study horizons. Further, ratings on the 69-kV system were not enforced for 10-year assessments because ERCOT assumed those issues would be resolved in shorter-term study horizons. For 20-year assessments for a few scenarios, ERCOT explored the option of enforcing transfer limits on only the 345-kV system. This relaxation of transfer limits reduced reliability upgrade iterations from 20 passes, to less than five. Despite this tremendous gain in study speed,

- Production costs were roughly congruent,
- Reliability and economic opportunities were apparent and comparable to previous process results, and
- Inter-regional system needs were equally or more apparent.

9.1.2 Resource Siting Process

A generation siting process was developed to provide a consistent approach for siting that can be applied to the various scenarios evaluated as part of this study effort. Similar to the generation expansion process, the siting process is not intended to produce the optimal locations for new resources; rather it is designed to mimic the ERCOT market, in which independent developers site their units based on a variety of factors.

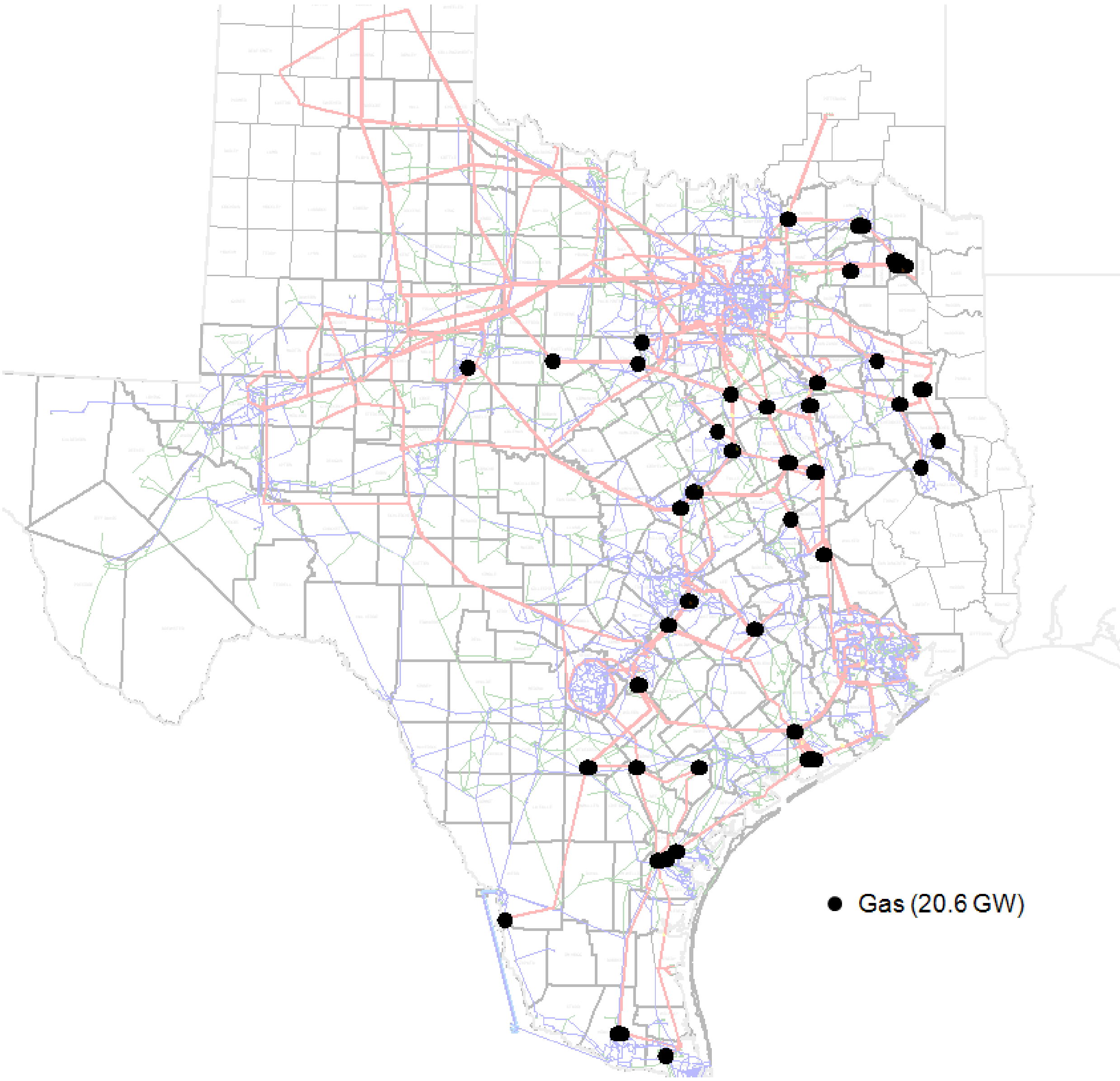
The various factors that were used to evaluate potential siting locations for specific technologies were:

- Natural gas pipeline density
- Railroad density
- Urban population density
- Environmental constraints
- Wind conditions
- Solar thermal conditions
- Surface water availability
- Solar photovoltaic (PV) conditions
- EPA Non-attainment areas

ERCOT applied detailed criteria to all counties to identify regions on the ERCOT system that could support individual or multiple resource technologies. Appendix R contains a detailed explanation of the siting process used in this analysis. At a bus level, 345-kV buses within a county capable of supporting a resource were selected in order of locational marginal price, with the highest-priced buses selected first. ERCOT determined the locational marginal prices based upon production cost simulations in a year sufficiently preceding the desired in-service date to allow hypothetical time for resource construction. Figures showing scenario-specific siting results are presented in Appendix K through Appendix Q.

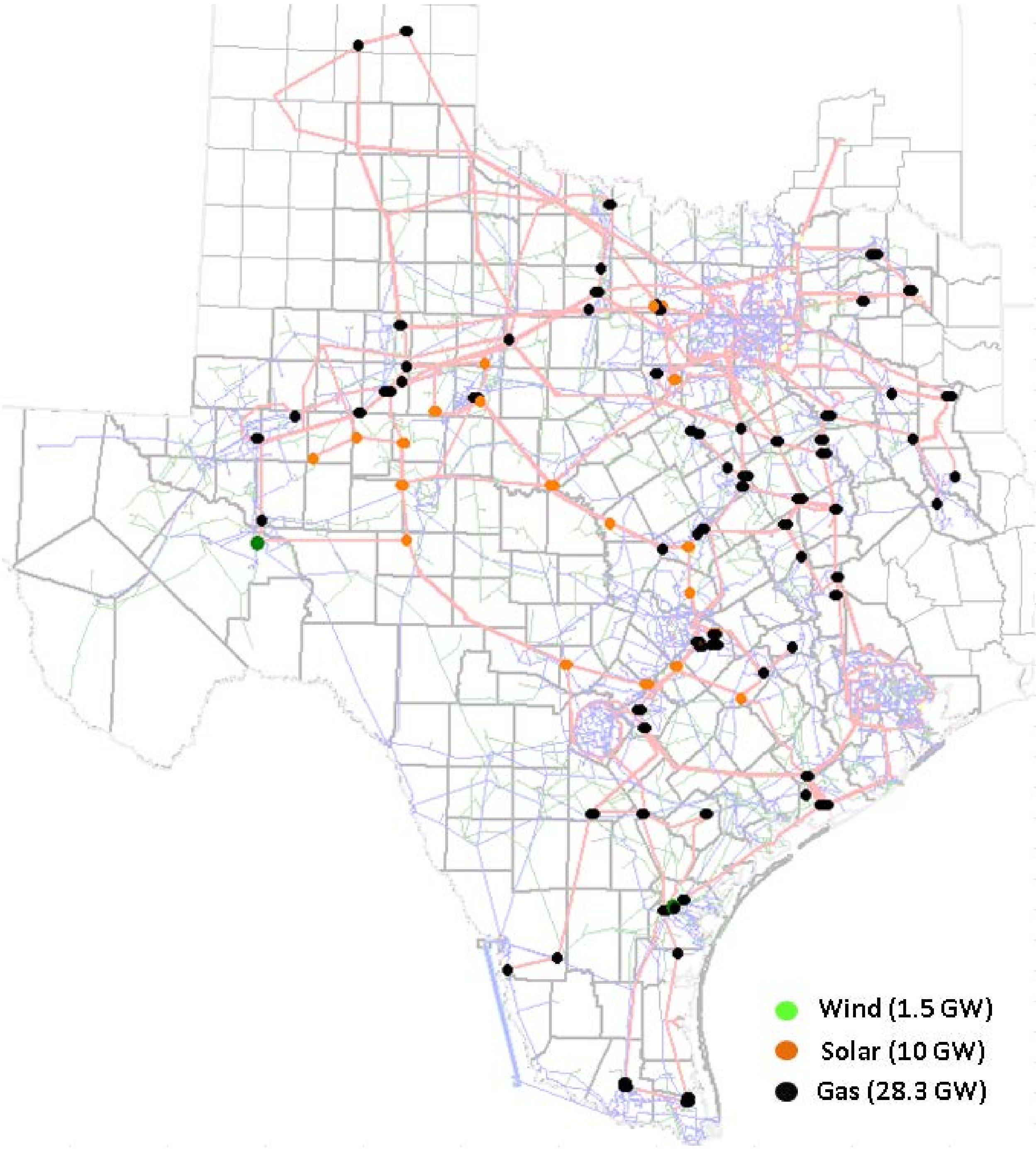
Appendix K Transmission Results — Business as Usual Scenario in 2032

New Resources Added by 2032



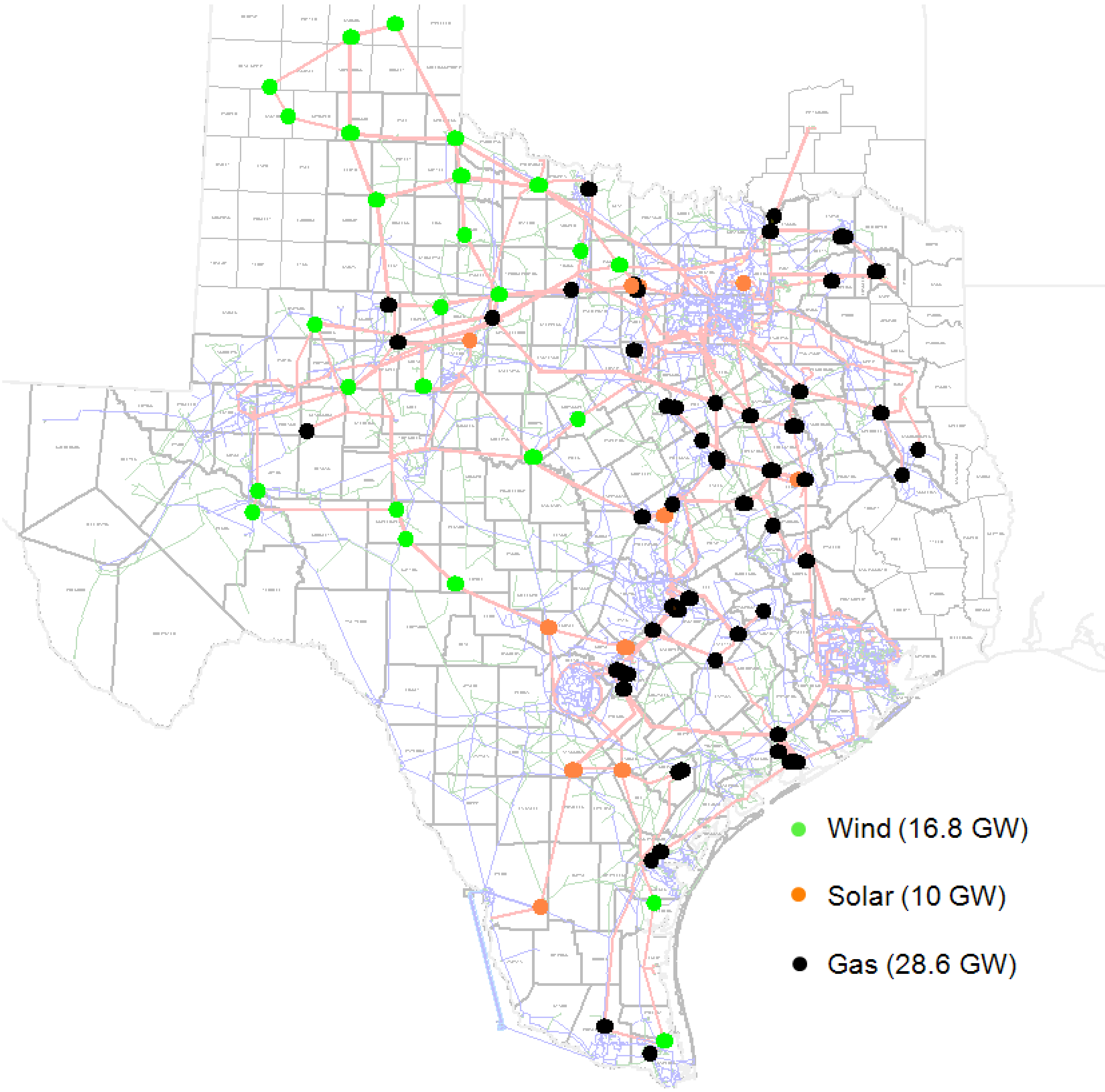
Appendix L Transmission Results — Business as Usual with Retirements Scenario in 2032

New Resources Added by 2032



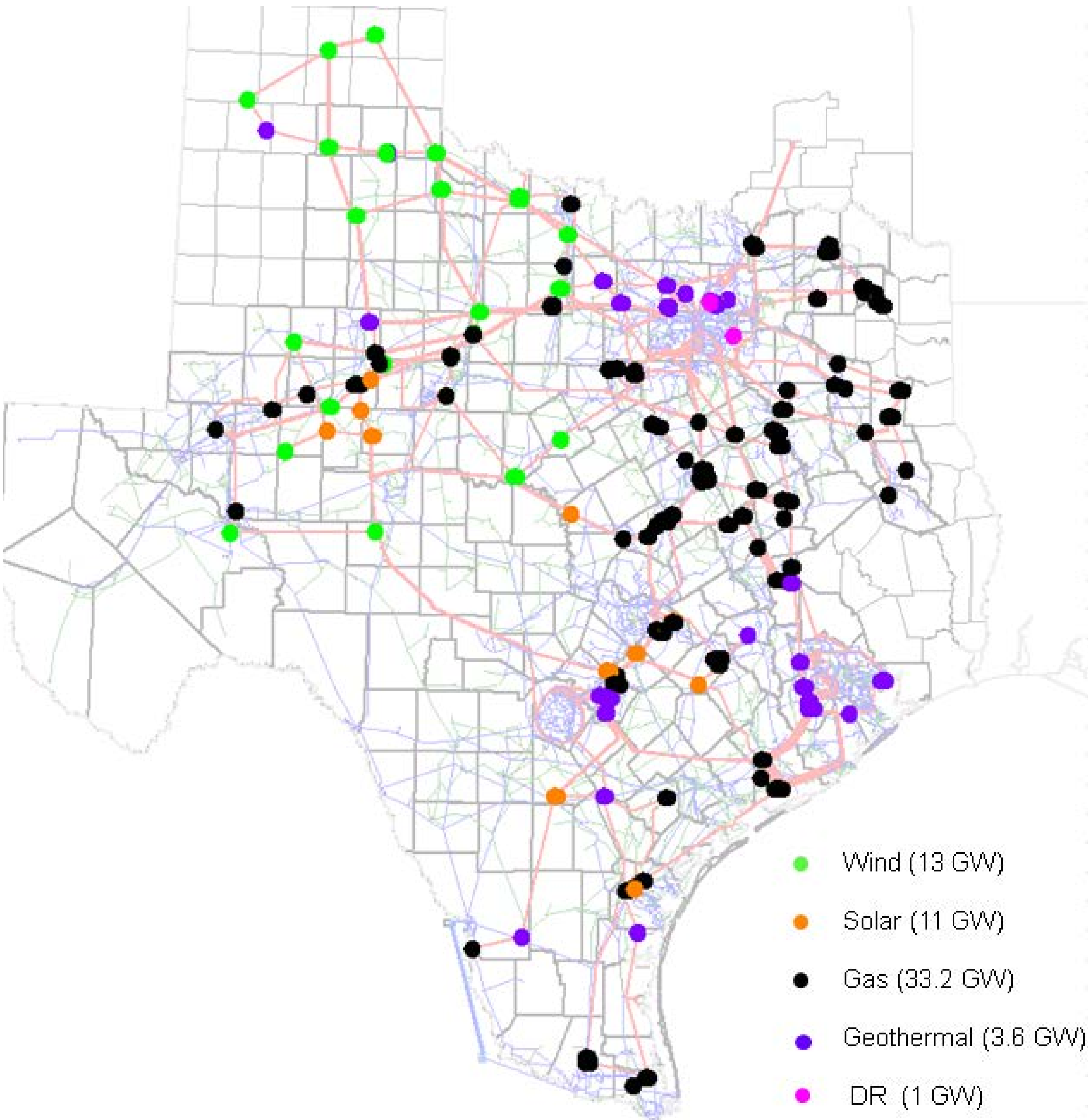
Appendix M Transmission Results — Business as Usual with Updated Wind Shapes Scenario in 2032

New Resources Added by 2032



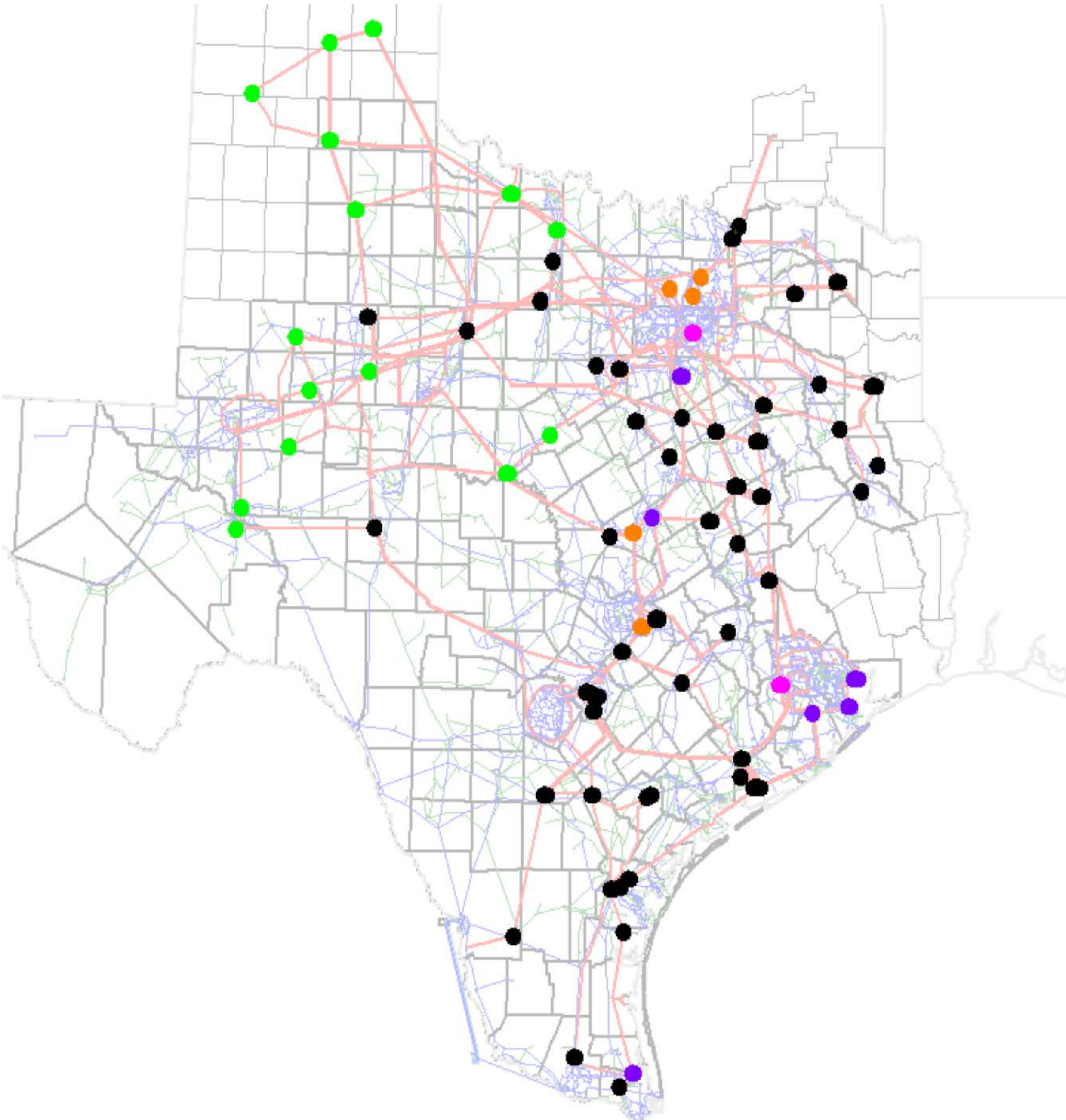
Appendix N Transmission Results — Drought Scenario in 2032

New Resources Added by 2032



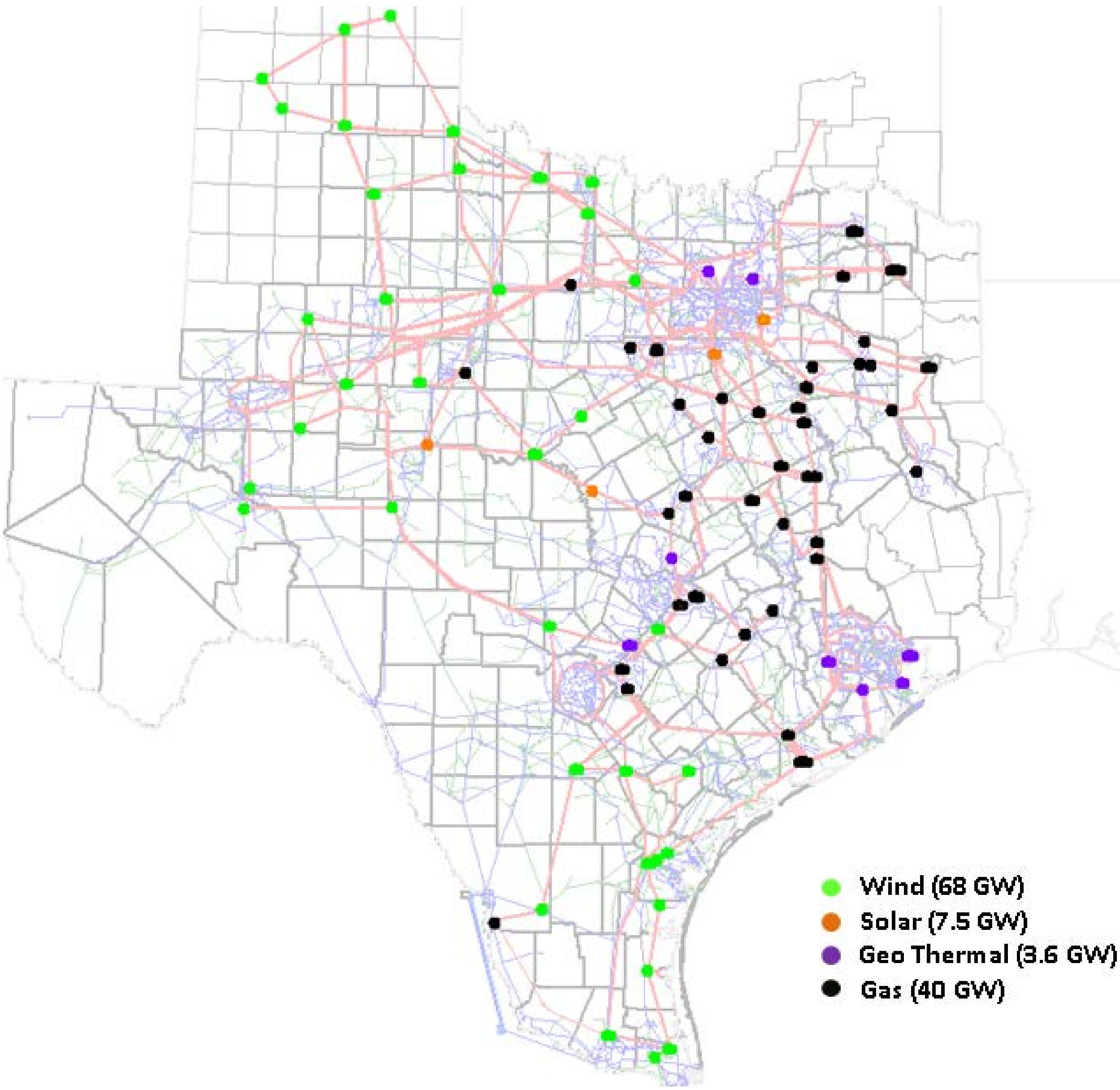
Appendix O Transmission Results — Drought with Low Natural Gas Price Scenario in 2032

New Resources Added by 2032



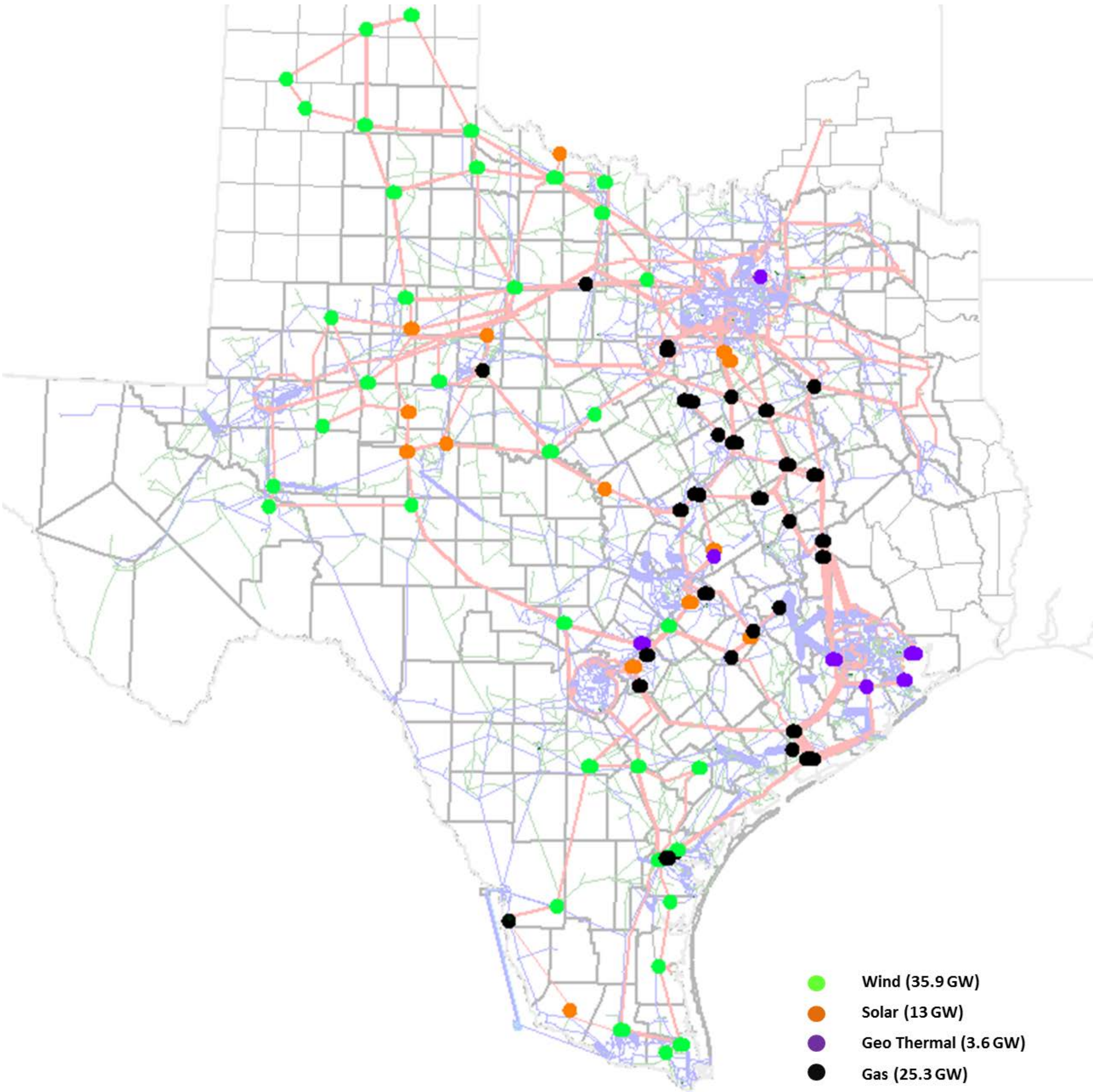
Appendix P Transmission Results — Drought with PTC Scenario in 2032

New Resources Added by 2032



Appendix Q Transmission Results — Business as Usual with High Natural Gas Prices Scenario in 2032

New Resources Added by 2032



Appendix R Generation Resource Siting Process

ERCOT obtained data from a variety of sources to create criteria for ranking generation sites. For each county, ERCOT evaluated each siting factor to determine the counties suitable to support each different possible expansion resource. Each siting constraint was assessed on a county-by-county basis. Then, the requirements for each expansion resource technology were determined, and the set of counties which met the technology-specific criteria were considered viable counties for a resource. The 345-kV buses in these selected counties were then used as potential siting locations for expansion resources. This process was not intended to result in precise locations for the new resources; instead it is designed to provide sufficient indication of the likely locations of new generation development to guide the assessment of the impacts of these resources on the need for changes to the extra-high voltage transmission network. Ultimately, ERCOT developed a ranked list of counties for each resource type that it could use to place the resources from the expansion process.

For natural gas pipelines and railroads, maps were visually inspected to categorize each county as having a high, medium, low, and very low pipeline or railroad density. To classify the natural gas pipelines, ERCOT performed a visual inspection of map of the network of gas pipelines in Texas from The Railroad Commission of Texas, one county at a time. According to the number and density of pipelines running through each county, ERCOT classified the counties into four grades (high, medium, low and very low). Combined cycle units and combustion turbines are the generation types that require gas pipelines near the site. The vast majority of Texas graded as medium or high density for natural gas pipelines. The following two figures show a map of natural gas pipelines in Texas and the pipeline grading ERCOT prepared and used for siting expansion resources.

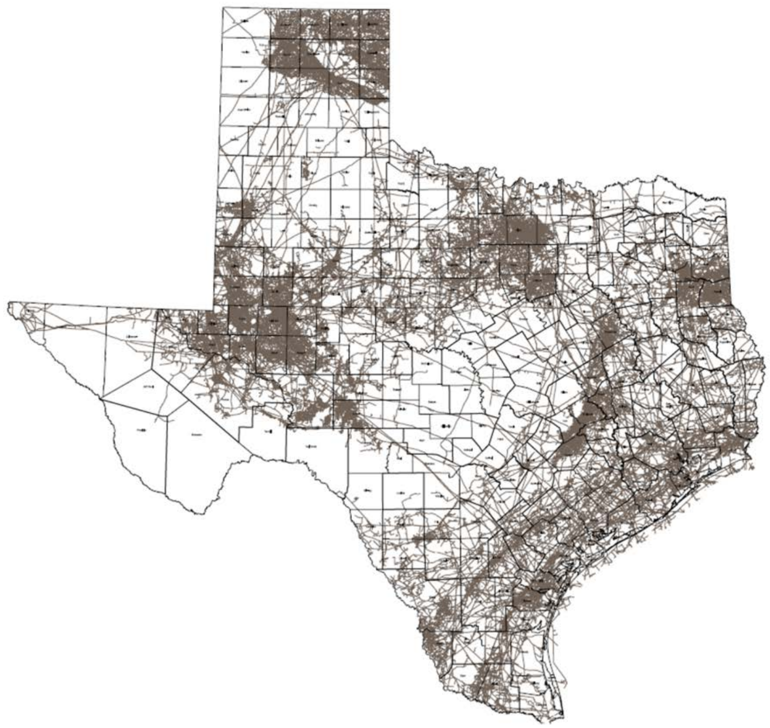


Figure R.1 — Natural Gas Pipeline Density[37]

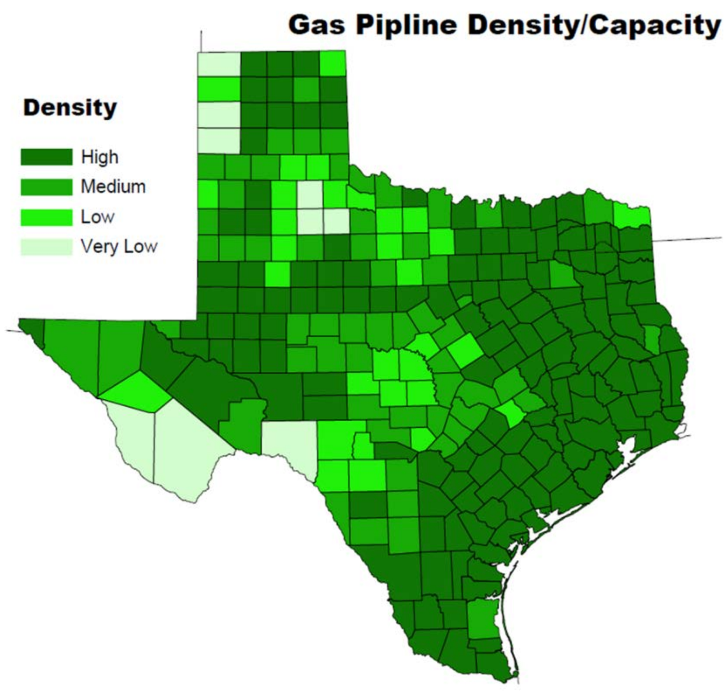


Figure R.2 – Natural Gas Pipeline Density Map for Resource Siting

[37] Source: Railroad Commission of Texas.

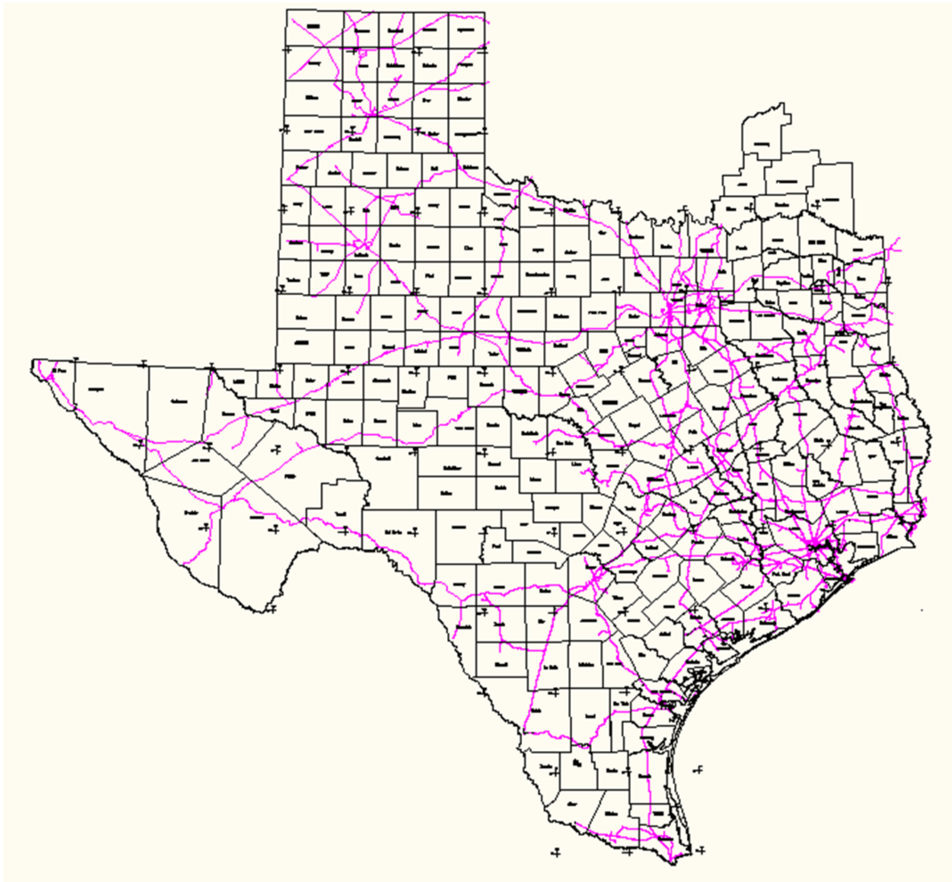


Figure R.3 — Railroad Lines in Texas[38]

To classify the quality of railroad access, ERCOT visually inspected a map of railroads in Texas from the Texas Department of Transportation to determine the number and density of railroads in each county. ERCOT considered a county with three or more railroads as having high density. ERCOT classified counties with two, one, or no railroads as medium, low, and very-low density, respectively. Figure R.4 shows the graded county map of railroad density ERCOT used in siting expansion resources. East Texas contained the majority of counties with high density grades for railroads. Numerous counties in other parts of Texas graded as having medium railroad density.

[38] Source: Texas Department of Transportation.

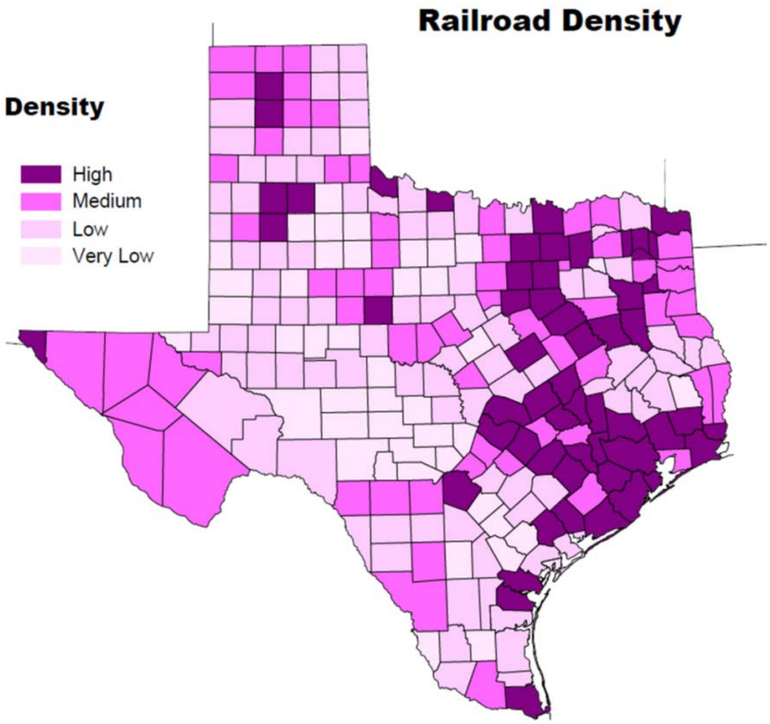


Figure R.4 - Railroad Density Map for Resource Siting

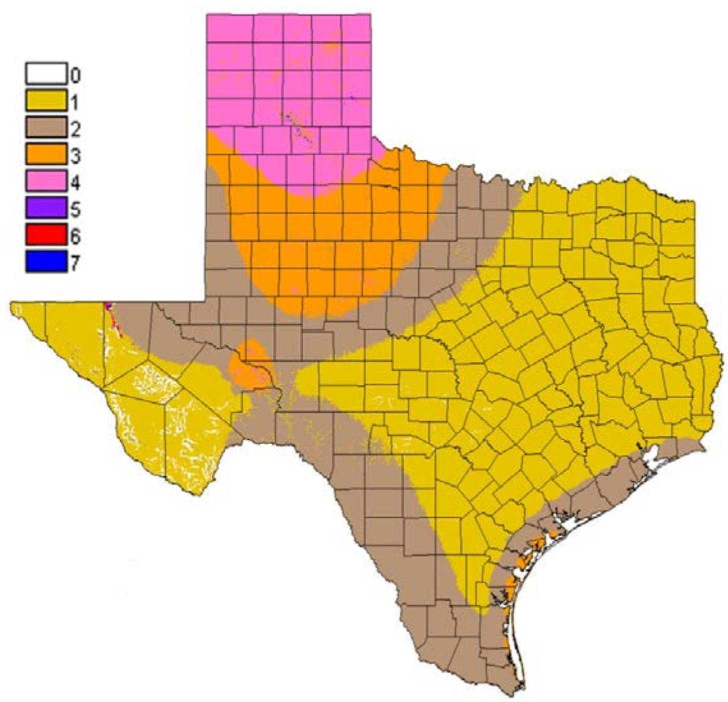


Figure R.5 — Texas Wind Class Map[39]

[39] *Simple Wind Class Map*, Alternative Energy Institute at West Texas A&M University (2004).

Wind resource data was obtained from Alternative Energy Institute at West Texas A&M University.[40] The Institute classifies Texas geographically into seven different zones, ranked 1 to 7, based on suitability for development of wind generation. Higher wind ranking numbers correspond to higher average wind speeds. Additional information regarding potential offshore wind locations was also incorporated into this analysis.

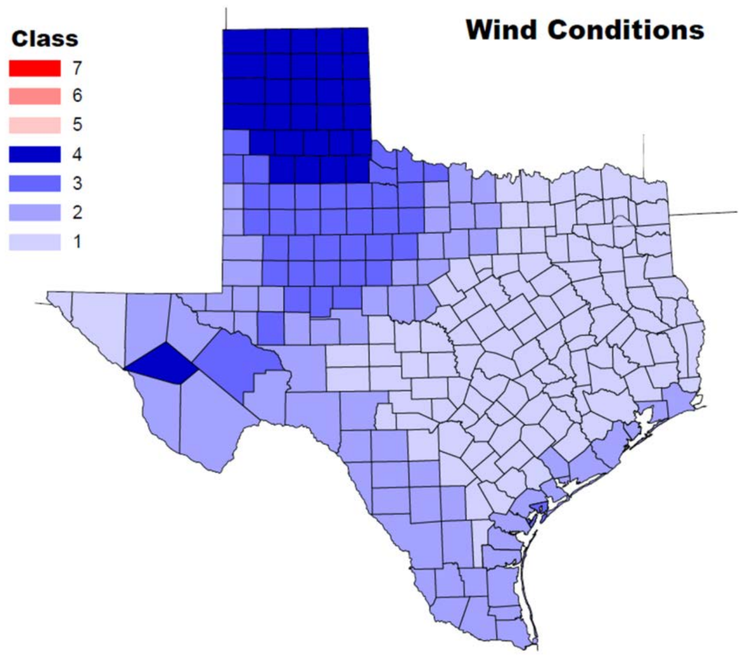


Figure R.6 – Wind Resource Quality by County

ERCOT obtained information regarding solar thermal and solar photovoltaic resources in Texas from the National Renewable Energy Lab (NREL). This information is depicted in the following two figures. Solar radiation in these maps is measured in units of kilowatt-hours (kWh) per square meter. Direct normal irradiance, which is the component of solar radiation that is tracked by solar thermal concentrators, is the amount of solar radiation received per unit area by a surface held normal to the sun's rays.

The following groupings were assigned ranges of solar radiation:

- good: 6.5-7 kWh/m^2
- average: 6-6.5 kWh/m^2
- below average: 5.5-6 kWh/m^2
- poor: ≤ 5.5 kWh/m^2

[40] Alternative Energy Institute, West Texas A&M University.

As per NREL, based on solar irradiance, the Far West weather zone in ERCOT has acceptable sites for solar thermal units. NREL considers areas having more than 6.75 $kWh/m^2/day$ annual average direct normal solar resource ideal. To identify more potential sites suitable for solar thermal generation, ERCOT did not restrict itself to only resource areas with average annual direct normal solar radiance equal to or greater than NREL's threshold. Figure S.4 shows a map of the direct normal solar radiation in Texas. The map clearly shows the direct solar resource in Texas increases from the east to the west.

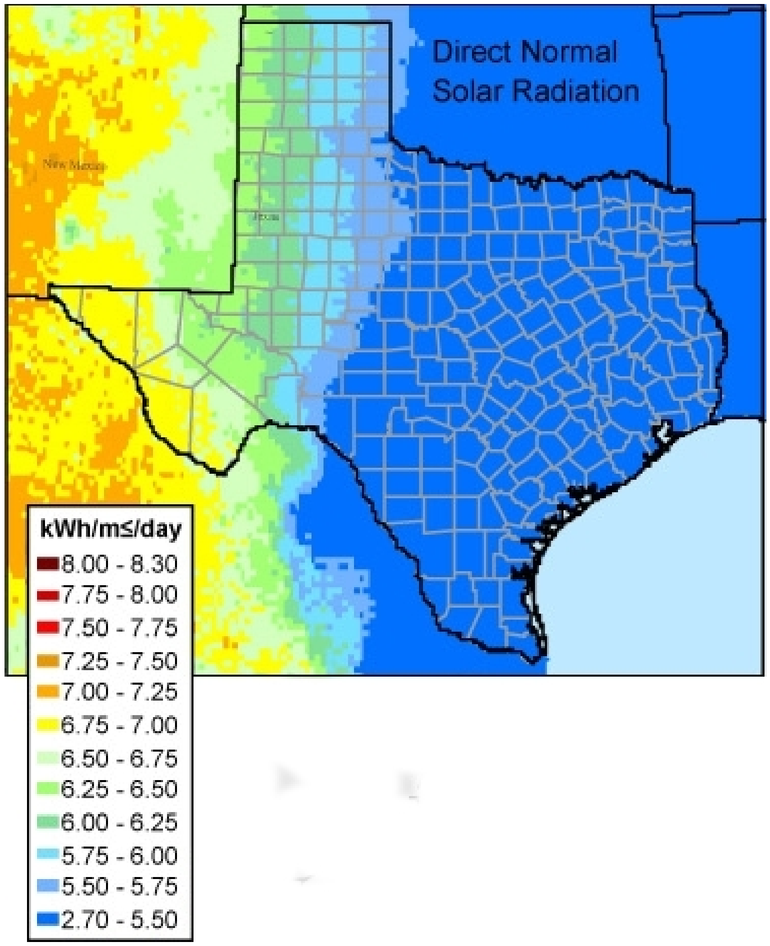


Figure R.7 — Distribution of Direct Normal Solar Radiation[41]

[41] Source: NREL.

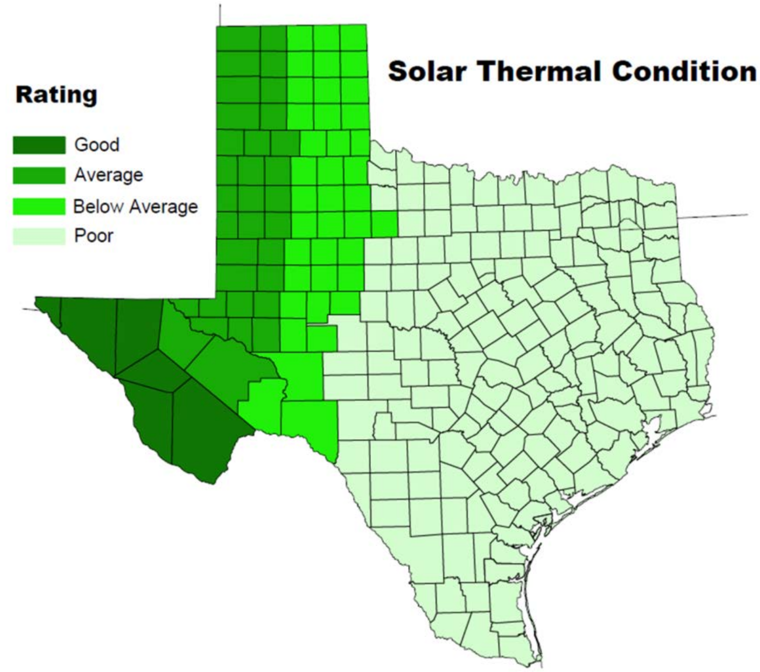


Figure R.8 – Solar Thermal Resource Quality by County

Similarly to solar thermal, solar photovoltaic (PV) resource, is measured by energy per surface area squared (kWh/m^2). However, unlike solar thermal systems, PV harnesses energy contained in the direct normal radiation as well as the radiation diffused by atmospheric components. The counties suitable for solar PV were divided into very high, high and medium insolation groups. PV energy production increases proportionally with increases in the solar radiation that strikes the panel. The map presented in Figure R.7 shows that most of Texas has high levels (>5 kWh/m^2/day) of average daily solar radiation.

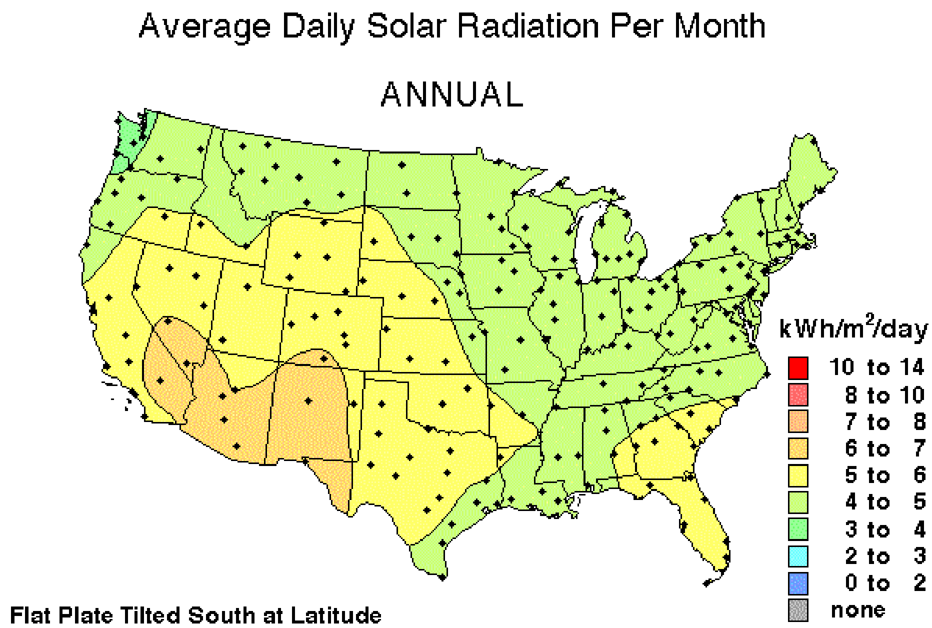


Figure R.9 — U.S. Average Daily Solar Radiation per Month[42]

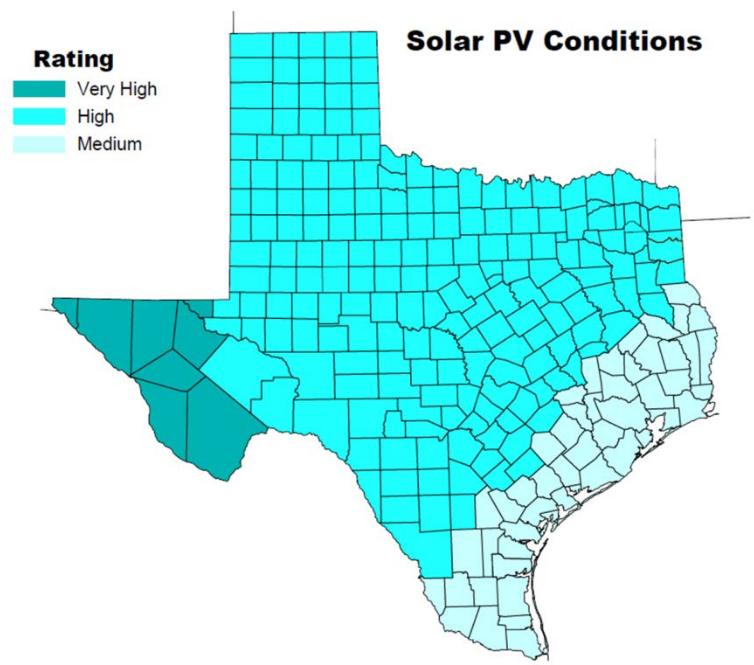


Figure R.10 – Photovoltaic Resource Quality by County

Similarly, prevalence of surface water supplies (streams, rivers, and lakes) were categorized by county based on visual inspection into areas of high, medium and low surface water conditions

[42] Source: NREL.

depending on the number and density of rivers/streams and lakes. ERCOT relied on work by Sandia National Laboratories and Black & Veatch to develop an effective way to incorporate water resource considerations into the siting selection process.

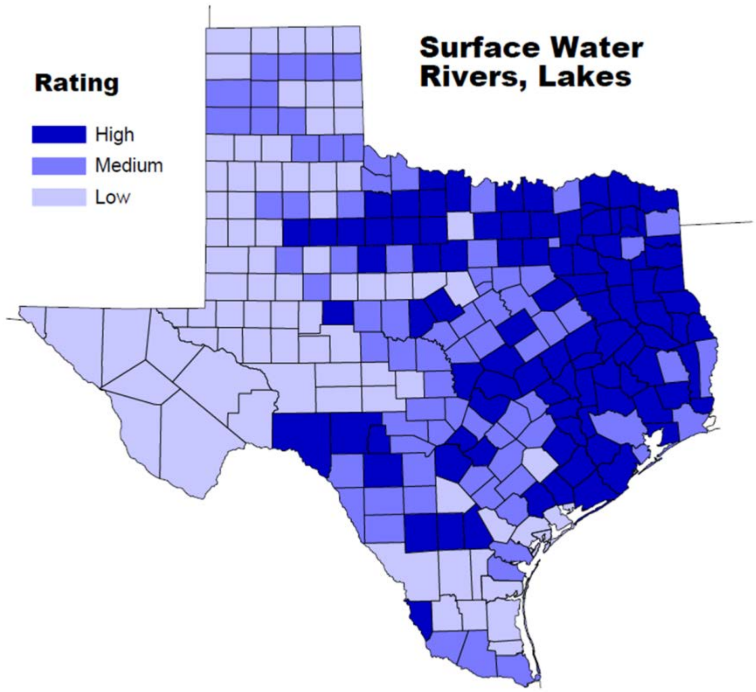


Figure R.11 – Water Availability by County

For those resources that require air permits to operate, ERCOT identified, counties designated as non-attainment zones based on ambient air quality standards by the Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ). These counties are listed below:

- Houston/Beaumont Region: Brazoria, Chambers, Fort Bend, Harris, Galveston, Liberty, Montgomery, and Waller
- Dallas/Ft. Worth Region: Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, and Tarrant.

Information obtained from the TCEQ also indicated that the following counties may soon be designated as non-attainment zones as a result of the possibility of new, more stringent ozone standards: El Paso, Smith, Hood, Gregg, Rusk, Travis, and Bexar. The designation of a county as a non-attainment zone results in additional restrictions on NO_X emissions from large stationary sources such as power plants, and would likely limit development of such resources in these counties or the redevelopment of existing sites.

Table R.1: Generation Technologies and Resource Limitations	
Resource Type	**Resource Limitations**
Wind good	Low Urban Density; Wind Zone 3-4
Wind average	Low Urban Density; Wind Zone 2
Solar Thermal - good	Low Urban Density; Good Direct Solar Resource; High Water Availability
Solar Thermal - average	Low Urban Density; Average to Good Direct Solar Resource; Medium to High Water Availability
NG CT - good	Low Urban Density; High Availability of Natural Gas Supply; Cannot Build in Non-Attainment Area
NG CT - average	Low Urban Density; Medium to High Availability of Natural Gas Supply; Cannot Build in Non-Attainment Area
NG CC - good	Low Urban Density; High Availability of Natural Gas Supply; Cannot Build in Non-Attainment Area or Potential Non-Attainment Area: Medium to High Water Availability
NG CC - average	Low Urban Density; Medium to High Availability of Natural Gas Supply; Cannot Build in Non-Attainment Area or Potential Non-Attainment Area: Medium to High Water Availability
Coal	Low Urban Density; Medium to High Availability of Rail Transportation; Cannot Build in Non-Attainment Area: Medium to High Water Availability
Biomass	Low Urban Density; Low to High Availability of Rail Transportation
Nuclear	Low Urban Density; High Water Availability
Geothermal	Low Urban Density
Solar PV - good	High to Very High Total Solar Resource
Solar PV - average	

Considering all of these factors, along with each resource technology's site requirements, ERCOT developed a list of acceptable counties for each expansion resource type. Site requirements by technology are provided in Table R.1. For each resource technology, the 345-kV buses that were located in the list of acceptable counties were used as potential siting locations. New resource locations were limited to 345-kV buses to facilitate transmission planning. Resources placed on 138-kV buses would likely require additional nearby transmission infrastructure added to the model to allow the unit to reach full output. By siting expansion resources only on 345-kV buses, ERCOT reduced the number of additional projects that would have to be added as part of the "interconnection process." The 345-kV buses selected for each technology were further ranked based on a review of locational market prices from preliminary PROMOD IV runs. To limit the localized impact of adding too many new generation resources into certain areas, for each technology type, ERCOT would locate only one expansion plant in each county until it exhausted all counties capable of supporting that technology. After it exhausted the counties capable of hosting a specific technology type, ERCOT would begin to reuse counties.

Ultimately, ERCOT combined all the technology requirements with the graded resource assessments and access to nearby bulk power transmission to identify specific buses on the transmission system appropriate for each technology type. Table R.2 shows the technology types and the Texas counties that fulfill their resource requirements and the number of buses to which those potential expansion generators could connect.

Table R.2: Number of Counties in ERCOT Suitable for Siting Generation and Number of 345-kV Buses		
Generation Type	**No. of Texas Counties Fulfilling Generation-Type Requirements**	**No. of 345-kV Buses in Counties Fulfilling Generation-Type Requirements**
Wind - good	39	68
Wind - average	99	123
Solar Thermal - good	0	0
Solar Thermal - average	6	0
NG CT - good	99	161
NG CT - average	143	201
NG CC - good	63	108
NG CC average	107	171
Coal	60	93
Biomass	150	227
Nuclear	74	107
Geothermal	191	260
Solar PV - good	156	212
Solar PV - average	196	333