well as the categorization of the individual datasets. Composite screening layers were then created by combining the individual datasets. In cases of overlapping input data, the highest sensitivity level was retained in the composite.

The majority of the datasets included in the habitat and protected lands screening layers were compiled by NatureServe and an NGO caucus of the Eastern Interconnection Planning Collaborative (EIPC) as an initial set of data layers to be considered during the assessment of clean energy zones. The EFG then identified several additional datasets to augment the initial list while attempting to eliminate redundant data. When identifying additional datasets to include in the composite screening layers, the EFG focused on high-quality regional environmental datasets and green infrastructure data. These datasets identify core conservation areas and emphasize connectivity among them at a landscape scale, rather than focusing on species-specific habitat covering small areas. The EZMT is not designed for project siting, thus more detailed information is necessary for that level of analysis. The resulting habitat and protected lands composite screening layers consist of a wide range of state, regional, and national datasets which collectively cover the Eastern Interconnection.

The imperiled species composite screening layer was created by and procured from NatureServe. NatureServe obtained data from state natural heritage programs and created a species-blind dataset. The dataset was categorized according to the four-tier sensitivity levels based on the Element Occurrences of imperiled plant and animal species and their federal and state listing status, as well as their NatureServe conservation status ranks: Global conservation status rank (G-rank), Subnational conservation status rank (S-rank), and Infraspecific taxon status rank (subspecies, varieties, and other designations below the level of the species) (T-rank) (Table 3-2).

Table 3-2: Descriptions of species rankings.

Species Ranking	Description	Species Ranking	Description
G1	Globally critically imperiled species	ESA-P	Proposed species for federal listing
G2	Globally imperiled species	ESA-PDL	Proposed for delisting
G3	Globally vulnerable species	ESA-E	Federally endangered species
T1	Critically imperiled subspecies	ESA-T	Federally threatened species
T2	Imperiled subspecies	ESA-SAT	Federally threatened species due to similarity of appearance
T3	Vulnerable subspecies	ESA-SC	Federal species of concern
S1	State critically imperiled species	ESA-XN	Nonessential experimental population
S2	State imperiled species	State-E	State endangered species
ESA-C	Candidate species for federal listing	State-T	State threatened species

Areas not identified as sensitive to energy development in any of the three composite environmental screening layers are not necessarily low-impact areas but could also represent areas not surveyed during the studies used to create the individual datasets contained in the composite layers. The availability of environmental data varied extensively within the Eastern Interconnection. Several regional datasets that cover the southeastern and northeastern United States were included in the habitat composite screening layer; however, no regional datasets were available for the Midwestern states. Environmental sensitivity to energy development may appear to be greater in the eastern EISPC region than the western EISPC region because of greater data availability. Limitations of the imperiled species layer include showing locations more generally to reduce sensitivity of the layer for improper use, data gaps for some states not wanting to participate, and limitations to available data about imperiled species. Overall, the three environmental layers provide useful screening-level information for energy zone planning, and since the information used to develop them are also available in the tool (as mapping layers and report content), a considerable amount of information is available to users. Site-specific surveys must still be conducted at the project level to ensure avoidance of highly sensitive environments.

3.2 Modeling

The EZMT is capable of running suitability models for 21 types of clean, electrical-energy-generating plant technologies listed in Table 3-3. Each technology has no carbon or reduced carbon output. The three coal technologies listed make use of underground carbon dioxide (CO_2) capture and sequestration. Most of these technologies are largely energy resource-dependent in their siting criteria, including biomass, geothermal, solar, storage, and wind. Several of the technologies are unique in that the energy resource can be transported to the energy zone location, such as coal, natural gas, and nuclear.

Table 3-3: The 21 clean-energy technologies with suitability models in the EZMT.

Resource	Technology	Resource	Technology
Biomass	New facility	Nuclear	Large light-water reactor
Biomass	Co-fired with coal	Nuclear	Small modular reactor
Coal	Fluidized bed	Solar	Concentrating solar power
Coal	Integrated gasification combined cycle	Solar	Utility-scale photovoltaic
Coal	Pulverized coal	Storage	Compressed air energy storage
Geothermal	Enhanced geothermal systems	Water	Marine tidal hydrokinetic
Geothermal	Geopressured	Wind	Land-based wind turbine (100 m)
Natural gas	Combined-cycle gas turbine	Wind	Land-based wind turbine (80 m)
Natural gas	Underground natural gas storage technologies	Wind	Offshore wind turbine (100 m)
Natural gas	Above ground natural gas storage technologies	Wind	Offshore wind turbine (80 m)
Nuclear	High-temperature gas-cooled reactor		

The models listed in Table 3-3 are all created in the same manner. They have an energy resource, a set of screening layers specific to the technology that eliminate or favor certain geographic areas, and the three environmental layers.

3.2.1 Layer Descriptions

Resource layers represent areas that are known to have the specific resource that is needed for the technology. For example, the wind model uses a layer that represents the gross capacity factor (GCF) of a Class II wind turbine at an 80- or 100-m hub height. Generally, these are in the form of vector data; in many cases, this required converting the vector data to raster format to run in the model. Resource layers are always located at the top of a model layer dialog (Figure 3-1).

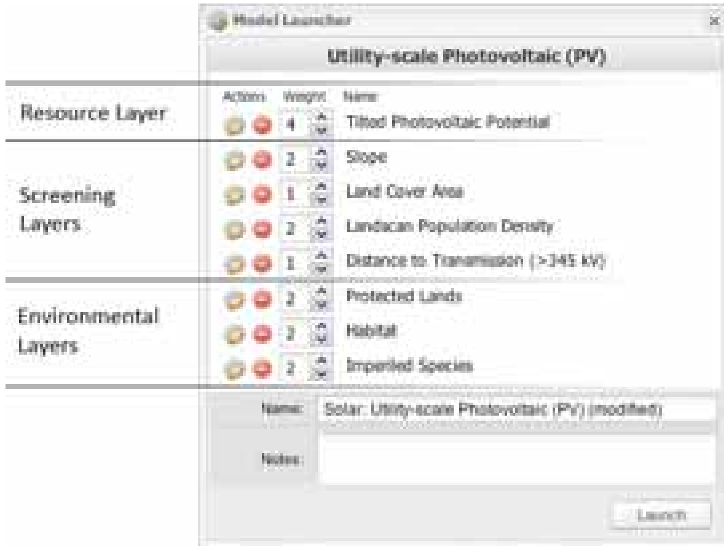

Figure 3-1: Utility-scale photovoltaic model dialog with layer types noted.

Screening layers are layers that either eliminate unfavorable areas for a technology or represent advantageous areas for the technology. Some of these are physical constraints imposed on the technology, or, in some cases, social or political constraints. An example of a screening layer is the slope layer. Most of the models have a slope constraint that typically eliminates areas of high slope.

Section 2.2 details the environmental layers included in each of the models: protected lands, habitat, and imperiled species. They are listed at the end of the model layers dialog (Figure 3-1).

3.2.2 Resource Focus Teams

For each energy resource type, Resource Focus Teams (RFTs) were formed to help identify and obtain suitable data, design models, and provide quality assurance for each model. These groups were composed of subject matter experts in the respective fields from the three National Laboratories that participated in the project: Argonne National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory. After each model was created, it was reviewed by the leader of each RFT. The results of this review are captured in each model's parameters on the website. This provides a set of default criteria on which a user can base a model run. In areas in which users do not agree with the RFT, the models have the flexibility of being adjusted within certain limits.

3.2.3 Single Resource Analysis

To identify areas suitable for the development of a specific clean energy technology, the user can perform a screening process using the EZMT (Figure 3-2). Starting with the energy resource, a user can define which thresholds of the resource are suitable for the technology of interest in order to focus only on areas that satisfy certain economic or technical criteria. Other screening criteria are then applied to

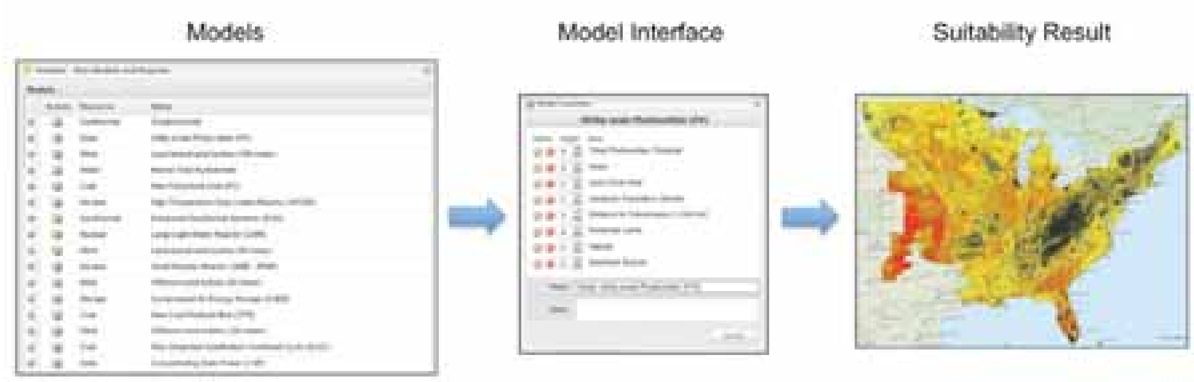

Figure 3-2: Workflow for single-resource analysis.

filter out areas unsuitable for resource development because of engineering constraints, cost, land use, ecological, and other constraints. For example, these types of criteria might exclude areas with high geographical slope, high population density, airports, and protected lands. Model results are computed using a geometric mean calculation based on the layers selected and layer parameters. The map is depicted as a range of high to low suitability to highlight the areas most suitable for developing the selected clean energy resource. A map of energy infrastructure facilities (e.g., transmission grid, pipeline network) can be superimposed on the analysis results to show the proximity of the existing energy infrastructure to areas indicated as high suitability by the model.

Single resource analysis begins with the selection of one of the technologies listed in Table 3-3. For most of these technologies, the system will then display a dialog similar to the one in Figure 3-3 showing the land-based wind turbine (100-m) model. The dialog will default to predetermined resource, screening layers, and suitability levels, but users have the ability to omit existing screening layers, adjust the weights for the layers, or edit the suitability values. For the energy resource, a minimum threshold level can be specified by adjusting the suitability values for the layer.

The interface allows the exclusion criteria for each screening layer to be adjusted. Figure 3-4 shows an example dialog for adjusting the suitability of each resource interval (left) and a non-resource layer (right), which uses categorical intervals. Screening layers can also be entirely removed from a model run by clicking the red “Remove layer” icon.

When the screening layers, weights, and parameters have been set, the user can run the model, which also saves the customizations. These can later be retrieved and adjusted again to run a revised version of the model. The model computes a composite suitability value for each 250-m × 250-m cell in the EISPC region using a geometric mean operation and the specified settings of each model run. The end product is a suitability map with values ranging from 0 to 100. Values of no suitability will occur when one or more input layers have a suitability value of zero defined. Values of 100 represent the highest suitability. For any given technology, the minimal parameters that define the technology as suitable are given a value of 50. The model results are displayed to the user with a gradational color scheme on the map. Model output map results are available as layers in the tool, with the same functionality as any other layer in the mapping interface: zooming in and out, transparency, and retrieving a cell’s value with

Figure 3-3: User interface for land-based wind turbine (100-m) model.

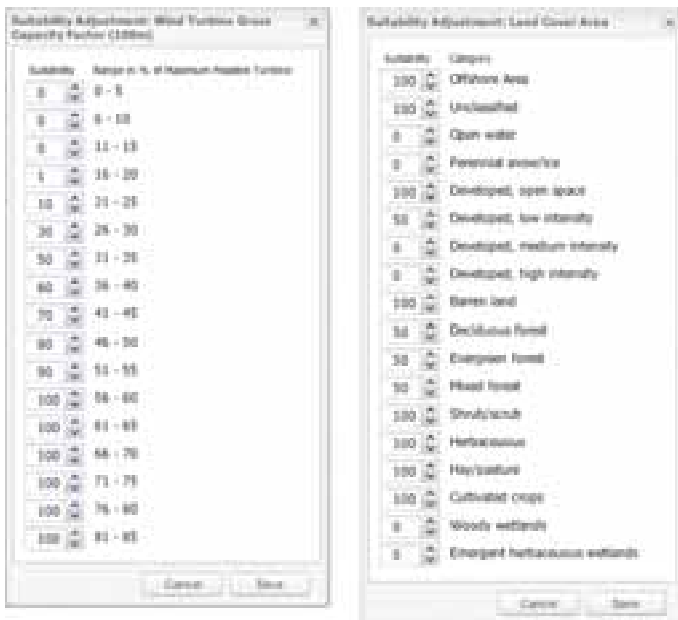

Figure 3-4: Suitability adjustment window for an interval-based resource layer (left) and categorical screening layer (right).

the information tool. Model input layers and any other layer in the EISPC catalog can be superimposed over the model results to examine the contributing factors for high or low-suitability areas, or to look up other contextual information on the feature. Two methods exist for this; adding the actual modeling layer that the model uses from the Model Layer Catalog, or adding the raw data from the Map Layer Catalog.

4. Results

Subject matter experts from three National Laboratories created the parameters that are used as defaults within each model. Consequently, a hypothetical suitability raster can be generated for each technology. This section will briefly investigate one of these results as well as a hypothetical synergy between two of the models.

4.1 Wind

The two options for wind models are land-based and offshore. Each of these models has the option to be run with a wind GCF of a Class II turbine at either an 80- or 100-m hub height. Figure 4-1 shows the suitability results for a land-based, 80-m wind suitability model.

The results presented in Figure 4-1 use all of the default weights and suitability values that are offered on the web tool. The wind model begins with a marginal suitability of 50 at a GCF of 31 to 35 percent. It then ramps up to being 100 percent suitable at 56 to 60 percent GCF and greater.

Screening layers in the model represent slope, land cover area, population density with a 2-mile buffer around areas greater than 500 people per square mile, distance to major roads, distance to airports, and distance to transmission lines. The layers that represent a distance to feature are created using the Euclidean distance to the nearest feature.

The results of the model indicate that areas in the Midwest are most well suited for wind. The GCF for this region is generally higher than that for the southeastern and northeastern United States. The EZMT has a wind turbine tower database layer from Federal Aviation Administration (FAA) data. This provides an overlay on the map that correlates well with higher wind GCP areas and higher suitability from the model.

4.2 Concentrating Solar Power and New Pulverized Coal Synergy

This section describes a hypothetical example of using the EZMT to investigate a zone intended for co-locating concentrating solar power (CSP) and coal technologies. By co-locating these technologies, the CSP plant could preheat water or create steam, which would then be used in the coal plant to generate electricity.

The EZMT can be used to help identify regions where this technology may be feasible to implement. In this example, a new pulverized coal (PC) with carbon capture and sequestration technology is considered, coupled with a CSP plant located on site. The PC model uses a layer that represents the proximity to geologic formations that are considered suitable to store CO_2. This unique coupling of technologies results in a low-carbon-emission power plant. Bedded salt, domal salt, and aquifer regions are potential geologic formations for CO_2 storage.

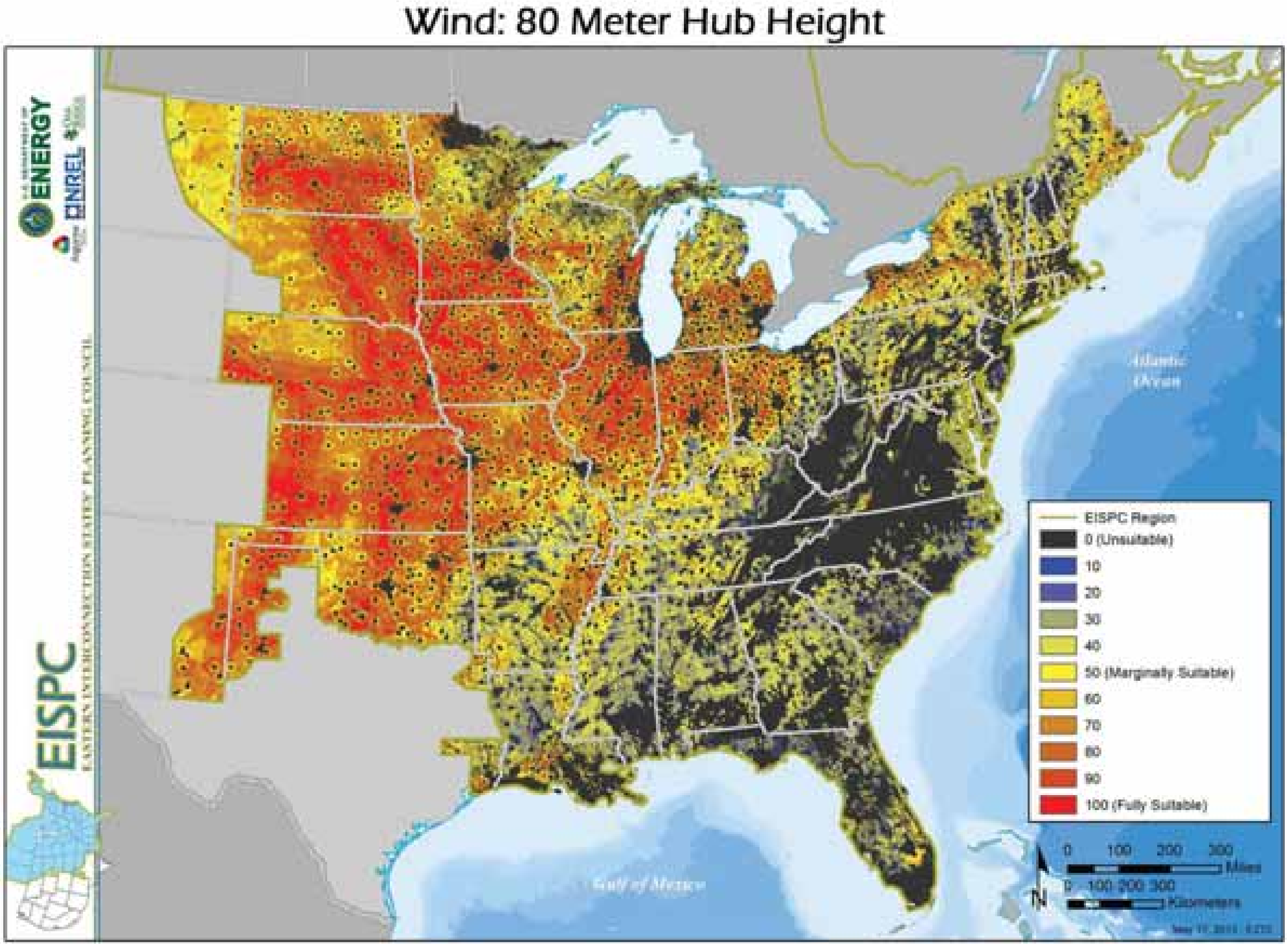

Figure 4-1: Example land-based 80-m hub-height wind suitability result.

First, a model representing the PC technology is run. The user has a choice between accepting the model's default configuration, which is based on guidance by technology experts led by Oak Ridge National Laboratory, or modifying the weighting and suitability scheme in the tool. In this example, the default configuration will suffice. The results of this model show that the highest suitability areas are near Indiana, eastern Kansas, eastern Arkansas, and eastern Ohio, primarily because of the saline aquifer layer representing opportunities for CO_2 to be stored.

Running the CSP model indicates that the southwestern part of the Eastern Interconnection is most highly suited to this technology. In this region, insolation values are the highest, which is the most important siting factor in the model. Other factors aid in screening out areas where water availability, steep slopes, or other constraints do not allow for the development of this technology.

The results of the two models will eventually be able to be run through a function of the tool that allows for areas of best overlap to be shown together (Figure 4-2). This allows two or more technologies to be analyzed together to find areas of common suitability. Weights can be assigned to the suitability inputs to prioritize a particular technology. In this example, the CSP model was given a two to one preference over the coal technology. The area with greatest combined suitability occurred in eastern Kansas.

In the example presented here, areas outside of the preferred region are incompatible, or listed as marginally suitable because of the physical constraints of the technology requirements. CSP and coal technologies require a supply of water. In this case, the PC coal technology is assumed to require 10 percent of the water from a river with at least a 125,000 gallon per minute (GPM) flow, and the CSP technology would require a river with at least 64,000 GPM flow. Because the coal plant requires a larger amount of water and the CSP plant would not require additional water, the water layer was removed from the CSP model.

Further analysis of the synergistic areas could be investigated by using the various reporting options available in the EZMT, especially Electrical Transmission, Protected Lands, Habitat, Imperiled Species, and Brownfield Sites reports, and searches of the Policies and Incentives database.

5 Conclusion

The intended audience of the EZMT includes EISPC members with significant expertise in electrical generation and transmission planning, EIPC stakeholders such as electrical generation companies and NGOs, policy makers, and the general public. The EZMT will enable collaboration and facilitate coordination around interconnection-wide transmission planning through its unprecedented catalog of energy-related data and information for the entire Eastern Interconnection, models to help locate areas most suitable for a broad range of energy production technologies, and location-specific reporting capability. The environmental layers represent a unique and comprehensive collection of high-quality, regional datasets vetted by environmental experts for use in the models. The user can customize these screening layers, in addition to other resource, social, political, and physical constraints, to run

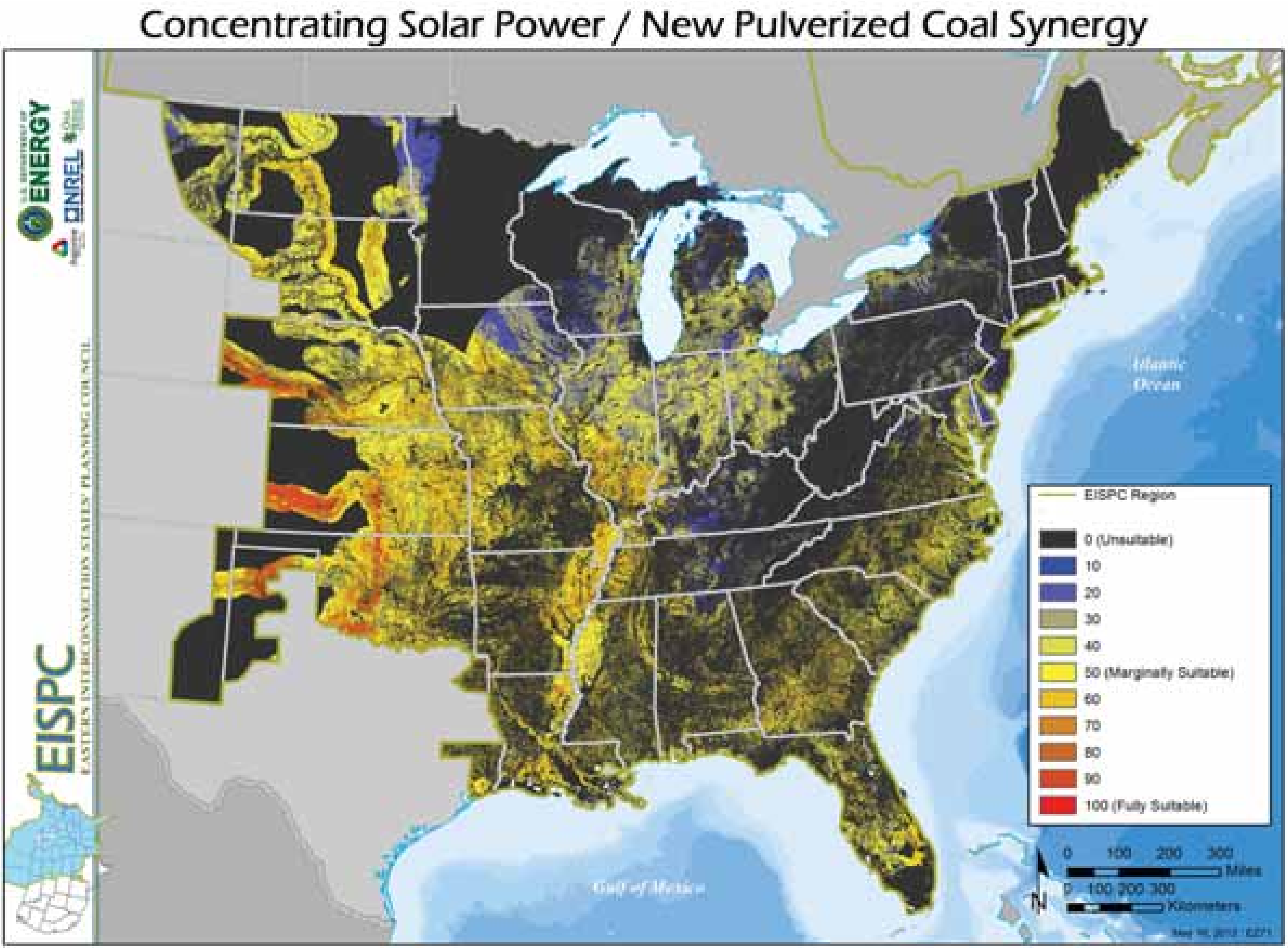

Figure 4-2: An example synergy between concentrating solar power and pulverized coal power technologies.

suitability models and determine energy zones conducive to a single resource or a synergistic co-location of multiple resources.

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